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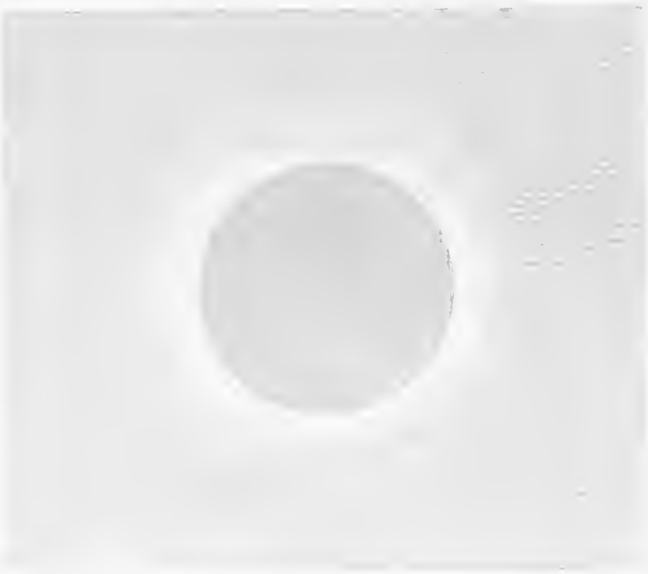

THE SOLAR SYSTEM:

A DESCRIPTIVE TREATISE

UPON THE SUN, MOON, AND PLANETS,

INCLUDING

An Account of all the Recent Discoveries

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TO

DR. MARSHALL HALL,

FELLOW OF THE ROYAL COLLEGE OF PHYSICIANS, AND OF
THE ROYAL SOCIETY, AND OF THE ROYAL SOCIETY OF
EDINBURGH, FOREIGN ASSOCIATE OF THE NATIONAL
ACADEMY OF MEDICINE OF FRANCE, ETC., ETC.,
AND THE DISCOVERER OF THE SPINAL SYSTEM IN PHYSIOLOGY,

This Treatise

IS INSCRIBED, AS A SLIGHT TOKEN
OF GRATITUDE AND ESTEEM,
AND OF ADMIRATION OF HIS SCIENTIFIC LABORS,
BY

THE AUTHOR.

PREFACE.

THE present work differs in its arrangement and general contents from any exclusively astronomical treatise with which I am acquainted. I have had in view the production of a *descriptive* work, presenting the reader with the latest information on all points connected with the Solar System, yet written in a style as popular as the nature of the subject will admit. It will, therefore, be understood that this little volume has no pretences to the character of an *explanatory* treatise on astronomy, but is rather addressed to that numerous class of readers whose time and inclination do not permit of any regular study of the principles of the science, but are yet desirous of informing themselves as to the present state of our knowledge of the heavenly bodies, what has already been accomplished, and how much there yet remains to be done.

I have thought it necessary, however, to introduce frequent explanatory remarks, for the more ready comprehension of those parts of the work, which, without such additions, might appear obscure or unintelligible.

The present treatise is confined to the *Sun*, *Moon*, *and Planets;* but, if life and health be spared me, I hope to carry out the same plan to *Cometary and Meteoric Astronomy*, and also to *the Stars and Nebulæ*. The subjects are all so widely different, that it is no disadvantage to treat of them in separate works.

To M. Le Verrier, and to those English Astronomers who have kindly furnished me with more definite information on certain points connected with their investigations than was to be found in printed authorities, I have to return my best thanks.

J. RUSSELL HIND.

GROVE ROAD, ST. JOHN'S WOOD, LONDON,
December, 1851.

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THE SOLAR SYSTEM:

OR

THE SUN, MOON, AND PLANETS.

CHAPTER I.

THE SUN. ⊙

THE Sun, as the great originator of light and heat, and the mighty centre of the system, first claims our attention.

The distance of this splendid luminary from the earth, which is employed by astronomers as a common unit of measurement, has been ascertained with very great accuracy from the transit of Venus over the Sun's disc in 1769. It will readily be imagined that an exact knowledge of this distance is of high importance in various astronomical investigations, and it has accordingly formed the subject of several elaborate inquiries. Professor Encke, of Berlin, has produced a masterly treatise on the results to be deduced from the transit of 1769; he concludes that at the mean distance of the earth from the Sun, the equatorial semi-diameter of our globe would subtend an angle of 8″.5776,* which is called the *equatorial horizontal*

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* Since the above was written, Mr. Adams has drawn my attention to a remark of Professor Encke's, in his Astronomical *Jahrbuch* for 1852, from which it appears, that in order to satisfy the observations of the transit of Venus by Pere Hell, in 1769, a small correction is

parallax of the Sun; hence we infer by trigonometry, that this luminary is separated from us by 24,047 times the earth's equatorial radius, or, more exactly, 95,298,260 English miles. And this is the most probable value that we are able to derive from existing data, though it is possible future observations may furnish a result with greater pretensions to accuracy. It may be safely asserted, that we know the true distance of the earth from the Sun, within the 300th part of the whole; a most satisfactory conclusion, considering the magnitude and importance of the question.

Knowing the mean distance of the Earth from the Sun in semi-diameters of our globe, it is easy to determine the real diameter of the solar orb referred to the same unit of measurement. The best and latest observations prove that when the Sun is at his mean distance from us, the diameter subtends an angle of 32′ 0″; and there appears to be little, if any, appreciable difference between the diameters measured in a vertical and horizontal direction. Hence we conclude that the true diameter of the Sun exceeds the equatorial radius of the earth 223.83 times, or measures 887,076 miles. This enormous globe has, therefore, 1,401,910 times the volume of the earth, and the mass is found to be upwards of 355,000 times greater.

The appearance of the Sun, with the aid of telescopes, may be briefly described. When we examine his disc through the intervention of a dark glass, we perceive upon it black spots, or *maculæ*, surrounded by a lighter shade, or penumbra, which in most cases has a similar form to the inclosed spot, though

necessary to the above value of the Equatorial Horizontal Parallax. It is, however, so small, that it has not been thought necessary, or even advisable, to recompute the various distances of planets from the Sun, &c., given in this work. Professor Encke's result for the Parallax is confirmed in a remarkable manner by the independent researches of a Spanish Astronomer, Don Jose de Ferrer.—AUTHOR.

this does not invariably happen, several dark spots being occasionally included in a common penumbra. Generally they are confined to zones, extending 35° on each side of the Solar Equator, leaving an intermediate belt where they appear much more rarely. They have now and then been noticed in higher latitudes; but these instances may be considered as forming exceptions to the general rule. The solar spots are not permanent, they change their form from day to day, or even from hour to hour, sometimes vanishing in an incredibly short space of time, while others make their appearance as suddenly. The dark, or central part of the spot, disappears first, and the penumbra gradually closes in upon it. When a spot is observed for any length of time, it is found to change its apparent position on the Sun's surface, becoming visible at first upon the eastern side, and in somewhat less than a fortnight disappearing near the western limb, while after the lapse of another like period, if it remain as before, it will re-appear upon the eastern limb, and again traverse the disc. To account for these phenomena, it is necessary to admit that the Sun rotates upon his axis in a direction similar to that of the diurnal revolution of the earth, or from west to east.

Tobias Mayer records the appearance of a black spot upon the Sun on March 15, 1758, the diameter of which was one twentieth of that of the Sun. Sir W. Herschel saw one on the 19th of April, 1779, sufficiently large and well-defined to be visible to the naked eye. More recently M. Schwabe, of Dessau, who has paid much attention to solar phenomena, has observed several spots without the aid of a telescope. One visible in June, 1843, measured 167$''$ in breadth, and was seen with the naked eye for a whole week. As one second of arc on the Sun's surface includes a breadth of 460 miles, we infer that the spot viewed by M. Schwabe must have occupied a space 77,000 miles in diameter, or ten times greater than that of the Earth. A group of spots with the penumbra surrounding it, will frequently cover a much larger portion of the Sun's disc. One noticed in April, 1845, measured 5′ 20″, and another on the 6th of December, of the same year, was nearly of equal length. A cluster of spots seen at the Cape of Good Hope by Sir John Herschel, at the end of March, 1837, covered an area of nearly five square minutes, a space which the reader will duly appreciate on remembering that the diameter of the Sun is only thirty-two minutes. A minute in linear dimension on his disc being 27,500 English miles, and a square minute 756,000,000. Sir John Herschel observes, that we have an area of 3,780,000,000 miles included in one vast region of disturbance on this occasion. M. Schmidt, of Bonn, counted upwards of two hundred single spots and points in one of these large groups visible on the 26th of April, 1846, and one hundred and eighty in another cluster in August of the preceding year.

It has been found by continual observation of the spots that their number varies considerably in different years. It will sometimes happen on every clear day during a particular year, the Sun's disc always contains one or more of them, while, in another year, for weeks or even months together, no spots of any kind can be perceived. M. Schwabe, after twenty-five years close attention to the appearance of the Sun's surface, thinks he has discovered something like regularity in the prevalence or otherwise of these phenomena, and is induced to suppose that the period of variation in the number is not far from ten years. It is not easy to imagine any adequate cause for this cyclical appearance of the spots; but in the present state of astronomy it is unsafe to reject any of the indications of careful observation, simply because we cannot fully account for them.* We would particularly recommend the solar phenom-

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* M. Schwabe has furnished a table exhibiting the number of days in each year between 1826 and 1843 on which the sun was free from

ena to the attention of amateur astronomers, who with ordinary telescopes may do good service to the science by regularly watching and mapping down the spots day by day; a work almost beyond the power of the professed observer, who has so many other claims upon his time and attention.

Besides the dark spots already described, we remark upon the Sun's disc curved lines or streaks of light of a more luminous character than the rest of the surface, which are generally found in the neighborhood of the black spots, or where they have previously existed; not unfrequently the dark spots break out amongst them. These phenomena are termed *faculæ* (*lichtstreifen* by the Germans), and are considered by Sir John Herschel as the ridges of immense waves in the luminous regions of the Sun's atmosphere, indicative of violent agitation

spots, and the number of groups showed. This table is interesting in more than one point of view, and is here subjoined:—

Year.	Groups of spots observed.	Days on which the Sun was free from spots.	Number of observing days.
1826	118	22	277
1827	161	2	273
1828	225	0	282
1829	199	0	244
1830	190	1	217
1831	149	3	239
1832	84	49	270
1833	33	139	267
1834	51	120	273
1835	173	18	244
1836	272	0	200
1837	333	0	168
1838	282	0	202
1839	162	0	205
1840	152	3	263
1841	102	15	283
1842	68	64	307
1843	34	149	324

in the neighborhood. The *faculæ* are not so generally noticed as the spots, possibly because they require much better optical means to show them well. Yet M. Schmidt says in the year 1845 he never saw them at all, though during the early part of the year he used one of Fraunhofer's celebrated telescopes, of four feet focal length; but on one day in 1844 they were unusually distinct and visible in considerable numbers. Careful examination, with proper optical aid, shows that the Sun's disc is covered with a fine mottled appearance, consisting of minute points, or, as Sir John Herschel terms them, "dark dots or pores," which are constantly undergoing some alteration. The appearance presented by this uniform mottling of the Sun's disc has been aptly compared by the same eminent astronomer to the "slow subsidence of some flocculent chemical precipitates in a transparent fluid, when viewed perpendicularly from above."

The rotation of the Sun upon his axis was inferred, as already remarked, from observations on the positions of the spots upon his disc on successive days. Astronomers have differed a good deal in the periods they assign to this rotation; still it is certain that we have now approximated within a very few hours of the truth.* Perhaps the period assigned by M. Bianchini, from very careful measures, in the year 1817, may be taken as

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* We subjoin the times of the Sun's rotation, according to the various astronomers, from the age of Cassini to the present day:—

	D.	H.	M.
Cassini I. by comparing his own observations with those of Scheiner, &c.,	25	14	5
De La Hire,	25	8	56
Lalande,	25	10	0
Flauguergues, from observations in 1798,	25	1	2
Delambre,	25	0	17
Mossotti,	25	10	13
Taylor in 1835–6,	25	14	0
Petersen,	25	4	30
Laugier,	25	8	10

one of the best results; this gives 25d. 7h. 48m. for one sidereal revolution upon the axis, agreeing closely with the more recent calculation of M. Laugier. Besides the time of rotation, observations of the solar spots enable us to ascertain the position of the equator, and its nodes in reference to the ecliptic or the great circle of the heavens in which the plane of the earth's path lies. According to the eminent mathematician and astronomer, M. Delambre, the angle between the solar equator and the ecliptic is 7° 19′, and the longitude of the node, or the point where the equator intersects the ecliptic is 80° 45′. Some later observations by Dr. Petersen at Altona, assign 6° 51′ for the inclination, and 73° 29′ for the position of the node. There are difficulties in the way of an exact determination of these quantities, and not practical ones only, for some astronomers have strongly suspected that the spots *really* alter their position upon the Sun's disc, in which case the apparent diurnal movement of the spots given by our observations will not be the real change due to axial rotation, but must be partly influenced by the proper motion of the spot itself. Hence probably arise the discordances which are apparent in the results of different astronomers, and in the times of rotation deduced by the same observer from observations of different spots.

The Earth is in the line of nodes about the first weeks of June and December, and at these times the spots, in traversing the Sun's disc, appear to us to describe straight lines. As our globe recedes from the line of nodes, the apparent paths become more and more elliptical, until we have advanced through an arc of longitude of 90°, or arrived at our greatest heliocentric declination, when the ellipticity reaches its maximum, diminishing again as we are carried forward to the other node. The paths of the solar spots consequently present the greatest curvature about the commencement of March and the middle of September.

The discovery of the spots is usually dated about the beginning of the seventeenth century, or soon after telescopes came into use. It appears, from the papers of our countryman Harriot, that he observed them on the 8th of December, 1610. Christopher Scheiner, Professor of Mathematics at Ingoldstadt, remarked them in March following, and published a voluminous work upon the subject, entitled *Rosa Ursina.* The celebrated Galileo noticed the spots about the same time, and, in a tract printed in 1613, he affirms that he had shown them to several persons at Rome in 1611, and had mentioned their existence to other friends at Florence some months previous. John Fabricius observed them at Wittenburg about the same time as Scheiner, and gave an account of them in a small work published in June, 1611. All these discoveries were very probably entirely independent of each other; but it seems quite certain that the first notice of a solar spot is to be dated at a much earlier period. Adelmus, a Benedictine monk, in a life of Charlemagne, mentions a black spot observed upon the Sun in the year 807, on the 16th of the calends of April or March 17th: this circumstance is recorded by many historians, including Bede, Polydorus Virgil, and Aimoin, monk of St. Germain de Pres. Averroes, a Spanish Moor, is reported to have observed dark spots upon the Sun's disc about the middle of the twelfth century. It has been suggested that the otherwise mysterious diminutions of the Sun's light when there was no eclipse, mentioned more than once by historians,* may have been owing to a great accumulation of spots upon his disc; but

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* A remarkable instance is recorded by Keppler, *Astronomiæ pars optica,* in the following words—"Refert Gemma Pater et Filius, anno 1547 ante conflictum Caroli V. cum Saxoniæ Duce, solem per tres dies seu sanguine perfusum comparuisse ut etiam stellæ pleræque in meridie conspicerentur." The battle alluded to is that of Mühlberg, which was fought on the 24th of April, 1547.

it certainly appears questionable whether they could congregate in such numbers as to materially lessen the intensity of the solar rays.

A great number of opinions have been advanced with regard to the nature of the solar spots. Scheiner at first considered them to be solid bodies revolving round the Sun, and very near his surface; in this opinion he was followed by Malapert, who termed them *Sidera Austriaca Periheliaca;* by John Tardè, who, in his turn, called them *Borboina Sidera*, as having been discovered in the reign of Louis XIII.; and by the capuchin Antonio de Rheita, who thought he had accounted for the *faculæ*, or luminous spots, also, by supposing them to be owing to the intense light reflected from the revolving planets on the Sun's surface. Galileo differed entirely from Scheiner and his followers, regarding the spots merely as clouds or exhalations from the Sun's surface, and urging as a fatal objection to Scheiner's theory, that they are ever changing their form and general appearance, sometimes vanishing suddenly, and bursting forth again with equal rapidity in other places. The idea of their being solid bodies was therefore soon rejected.

The opinion prevailing among the best authorities of the present day is, that these spots are portions of the dark body or surface of the Sun, which are occasionally rendered visible from the temporary removal of the interposing luminous atmosphere, owing to local causes of disturbance, which, whatever be their true nature, appear to be predominant in the equatorial regions. Sir William Herschel has accounted for the penumbra, and general appearance of the spots, by supposing the existence of a transparent medium, which sustains the luminous atmosphere at a great altitude above the Sun's solid dark body, "carrying on its upper surface a cloudy stratum, which, being strongly illuminated from above, reflects a considerable portion of the light to our eyes, and forms a penumbra, while the solid body, shaded by the clouds, reflects none." The disturbances which give rise to the visibility of the spots, Sir William thinks to be due to powerful upward currents of the atmosphere.

Before closing our account of solar phenomena, we must not omit a brief notice of the *zodiacal light.* In these high latitudes, it is not usually visible except about the months of March and April, in the evenings, after Sun-set, and September and October, in the mornings, before Sun-rise; yet in some years it has exhibited itself in uncommon brilliancy as early as January. In tropical climates, the zodiacal light is far brighter, and more sharply defined than we ever see it in this country. Its appearance is that of a conical-shaped light, extending from the horizon nearly along the course of the ecliptic, the vertex attaining distances of 70° or 80° from the Sun's place, or, as some observations would show, extending 100° from the same point. Hence it is evident its real extent must include the orbits both of Mercury and Venus, and possibly even that of the Earth. The visible length above the horizon, and the breadth of the light at its base, vary under different circumstances, the latter from about 10° to 30°. The general opinion is, that the axis of the zodiacal light is in the plane of the Sun's equator. M. Houzeau has endeavored to show, by calculation of a considerable number of observations by Cassini and others, that the elements of the zodiacal light are materially different from those of the Sun's equator: he fixes the node of the light in 2° heliocentric longitude, subject to a probable error of 12° or 13°, and its inclination to the plane of the ecliptic 3°.35′, subject to an uncertainty of rather more than 2°. With these elements he finds his series of sixty observations rather better represented than if the elements of the Sun's equator were employed; but the preference to be given to the former is by no means decided. The subject deserves further investigation, when a much larger number of observations are in our possession than that employed by M. Houzeau. At present, we think the evidence against the supposed coincidence of the above elements by no means sufficient to outweigh the probabilities in its favor derived from other considerations. Sir John Herschel suggests that the zodiacal light may be "no other than the denser part of the resisting medium," which, as we are now aware, has disturbed the movements of one, at least, of the periodical comets, "loaded perhaps with the actual materials of the tails of millions of those bodies of which they have been stripped in their successive perihelion passages;" and the same eminent astronomer shows that it cannot be, as some persons have supposed, an *atmosphere* of the Sun, in the common acceptation of the term, for dynamical reasons.

In connection with Sir John Herschel's idea relative to the nature of the light, it is perhaps worthy of mention, that during the visibility of the magnificent comet of March 1843, which exhibited a tail 50° long, and almost grazed the solar orb, the zodiacal light was unusually brilliant—so much so, in fact, that some confusion was caused by the publication of descriptions, of the latter phenomenon, which the observer appears to have mistaken for the cometary train.

On no recent occasion has the Light shown itself so conspicuously or for so long a period, as during the early part of the year 1850. From the middle of January to the latter end of March it was constantly visible on clear evenings, but was brightest early in February, when it decidedly excelled the most condensed part of the Via Lactea about the constellation Cygnus. Observers who paid particular attention to the position of the borders of the light among the stars on this occasion, from pretty distant stations in England, have suspected the existence of a very sensible parallax, but it is hardly necessary to remark that the apparent variation in the position of the outline, as assigned at two distant places on the same evening, may be satisfactorily accounted for by the supposition of varying atmospheric conditions. It is not possible to admit the reality of the parallax, if the luminosity observed in the western heavens in the early part of 1850, were, as we are at present under the necessity of regarding it, an appearance of the zodiacal light.

The first particular description of this phenomenon was given by Cassini the Elder in 1683, but it had been previously treated of by Descartes and Childrey, and it seems probable that it may have been remarked more than two thousand years ago.

CHAPTER II.

THE INFERIOR PLANETS.

WITHIN the orbit of the Earth revolve the two planets Mercury and Venus, recognized as such from the most remote antiquity. We know that these bodies move in smaller orbits than our globe; first, because they never appear in the opposite part of the heavens to that which the Sun occupies, or, to use astronomical language, never come into *opposition* with that luminary: secondly, because under telescopic aid they present every variety of phase from the thin crescent to the fully illuminated disc, which should occur if, receiving their light from the Sun, they were always situated within the Earth's orbit; and, thirdly, because at certain times we actually observe them projected upon the disc of the Sun in their passage between that body and our globe, and have watched them in their passage over him; a phenomenon known as a *transit.*

MERCURY. ☿

The first of the inferior planets is Mercury, who performs his revolution round the Sun in 87d. 23h. 15m. 43.9s. at a mean distance of 36,890,000 miles. When between the Earth and the Sun, or near the time of *inferior conjunction*, the disc of this planet, as viewed from our globe, subtends an angle of about twelve seconds of arc, but the diameter dwindles down as Mercury approaches the opposite part of the orbit, where the breadth would not exceed five seconds.

The constant proximity of the planet to the solar rays, has greatly interfered with observations of its physical appearance. The German astronomer, Schröter, who observed at the beginning of the present century and paid much attention to the subject, considered he had decided evidence of the existence of high mountains on the surface of Mercury, and it was by examining them at various times that he concluded the planet had a revolution upon its axis in 24h. 5m. 28s.; but this inference may yet require very considerable modification. Sir W. Herschel never remarked any spots upon the planet's surface, by which he could approximate to the time of rotation, nor are we aware that any astronomer since the time of Schröter has been able to add to our knowledge on these points.

The eccentricity of the orbit of Mercury, or the deviation of his orbit from a circle, is much larger than in the case of any other of the old planets, and this circumstance, combined with the great inclination of his equator to the plane of his annual path, which Schröter thinks may amount to 70°, must produce a vast variety of seasons, with great extremes of heat and cold. At perihelion, Mercury is only 29,305,000 miles from the Sun's centre, while in the opposite part of the orbit, or in aphelion, he reaches to 44,474,000, making a variation of distance arising from the eccentricity of his annual track, of no less than 15,169,000 miles, which is nearly five times as great as in the case of the Earth.

The elongation or angular distance of Mercury from the Sun, measured as an arc of longitude, is never so great as 30°: consequently he cannot be seen except in strong twilight, either morning or evening, and under the most favorable circumstances does not appear conspicuous to the naked eye, but twinkles like a star of the third magnitude with a pale rosy light. We cannot, therefore, too highly appreciate the diligence and attention of the ancient astronomers, who were not only aware of the existence of the planet, but approximated very closely to his period, and were able to explain the general nature of his path in the heavens. Nevertheless we read of astronomers, and by no means inattentive ones either, who have lived and died without once seeing Mercury. Even Copernicus, the celebrated reviver of the true system of the Universe, was never favored with a view of the planet, a circumstance attributed by Gassendi to the vapors prevailing near the horizon on the banks of the Vistula.

On examining Mercury with telescopes of adequate power in different parts of his orbit, we notice *phases* similar to those presented by the Moon in the course of her revolution round the Earth, with which every one is familiar. At the greatest elongations eastward or westward we see only half the disc illuminated, as in the case of our own satellite at first or last quarter. As he moves towards superior conjunction, his form becomes *gibbous*, and the breadth of the illuminated part increases, or the outline of the disc becomes more nearly circular the nearer he approaches that position. Owing to the intensity of the solar light we lose the planet for some little time previous and subsequent to the superior conjunction, but, on emergence from the Sun's rays, we find the form still *gibbous*, the gibbosity being now on the opposite side. The illuminated part diminishes as the planet draws near its greatest elongation, about which time it is again seen as a half-moon under telescopic aid; and, as it advances towards inferior conjunction, the form becomes more nearly that of a crescent, until it is lost for the second time in the Sun's refulgence, except at certain epochs of not very frequent occurrence when we see it as a black spot traversing his disc; a phenomenon appropriately termed a *Transit of Mercury.*

The real diameter of Mercury appears to be about 2950 miles; this value being deduced from very accurate measures taken during the last few years. There is but little difference between the polar and equatorial diameters, the *compression* probably not exceeding 1–150.

As far as we are aware, Mercury is not attended by a satellite, and the determination of his *mass*, therefore, becomes a very difficult and uncertain matter. But it fortunately happens that we have a curious method of approximating to this element, viz., by the perturbations produced by the planet in the movements of a comet known as Encke's, which revolves round the Sun in little more than three years, and occasionally approaches very near Mercury about the times of perihelion passage. On this subject we shall have more to say when we come to treat of the comets. We shall here merely state the result thus obtained, which indicates that the mass of the Sun exceeds that of the planet 4,865,750 times, or the mass, as usually expressed, is 1–4,865,750. The density of Mercury under this new mass is 1.12, that of the Earth being put equal to unity.

In order that a *transit* of this planet over the disc of the Sun may take place, it is necessary that the Earth should be in the line of nodes of Mercury at, or very near, the time of his passage through them, this bringing the three bodies very nearly in the same line. The nodes are situate at present in 46.7° and 226.7° of heliocentric longitude, at which points the Earth arrives about the 10th of November and the 7th of May, and in consequence of the very slow sidereal motion of the nodes (amounting to only 13′ in one hundred years), the transits of Mercury must occur for a long time to come in one or other of these months, those at the Ascending Node taking place in November, and those at the Descending Node in May.

The first recorded phenomenon of this kind occurred on the 7th of November, 1631. In a dissertation published at Leipsic in 1629, Kepler notified to astronomers, that according to his calculations a transit must occur on this day, since at the time of conjunction he had found the latitude of Mercury by his tables less than the Sun's semi-diameter. This interesting prediction was verified by Gassendi, at Paris. ·He discovered the planet on the disc of the Sun shortly before nine o'clock in the morning. At first he thought it a spot which had not been remarked on the preceding day, but continuing his observations, its motion was soon detected, and he saw the planet leave the Sun's disc on the western limb about half-past ten, A.M. It was found that Kepler's tables represented the circumstances with far greater precision than even the author himself had hoped for.

The second observation of a transit of Mercury was made by Jeremiah Shakerley, on the morning of the 3d of November, 1651, at Surat, in the East Indies. It is said Shakerley was so desirous of witnessing the phenomenon that, having found by his calculations it would be invisible in England, he made the voyage to India for the purpose.

The third recorded transit was observed at Dantzic by the celebrated astronomer, Hevelius, on the 3d of May, 1661. He saw the planet on the Sun's disc four hours and a half.

The next transit took place on the 7th of November, 1677, and was witnessed by our illustrious Halley, at St. Helena, and by M. Gallet, at Avignon. Halley thought the times of ingress and egress might be observed within a single second of time, and pointed out how the Sun's parallax might be ascertained from such observations, taken at places widely distant from one another, remarking, however, that the difference of the parallaxes would not be large enough to give very certain results. Accordingly, the transits of Mercury have not been employed for the above purpose, but we shall presently have occasion to notice a similar phenomenon in the case of Venus, which is far better adapted to give us a correct value of the Solar Parallax.

A transit of Mercury occurred on November 10, 1690, and was observed in China by the Jesuit missionaries, at Erfurt by Godfrey Kirch, and at Nuremberg by Wurzelbaur. Another in 1697, on November 3, was witnessed by astronomers at Paris, and other places. One on the ninth of November, 1723, was watched at Paris, Genoa, Bologna and Padua, but the *first* complete European observation of a transit of Mercury bears date November 11, 1736, when nearly all the astronomers of the time observed the planet in its progress across the Sun. Since this epoch the phenomena have been pretty closely watched. The transit of 1802, November 9, was seen by the well-known Jerôme de Lalande, who was the more interested in it, inasmuch as he remarks it was the last he could hope to witness. That of 1832, May 5, was visible in this country, though a general prevalence of unfavorable weather occasioned much disappointment. The next occurred on the 7th of November, 1835, but was not visible in these parts of the Earth. Another on 1845, May 8, was partially observed in this country, and also the last, on November 8, 1848, which is the twenty-fifth that has occurred since the phenomenon was first noted by Gassendi.

The following table exhibits the circumstances under which the remaining transits of the present century will take place. The numbers have no pretensions to extreme accuracy, as the tables, both of the Sun and planet, have been considerably improved since the calculations were made by M. Lalande:—

YEAR AND DAY.	Greenwich Mean Time of Conjunction.			Duration of Transit.			Least Distance of Mercury from the Sun's centre.	
	H.	M.	S.	H.	M.	S.	M.	S.
1861, November 11,	19	20	12	4	0	46	10	52 N.
1868, November 4,	18	43	44	3	30	42	12	20 S.
1878, May 6, ...	6	38	29	7	47	2	4	39 N.
1881, November 7,	12	37	37	5	18	18	3	57 S.
1891, May 9, ...	14	44	56	5	8	40	12	21 N.
1894, November 10,	6	27	4	5	15	12	4	20 N.

In describing their observations of the transits of Mercury, astronomers make use of the terms *internal* and *external* contacts. At the ingress or entrance of the planet upon the Sun's disc, the *external* contact takes place when the limb of the planet first makes a perceptible indentation on the limb of the Sun; this phenomenon can never be observed with any great degree of accuracy, and is therefore less important than the observation of *internal* contact, or the moment when the whole disc of the planet is fairly projected on the Sun's surface. When a fine thread of light is seen between the outer limb of the planet and the Sun's limb, the *internal* contact has passed. At the egress, or on the planet's leaving the solar disc, these contacts of course recur, but in reversed order. The moment of internal contact is indicated by the disappearance of the thread of light, and that of external contact by the absence of all appearance of indentation or distortion of the Sun's limb.

Before leaving this subject, we may notice several curious phenomena which have been remarked by astronomers during their observations of the Transits of Mercury. At the first external contact, something like a penumbra or light shade upon the Sun's disc has been remarked. As the planet advances towards the internal contact, a "black drop" or line has appeared to connect its limb with that of the Sun, or the contour of the planet has been seen distorted in such a manner as to give it a pear-shaped form just before the formation of the luminous thread. Such appearances are doubtless to be ascribed partly to atmospheric circumstances; but this cause alone is not sufficient to account for them completely, for different telescopes at the *same* station have frequently given very different results, the distortion of the outer limb of Mercury being apparent in some instruments, while in others nothing of the kind has been remarked. It happened thus at the last transit in November 1848, when an elongation of the planet's limb was distinctly seen with one telescope at the Royal Observatory, though others afforded no indications of it. Another singular appearance which has been mentioned by several observers at different transits, is that of a luminous spot or "globule" upon the disc of the planet when projected upon the Sun. It was remarked by Wurzelbaur at Nuremberg, in November 1697; again at Utrecht, in May 1832, by Professor Moll, who says its periphery was not well defined, but seemed gradually to sink from a grayish white to the dark color of the planet's disc: it was always situated in the same position, or a little south—preceding the centre of Mercury. A telescope by Dollond and another by Fraunhofer showed the spot in precisely the same manner, though various eye-pieces, magnifying from 96 to 324 times, were employed. A similar roundish spot of a grayish tinge was noticed at the last transit in 1848, in England and America. Luminous rings round the disc of the planet have been repeatedly noticed, and on other occasions dark or nebulous rings have been remarked. In 1799 and 1832, the ring had a darker tinge of a violet hue, the color being strongest near the planet. These phenomena may probably arise from a simple cause, though at present it is very imperfectly understood. An American observer of the transit in 1848, says the dusky ring only appeared when the Sun was covered by a thin haze; yet it is not improbable that the planet's atmosphere may cause a similar nebulous-looking ring. The "black drop" already mentioned as having been observed at the *ingress*, is occasionally recorded at the *egress*, the limb of Mercury being drawn toward that of the Sun, so as to cause a distortion in the opposite direction to that which is observed to take place at the planet's entrance upon the Sun's disc.

Such are the most remarkable circumstances connected with the appearance of Mercury during his transits.

The most ancient observation of this planet that has descended to us is dated in the year of Nabonassar 494, or 60 years after the death of Alexander the Great, on the morning of the 19th of the Egyptian month *Thoth*, answering to the 15th of November in the year 265 before the Christian era. The planet was observed to be distant from the right line joining the stars called β and δ in Scorpio, one diameter of the Moon; and from the star β, two diameters towards the north, and following it in Right Ascension. Claudius Ptolemy reports this and many similar observations extending to the year 134 of our era, in his great work known as the Almagest.

We have also observations of the planet Mercury by the Chinese astronomers, as far back as the year A.D. 118. These observations consist, for the most part, of approximations of the planet to stars. M. Leverrier, the eminent French geometer, has tested many of these Chinese observations by the best modern tables of the movements of Mercury, and finds, in the greater number of cases, a very satisfactory agreement. Thus, on the 9th of June 118, the Chinese observed the planet near a cluster of stars in the constellation Cancer, usually termed Præsepe; the calculation from modern theory shows that on the evening of the day mentioned, Mercury was less than one degree distant from the group of stars.

Although the extreme accuracy of observations at the present day renders it unnecessary to use these ancient positions of the planets in the determination of their orbits, they are still useful as a check upon our theory and calculations, and possess, moreover, a very high degree of interest on account of their remote antiquity.

The tables of Mercury at present employed in the computation of Ephemerides, or for predicting the place of the planet at any time, as viewed from the Earth or Sun, are those of Baron Lindenau, published in 1813. These tables still agree, within moderate limits, with the results of observation; but M. Leverrier bas greatly improved the theory of the planet within the last few years; and it is understood that tables based upon his more correct elements are in course of publication. We have given the numbers assigned by this eminent geometer in the table of Planetary Elements, together with those which form the basis of the Baron Lindenau's calculations.

CHAPTER III.

VENUS. ♀

THE second planet in order of distance from the Sun is Venus, the most conspicuous of all the members of the planetary system, when she is favorably placed with respect to our globe. Her sidereal revolution round the Sun is performed in 224d. 16h. 49m. 8s., at a mean distance of 68,770,000 miles, or nearly double that of Mercury.

The apparent diameter of Venus varies much more sensibly than that of Mercury, owing to the greater extent of variation of distance from the Earth. At inferior conjunction, or near this point, her disc subtends an angle of about seventy seconds of arc,—while, at superior conjunction, it is less than ten seconds. The disc is never fully illuminated except at superior conjunction, when the planet is lost in the Sun's rays: but with a good telescope we may trace the variations in her form from the full gibbous to the narrow crescent,—changes which follow the same law as in the case of Mercury.

The real diameter of the planet is not very accurately known; the best observations assign about 7,900 miles, or about the same as the diameter of the Earth. We have at present no means of determining from actual observation the exact difference between the polar and equatorial diameters, but it is certainly very small.

The disc of Venus under telescopic vision is far too bright and glaring to allow of our obtaining any very precise knowledge of the constitution of her surface. The elder Cassini watched the planet attentively about the year 1667, and on several occasions remarked ill-defined dusky spots, which he observed with the view of ascertaining the time of axial rotation. This he considered to be about 23h. 16m.

An Italian astronomer, Bianchini, soon afterwards published some observations, from which he inferred that Venus occupied no less than twenty-four *days* in revolving upon her axis. So marked a disagreement in the conclusions of two observers, could not fail to attract the attention of Sir William Herschel, who carried on for many years a careful examination of the planet's surface, partly with the view of determining which of the periods was the correct one. He occasionally saw spots upon the disc of Venus, particularly in the summer of 1780, but the result of his observations would not give the time of rotation. "For," he observes, "the spots assumed often the appearance of optical deceptions, such as might arise from prismatic affections, and I was always very unwilling to lay any stress upon the motion of spots, that either were extremely faint and changeable or whose situation could not be precisely ascertained." The great power and light of the forty-feet reflector was found to be rather an inconvenience than otherwise in these observations; in fact large telescopes of any kind have seldom been employed with advantage on the planet Venus. Sir William Herschel considered he had decisive evidence of the existence of a dense atmosphere, to the effects of which he attributed the appearance of a luminous border or bright margin on the fully illuminated limb of the planet, from which the light diminished pretty suddenly. The prolongation of the cusps of Venus beyond a semicircle was also thought to be owing to the refraction in the atmosphere. The terminations of the cusps were always observed to be sharply defined and perfectly free from irregularities, such as the appearance of mountains on the surface might occasion. Schröter, who paid much attention to his observations on this planet, assures us that mountains exist upon it of fifteen and even twenty miles altitude, or of far greater height than any upon the earth, and he remarked further that the greatest inequalities are in the Southern hemisphere.* The same astronomer, from closely watching the atmospheric spots and appearance of the horns, and from eight observations of a fixed point on the surface, ascertained that the time of rotation is 23h. 21m. 7.98s., a result which has been ,pretty generally received, though it may hereafter be somewhat modified. In confirmation of this period of revolution, it may be remarked that Cassini II. was able to show the fallacy of Bianchini's inference by comparing all his father's observations together, and he further proved that the particulars given by Bianchini could be represented by a rotation of little less than one of our days.† Sir William Herschel

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* For a month following the 11th of December, 1789, Schröter noticed that the Southern horn appeared blunt with an enlightened mountain in the dark part of the disc, which was found to be 18,000 toises in height, or rather less than twenty-two English miles. The highest mountain was supposed by Schröter to be 18,900 toises in altitude. These numbers, however, must be received with caution, for it may be doubted whether the micrometers, &c., employed by the diligent and able observer at Lilienthal, were sufficiently delicate for measures of this nature. His measures of the diameters of some of the minor planets are well known to be greatly in excess of the values given by the improved instruments of the present day.

† The same remark may probably apply to some observations on a spot upon the disc of Venus, by M. Flaguergues, at Viviers, between the 7th and 13th of July, 1796, which are said to favor Bianchini's conclusion with respect to the time of rotation. The observations indicated that the axis of Venus is inclined at an angle of 73° 32′, to that of the elliptic (which agrees with Cassini's result), the North Pole being directed to 321° 20′ longitude. These particulars were communicated by M. Flauguergues to the Academy of Sciences at Nismes, and are pretty satisfactory as regards the position of the axis.

was of opinion that the time of revolution could not be so long as twenty-four days, though, as above stated, his own experience did not enable him to assign the precise period. The late Professor De Vico, in the admirable sky of Rome, frequently *saw* spots upon Venus ; but for a steady view of them it was necessary to wait for the very best atmospheric conditions, even under an Italian sky, as the author was assured by this diligent observer. Professor Mädler has recently made a series of observations, from which he deduces the amount of horizontal refraction, and finds it one sixth greater than in our own atmosphere.

Venus is a *morning* star from inferior to superior conjunction, and an evening star from superior to inferior conjunction. Her greatest elongation from the Sun, in longitude, is about 47° 15′, hence she is never observable more than from three to four hours after sun-set or before sun-rise. Occasionally she attains so great a degree of brilliancy as to be distinguishable at noonday in a favorable sky, without the assistance of a telescope.* This happens once in eight years, when the planet is at or near its greatest north latitude, and about five weeks from the time of inferior conjunction. One fourth of the disc, or rather less,

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* Claudianus relates that in the fourth year of Honorius, Emperor of the West, or A.D. 398, a star was seen in the day-time as bright as Arcturus appears at night. Venus might be observed at noon-day about the end of January and beginning of February in this year. It was probably this planet that attracted attention in the day-time in 984, according to a Saxon Chronicle, and again on Easter Sunday, 1008, and at the end of the year 1014. Several writers mention the appearance of a star at the sixth hour of the day, or about noon, on Palm Sunday 1077 (April 9); Venus was then approaching her inferior conjunction, and might probably be the object here referred to. On the 29th of January, 1280, she was seen by day-light, and again for some days about the 27th of May, 1363, like a very small star. Very recently the curiosity of the Parisian public was excited by the discovery of a star in the day-time, which proved to be Venus.

is illuminated, and under these circumstances the planet has been observed to cast a very sensible shadow at night. The elongation from the Sun at the time of maximum brilliancy is rather less than 40°, and the diameter of the illuminated part about ten seconds of arc; the phase is therefore similar to that presented by our own satellite about three days from the New Moon.

Astronomers are by no means satisfied whether the planet Venus be attended by a satellite or not. Observations have been made which are strongly in favor of the existence of such an attendant, but many of the most diligent observers of past and present times have watched the planet under every variety of climate and atmospheric condition and with telescopes of all kinds, without once obtaining a glimpse of a satellite. It is a question of great interest, and must remain open for future decision. We shall here briefly recapitulate the evidence in favor of a satellite.

The celebrated Cassini was the first astronomer who noticed any suspicious object near the planet. On the mornings of January 25th, 1672, and August 27th, 1686, he distinctly perceived a luminous body, presenting on the first occasion the same phase as Venus, and about one quarter of her diameter. The well known optician, Short, remarked an object with the same phase as the planet, and about ten minutes of space from it, on the morning of the 3d of November, 1740. In the month of May, 1761, M. Montaigne, at Limoges, saw what he considered to be a satellite on four evenings. It was always one fourth of the diameter of Venus, with precisely the same form, and changed its position with respect to the planet. In March, 1764, the supposed satellite was observed by several astronomers, and, what is most important, at places widely distant from one another. Rödkier, Horrebow, and others at Copenhagen, with a refracting telescope, and Montbarron at

Auxerre, with a Gregorian reflector, repeatedly saw the attendant between the 3d and 29th of that month. Its diameter was estimated as before at one fourth of that of the planet.* Since that time, so far as we are aware, no suspicion of a satellite has been entertained by any observer. It has been urged, if there really be one in existence, it should have been readily seen at those times when Venus, like Mercury, has traversed the Sun's disc; yet only two of the very many who watched the transits of the last century profess to have seen any object resembling an attendant upon the planet. Sir W. Herschel perceived no traces of a satellite, neither did Schröter, though he was most assiduous in his observations of Venus. Still it is not easy to understand how all the observers of the last century can have been mistaken. In this state the question at present remains.

There are several methods by which the mass of this planet may be ascertained. The effect of its attraction upon our globe causes the Sun's place to differ by a sensible quantity from what it should be, supposing this attraction was not in force, and the planet also exercises an appreciable influence on the precession of the equinoctial points. The most accurate investigations show that the mass is 401,839 times less than that of

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* Professor Lambert collected the observations together, and succeeded in deducing from them a pretty consistent orbit. The period of revolution assigned was 11d. 5h. 13m., and the mean distance of the satellite from Venus 64½ semi-diameters of the Earth, or about 255,000 miles. The eccentricity given by Montaigne's observations appeared to be 0.195, and the position of the aphelion, in 1700, in longitude 256°: the node at the same epoch was 233°, and the plane of the orbit made with that of the elliptic an angle of 64°. There is one fatal objection to this orbit, notwithstanding its apparent agreement with observation; if it were correct, the mass of Venus would be ten times greater than the value found from theory by other methods. Lambert's calculations will be found in Bode's *Jharbuch* for 1777.

the Sun; it is, therefore, a little smaller than the mass of the Earth, though a nearer approach to it than obtains with any of the other planets.

Transits of Venus over the Sun's disc take place under the same circumstances as those of Mercury, or when she has the same heliocentric longitude as the Earth, at or near the times of the nodes. The present position of the line of nodes is in longitude 75°,6 and 255°,6, and the secular sidereal motion of this line is 31′, wherefore for a long time to come the transits of Venus must occur early in June or December, those in the former month at the Ascending Node, and those in the latter month at the Descending Node. Owing, however, to the length of time required after a conjunction to bring the Earth and planet into the same heliocentric position again, the transits of Venus are of rare occurrence, taking place at intervals of about eight and one hundred and thirteen years. They are phenommena of the highest importance as enabling astronomers to determine the distance of the Earth from the Sun, with far greater accuracy than any other method will give it. To do this successfully, it is necessary to have observations taken at places differing widely in latitude, so that the displacement of Venus upon the Sun's disc, owing to the effect of parallax, may be as large as possible. Now, under the circumstances that the transits of Venus at present occur, the distance of the planet from the Sun is to its distance from the earth as 73 to 29, or very nearly as 2½ to 1. Supposing we had observations taken at each of the poles of the Earth, it would be found that the displacement of Venus on the Sun's disc would occupy a space 2½ times as great as the Earth's diameter, viewed from that luminary, or five times as large as the Sun's horizontal parallax. Hence we see why the transits of Venus are so much more important than those of Mercury in the determination of this element, for similar considerations applied to the latter planet will show that the displacement upon the Sun's disc, instead of *exceeding* the horizontal parallax, will be half as small again, so that any error entailed in the observation will have an effect upon the final result equivalent to more than twice the amount of that error. In the case of Venus, however, any error of observation can only influence the deduced parallax by one fifth of its actual amount.

The observation consists in ascertaining the time of duration of a transit, or the interval elapsing between the ingress and egress of the planet upon the Sun's disc. The theory of Venus and the Sun's diameter being well-known, such observations readily give the parallax of the planet, and hence that of the Sun.

Venus was first observed upon the Sun's disc in the year 1639. Jeremiah Horrox, of Hoole, near Liverpool, while employed in calculating an ephemeris of the planet from Lansberg's tables, found that the geocentric latitude of the planet at the moment of inferior conjunction on the 24th of November, would be less than the Sun's semi-diameter, and consequently that it must appear upon his disc. These tables, however, had so often deceived him, that he had recourse to the *Tabulæ Rudolphinæ*, then newly published by Kepler, and based upon the observations of Tycho Brahe, the most exact astronomer of his age. According to Kepler's numbers, he found the transit of the planet equally certain, and, applying some corrections of his own, he expected to find the planet in conjunction at 4 P.M., on the 24th of November, about ten minutes south of the Sun's centre. Having thus satisfied himself that Venus must really appear projected upon the solar orb, he gave notice to his friend William Crabtree, a zealous astronomer, desiring him to observe it. Fortunately the planet was seen upon the Sun's disc by both observers, though Crabtree, interrupted by a cloudy sky, caught only a single glimpse of it. To make sure of the matter, Horrox commenced his examination of the Sun on the 23d of November, and repeatedly watched it until one o'clock, P.M., on the 24th, when he was called away by business. On returning at a quarter past three o'clock, he readily discerned the planet which had just fully immerged upon the solar disc; in fact, at the first view, its outer limb coincided with that of the Sun. He continued his observations until a few minutes before sun-set. Horrox transmitted the image of the Sun through a telescope into a darkened room, a mode of observation which was attended with great advantage.

Such are the circumstances under which the planet Venus was for the first time beheld as a black spot upon the Sun's disc.

No other transit of Venus occurred until the 5th of June, 1761. Dr. Halley had pointed out, many years previous, that the parallax of the Sun could be determined within a small fraction of a second from observations of this phenomenon, and a high degree of interest was awakened as that of 1761 drew near. Observers proceeded from Europe to distant parts of the earth to secure data for ascertaining this important quantity with exactness, and astronomers were on the watch from Tobolsk in Siberia to the Cape of Good Hope. The results have been discussed by Professor Encke, of Berlin, in a special treatise on the subject; but it is found that the individual values for the Sun's parallax do not agree so well as might have been anticipated, and it is most fortunate that another transit, on the 3d of June, 1769, has afforded more consistent numbers.

Very extensive preparations were made for observing the transit of 1769. An expedition was equipped, on a large scale, and despatched to Otaheite, under the command of Captain Cook, and at the expense of the British Government. Continental powers likewise joined in the preparations, and astronomers of various nations were sent out to the most advantageous points for observation. The ingress of the planet on the Sun's disc was seen at almost all the observatories of Europe; the egress at St. Petersburg, Pekin, Orenburg, Jakutsk, Manilla, Batavia, &c., and the complete duration of the transit at Cape Wardhus, Kola and Cajeneburg in Lapland, at Otaheite, Fort Prince of Wales and St. Joseph in California. The resulting parallax is considered certain within a very small fraction of a second of space; separate investigations by Professor Encke and M. de Ferrer having led to precisely the same value.

No transit of Venus has taken place since the year 1769; the next will occur on the morning of the 8th of December, 1874, but will be invisible in this country, the conjunction happening soon after four o'clock in the morning, and the egress of the planet nearly two hours before sun-rise. Another transit will take place on the 6th of December, 1882; the entrance of Venus on the Sun's disc will be observable in England, and her progress across it may be watched till sunset; but the egress will not occur until eight o'clock in the evening. No transit will happen during the twentieth century. The next, on the morning of the 7th of June, 2004, will be visible under favorable circumstances in these parts of the world.*

Similar phenomena to those we have already noticed as attending the transits of Mercury, take place on an extended scale during those of Venus. A kind of lucid wave gave the first in-

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* Transits of Venus occurred as follow, according to the calculations of M. Delambre:—

A.D.	902, November	26,	9 A.M.
"	910, November	32,	9 P.M.
"	1032, May	24,	7 P.M.
"	1040, May	22,	11 A.M.
"	1145, November	26,	8 A.M.
"	1153, November	23,	8 P.M.
A.D.	1275, May	25,	10 P.M.
"	1283, May	23,	3 P.M.
"	1388, November	26,	7 A.M.
"	1396, November	23,	7 P.M.
"	1518, May	26,	2 A.M.
"	1526, May	23,	6 P.M.

The hour given being that of conjunction of the Sun and planet in Greenwich time.

timation of the planet's approach to the Sun in 1769, according to an observer at Greenwich; this was followed by an apparent "boiling" of the solar limb at the same place, which continued visible for some seconds. When the planet had partially entered upon the disc, a distortion of its outline was remarked by several persons, the planet assuming an oval or elongated appearance; that part of it, which was still off the disc, seemed to be surrounded by a faint border of light. The "black drop," shortly before internal contact, is mentioned by numerous observers in Europe and America, and the completion of the luminous thread denoting that the contact had passed was very generally described. Narrow circles of light were noticed round the planet during its progress across the Sun, and one observer speaks of an illumination of the disc, possibly similar to that recorded occasionally in the transits of Mercury. Similar appearances to those noticed at the ingress have been found to offer themselves when the planet is leaving the Sun; but, of course, in reversed order.

The tables of Venus in present use for predicting the place of the planet in the heavens, are those of the Baron Lindenau, published at Gotha, in 1810. Within the last ten years the elements have been much improved by several English astronomers, with the aid of observations taken at our Royal Observatory. A most important addition has also been made to the theory of the planet by Mr. Airy, since the appearance of the above tables, consisting of a long inequality affecting the places of the earth and planet, as viewed from the Sun, to a very sensible amount. It arises from the near commensurability of the mean motions of the two bodies, *thirteen* times the period of Venus being nearly equal to *eight* times the period of the Earth. This inequality goes through all its changes of magnitude in about 240 years, and was at a maximum about the commencement of the present century, when the heliocentric place of the Earth was changed two seconds of space, and that of Venus about three seconds, by this cause. At present the tables of Baron Lindenau are quite exact enough for all practical purposes; but from what has been said, it will be evident that astronomers have the means of improving them very considerably.

Claudius Ptolemy has preserved for us, in his "Almagest," many observations of Venus by himself and other astronomers before him, at Alexandria, in Egypt. The most ancient of these observations is dated in the four hundred and seventy-sixth year of Nabonassar's era, and thirteenth of the reign of Ptolemy Philadelphus, on the night of the 17th of the Egyptian month Messori, when Timocharis saw the planet eclipse a star at the extremity of the wing of Virgo. The date answers to B.C. 271, October 12 A.M.

Similar occultations of stars and planets by Venus have been witnessed in modern times. Regulus, the bright star in Leo, was twice eclipsed by her in the sixteenth century: on the 16th of September, 1574, according to Mæstlin, and again on the 25th of September, 1598, as Kepler relates in his "Astronomiæ Pars Optica." Mars was occulted by Venus on the 3d of October, 1590, and Mercury suffered a similar eclipse on the 17th of May, 1737.

CHAPTER IV.

THE EARTH. ⊕

WE have now to consider the Earth on which we dwell, in its astronomical relations, as one of the primary planets revolving round the Sun, next in order, beyond the orbit of Venus.

Astronomical geography teaches us that the Earth is not a perfect sphere, but is somewhat flattened at the poles; the equatorial diameter, therefore, being the greatest, as we shall presently see to be the case with the superior planets. The form of the Earth is, consequently, an oblate spheroid. The elaborate calculations of Mr. Airy, and the late Professor Bessel, have furnished us with a very exact determination of the actual dimensions of our globe. According to the former astronomer, the equatorial diameter measures 41,847,426 English feet, and the polar diameter 41,707,620 feet. These measures, reduced into miles, give 7925.6 and 7899.2 respectively: the compression at the poles therefore amounts to 26½ miles, or it is about 1-300th part of the whole diameter.

The transits of Venus, as already remarked, have given us the value of the Sun's equatorial horizontal parallax with great exactness. This quantity is really the angular measure of the Earth's equatorial semi-diameter, at our average distance from the Sun. Wherefore, knowing the number of miles in the diameter of our globe, we can readily ascertain by trigonometry the mean distance of the Earth from the Sun in miles, which is 95,298,260.

That great circle of the heavens which the Sun appears to us to describe in the course of a year, owing to the annual revolution of the Earth round that body, is called the ecliptic, and the plane of the ecliptic, or of the Earth's orbit, is employed in nearly all astronomical calculations as a fundamental plane of reference. The equator of the heavens, which is a projection of the terrestrial equator to the sphere of the fixed stars, makes an angle with the ecliptic of about 23°.27′, termed the obliquity of the ecliptic. The two points where the celestial equator is intersected by the Sun's apparent path are called the equinoxes; and those where the Sun is 90° distant from the equinoxes, or at his greatest north and south declinations, are called the solstices. The spring equinox is the point from which astronomers reckon the right ascensions along the equator, and the longitudes on the ecliptic.

It is owing to the inclination of the ecliptic to the equator that, in the course of our annual revolution round the Sun, we experience the vicissitudes of the seasons—spring, summer, autumn, and winter. At present this inclination amounts to about 23° 27′; but it is subject to a very slow diminution, not exceeding 48″ in 100 years. It will not always, however, be on the decrease, for before it can have altered 1½°, the cause which produces this diminution must act in a contrary direction, and thus tend to increase the obliquity. Consequently, the change of obliquity is a phenomenon in which we are concerned only as astronomers, since it can never become sufficiently great to produce any sensible alteration of climate on the Earth's surface. A consideration of this remarkable astronomical fact cannot but remind us of the promise made to man after the deluge, that "while the earth remaineth, seed-time and harvest, and cold and heat, and summer and winter, and day and night shall not cease." The perturbation of obliquity, consisting merely of an oscillatory motion of the plane of the ecliptic, which will not permit of its ever becoming very great or very small, is an astronomical discovery in perfect unison with the declaration made to Noah, and explains how effectually the Creator had ordained the means for carrying out his promise, though the way it was to be accomplished remained a hidden secret, until the great discoveries of modern science placed it within human comprehension.

Anaximander, a disciple of Thales, who was born in the third year of the forty-second Olympiad, or B.C. 610, is reported by Pliny to have been the first of the ancients by whom reference is made to the *obliquity of the ecliptic.* Diogenes Laerces tells us that he erected a gnomon at Lacedemon, with which his observations were made. Other authorities attribute the first notice of the obliquity to Pythagoras, born about seventy years after Anaximander, while Diodorus Siculus, and after him Plutarch and Stobæus, inform us that Œnopides of Chio obtained the knowledge of this inclination of the equator and ecliptic from the Egyptians. Laplace, however, makes use of observations for ascertaining this angle said to have been taken in China by *Tcheou-kong* 1100 years before the Christian era. We subjoin a table exhibiting the various determinations of the obliquity of the ecliptic from the earliest times to the present day, from which the reader will see that observation had pointed out its gradual diminution long before analysis was sufficiently advanced to indicate the cause. Most of the ancient observations by the Greeks and Arabians were taken with gnomons or armillæ: their plan was to ascertain the length of the shadow in relation to the height of the gnomon, on the days of the solstices, when the Sun attains his greatest declinations north and south. Hence his altitude above the horizon could be found, and the difference between the results on the two solstitial epochs would give the distance between the tropics, half of which distance is the inclination of the ecliptic to the equator. The Chinese observations for taking the obliquity were taken with similar instruments, and are here given as reduced by Laplace in his paper on this subject, *Connaissance des Temps*, 1811 :—

A TABLE EXHIBITING THE PRINCIPAL DETERMINATIONS OF THE OBLIQUITY OF THE ECLIPTIC, IN ANCIENT AND MODERN TIMES.

		Obliquity.		
B.C.		°	′	″
1100.	Tcheou-kong	23	54	2
324.	Pytheas of Marseilles	23	49	20
230.	Eratosthenes of Cyrene, by observations with armillæ erected in a portico at Alexandria	23	51	15
140.	Hipparchus, the great astronomer	23	51	15
50.	Lieou-hang	23	45	39
A.D.				
140.	Claudius Ptolemy, the Egyptian astronomer	23	51	15
173.	Chinese observations at Layang	23	41	33
461.	Tsou-chong at Nan-king	23	38	52
629.	Litchun-foung at Siganfou	23	40	4
830.	Almamun, son of the famous Harun al Raschid	23	33	52
879.	Albategnius at Aracte	23	35	0
987.	Aboul Wefa at Bagdad	23	35	0
995.	Abul Rihau with a quadrant 25 feet radius	23	35	0
1080.	Arzachel in Spain	23	34	0
1279.	Cocheu-kong with a gnomon 40 feet height	23	32	12
1303.	Prophatius, a Spanish Jew	23	32	0
1430.	Ulugh Beigh at Sarmarcand	23	31	48
1460.	Regiomontanus in his tables	23	30	0
1587.	Tycho Brahe, the celebrated Danish astronomer	23	31	30
1660.	Hevelius at Dantzic	23	29	30
1690.	Flamsteed, the first astronomer at Greenwich	23	28	56
1750.	Bradley, La Caille, &c.	23	28	19
1769.	Maskelyne at Greenwich	23	28	10
1800.	Delambre and others	23	27	57
1825.	Bessel at Königsberg	23	27	43,4
1840.	By observations at Greenwich, Edinburgh, Cambridge, and other places	23	27	36,5

The phenomenon known as the *precession of the equinoxes* was discovered by the celebrated astronomer Hipparchus, of Nicea, in the second century before the Christian era. By comparing his own observations of the longitudes of several principal fixed stars with those of Timocharis and Aristyllus, taken at Alexandria about 150 years previously, he found they differed constantly in one direction—the distances of the stars from the first point of Aries having increased apparently at the rate of about 1° in a century. The effect was thus discovered, but the cause remained unknown till it was explained by our illustrious Newton. It consists chiefly in the action of the Sun and Moon upon the protuberant matter at the Earth's Equator: a minute effect is due to the influence of the planet Venus. It is called the *precession* of the equinoxes because the equinoctial point is carried forward in reference to the circle of diurnal movement, arising from the Earth's rotation on her axis; consequently, it retrogrades upon the ecliptic, and thereby causes an increase in the distance of all stars from the first point of Aries, measured upon that circle. The present rate of progression is about 1° 23′ 44″ in 100 years, or 50¼″ annually. Upwards of 25,800 years will be required for a complete revolution of the equinoctial points.

We may conceive the phenomena of *precession* to arise from the revolution of the pole of the celestial equator, or that point of the heavens to which the Earth's axis is directed, round the pole of the ecliptic, in the period of 25,800 years, at a mutual inclination of 23° 28′, and shall thus obtain an insight into the nature of another important inequality, called the *nutation* of the Earth's axis, which exercises very appreciable influence upon the positions of the stars, as we see them from the Earth, and goes through all its variations in somewhat less than nineteen years, or in the course of one revolution of the Moon's nodes. The same cause which operates in producing the precession of the equinoxes gives rise also to the nutation, in virtue of which the Earth's axis, instead of being continually directed to the same point in the celestial sphere, describes a small ellipse on the surface of the heavens, having the ratio of the greater axis to the lesser as 37 to 27, the length of the major axis in arc of a great circle being 18″.6.

Dr. Bradley first discovered and explained the nutation of the Earth's axis, soon after he had been led by his own observations to infer the existence of the aberration of light. We have, therefore, to thank this eminent astronomer for two of the most important discoveries connected with the science.

The Earth's orbit is not circular, but an ellipse of very moderate eccentricity, the perihelion point in 1800 answering to 279° 30′ 8″ of heliocentric longitude. The line of apsides is subject to an annual direct change of 11.29″, independent of the effect of precession, so that, allowing for the latter cause of disturbance, the annual movement of the apsides in reference to the variable equinox may be roughly taken at one minute of arc. One important consequence of this slow motion of the greater axis of the Earth's orbit is the variation in the length of the seasons in different centuries. In the time of Hipparchus, the longitude of the Sun's perigee was between the autumnal equinoctial point and the winter solstice, and the autumn was the shortest of the seasons; spring was longer than summer, and winter longer than autumn. About the middle of the thirteenth century the perigee coincided with the winter solstice, whence spring was equal to summer, and autumn to winter. In the year 1850 we find the time elapsing between

	d.	h.	m.
The spring equinox and summer solstice .	92	20	57
The summer solstice and autumnal equinox	93	14	0
The autumnal equinox and winter solstice .	89	17	38
The winter solstice and spring equinox . .	89	1	17

Hence the spring has become shorter than the summer, and the autumn longer than the winter.

About four thousand years before the Christian era, or singularly enough, near the epoch of the creation of man, according to chronologists, the perigee coincided with the *vernal equinox*, and the winter and spring were equal, and shorter than the summer and autumn, which were also equal. In A.D. 6485, or thereabouts, the perigee will have completed half a revolution, and will then coincide with the *autumnal equinox;* summer will be equal to autumn, and winter to spring, but the former seasons will be the shortest. All these changes, it is to be observed, are due in the first place to the eccentricity of the Earth's orbit, and to the progressive movement of the line of apsides. The eccentricity, as we have stated above, is not large; at the commencement of the present century it amounted to 0.0167923, but is subject to a slow diminution, not exceeding 0.000044 in one hundred years. Supposing this change permanent, the Earth's orbit must eventually become circular, but the theory of attraction enables us to prove that the diminution is not to continue beyond a certain time, and although we are not yet in a condition to assign definite limits to the oscillations, we know that after the lapse of many thousand years the eccentricity will be stationary for a time, and afterward *increase;* and, without some external cause of perturbation, these variations, within certain not very distant limits, must continue throughout all ages.

Were the Earth's orbit circular, and the plane of the equator coincident with that of the ecliptic, the Sun would appear to describe an equal arc of the heavens day after day, and consequently the interval elapsing between two successive passages over the meridian of any place on the Earth's surface would be sensibly the same, and the solar day would be something like an equable period of time. But, as we have seen, the

Earth's path round the Sun is elliptical, and the apparent diurnal velocity of the Sun varies with our distance from him. Moreover, the equator is inclined to the plane of her path at an angle of about 23° 28′, and this again has a great influence on the length of the arcs of *Right Ascension*, passed over by the Sun on successive days. It follows, therefore, that the solar day, or the interval elapsing between two consecutive meridian transits of the Sun, is of variable length. To secure an equable measure of time, astronomers assume the revolution of a *mean* Sun in the plane of the equator with the real Sun's mean diurnal motion in Right Ascension, and the time intervening between two successive transits of the mean Sun is called a mean solar day, which is the unit of time in common use at present.

The difference between the Right Ascension of the mean and true Suns is termed the *Equation of Time*, and in order to regulate a clock by observations of the time of culmination of the Sun it is necessary to know the amount of this equation for each day, and we, accordingly, have it tabulated in astronomical ephemerides and almanacs. The equation is at a maximum about the 10th of February, when an additional correction of about 14m. 32s. is required to reduce apparent solar time to mean solar time, or, in other words, the mean Sun is on the meridian 14m. 32s. before the true Sun. On the 15th of April there is no equation, the real and imaginary Suns being on the meridian at the same moment. In the middle of May the equation again reaches a maximum at 3m. 54s., and disappears on the 15th of June. Another maximum occurs about the 27th of July, when a correction of 6m. 11s. is required to be added to apparent solar time. On the 1st of September it again vanishes, but increases from that time until the beginning of November, when the equation amounts to 16m. 17s., subtractive from apparent time, and again becomes *zero* about the 25th of December; thus there are four maxima in each year.

The *sidereal* day is the time intervening between two consecutive passages of the same star over a meridian; it is consequently the length of the Earth's diurnal rotation upon her axis, and expressed in mean solar time is 23h. 56m. 4.9s. The sidereal day is subject to no sensible variation. It is in consequence of the acceleration of the sidereal upon the mean solar day that the aspect of the heavens is varied at different times of the year, those stars which at one time appeared on the meridian at midnight gradually gaining upon it, until they are lost in the western heavens at sunset, to make their reappearance in the east after the lapse of a few months.

The interval of time in which the Sun appears to us to complete an entire circuit of the heavens, in reference to the fixed stars, is called by astronomers a *sidereal year*, and consists of 365d. 6h. 9m. 10.7s. In this period, however, the equinox will have retrograded 50¼″, and the Sun will reach the same point of longitude from which he started in a shorter time, than would be required to elapse from the moment of his leaving a fixed star until he again returns to it. The revolution in respect to the equinox is thus shorter than the revolution in respect to the stars, by the interval occupied by the Earth in passing over an arc of 50¼″ upon her orbit, or by 0h. 20m. 22.9s., and we obtain 365d. 5h. 48m. 47.8s., for the length of the revolution in reference to the equinoctial point, or, as it is termed, the *tropical year*.

We have seen that the perihelion point of the Earth's orbit has an annual motion amongst the stars of about eleven seconds, by which quantity the longitude *exceeds* that of the preceding year. If the Sun start from the place of the perihelion he will require a longer interval of time than the sidereal year to reach it again, and the excess will be equal to the time necessary for the Earth to describe 11.29s. of her orbit, or 4m. 35.0s., which gives us 365d. 6h. 13m. 45.7s. for the duration of what is called the *anomalistic* year. This period is occasionally used in astronomical investigations, but mankind generally are more concerned in the *tropical year*, on which the return of the season depends. This year is subject at present to a slow diminution, amounting to little more than half a second in one hundred years, yet, like all variations of the kind by which the Earth's orbit is affected, the diminution is not to continue forever.

The ancient Egyptian year consisted of 365 days, as we learn from Herodotus. The Thebans, or inhabitants of Upper Egypt, are said to have perceived the necessity of an addition of six hours to this period, in order to make it agree with the annual course of the Sun. In the time of Democritus, about 450 years before Christ, the year was supposed to consist of 365¼ days. Eudoxus, who flourished soon afterwards, considered it somewhat longer, while Œnopides, of Chius, mentioned by Diodorus, made it 365d. 8h. 48m. The Calippic period of 76 years, commencing at the death of Darius, B.C. 329, consisted of 27,759 days, giving 365¼ days for the length of the year.

The great astronomer, Hipparchus, found by his own observations that the year of Calippus was somewhat too long, and, accordingly, diminished it by the three-hundredth part of a day, or 4m. 48s., whence he fixed the length of the tropical year at 365d. 5h. 55m. 12s., differing little more than six minutes from the best modern determination. Nearly three hundred years after the time of Hipparchus, Ptolemy appears to have investigated the length of a year, but concluded by adopting the duration assigned by the Greek astronomer, and employs it in the Solar Tables found in his Almagest.

The Arabian Prince Albategnius, who lived at the latter end of the ninth century, and observed at Aracte, in Chaldea, perceived the want of some correction to the Ptolemaic or Hipparchian year, and by comparison of his own observations with those at Alexandria, inferred that the length of the tropical year was 365d. 5h. 46m. 24s., as reported in his work *De Scientia Stellarum.* In the Alphonsine Tables, compiled about 1252, by Alphonsus X., King of Castile, with the assistance of the best astronomers of his age, we find the length of the year 365d. 5h. 49m. 16s., a very near approximation to the truth.

Since this epoch, the duration of the tropical year has formed the frequent subject of investigation. The following table exhibits the principal determinations up to the present time :—

	d.	h.	m.	s.
Nicolas Copernicus, in 1543	365	5	49	6
Tycho Brahe, in 1602	365	5	48	45⅛
Kepler, in the *Tabulæ Rudolphinæ* . . .	365	5	48	57.6
Cassini, in 1743, by comparison of his own observations of Equinoxes with those of previous observers	365	5	48	52.4
Flamsteed, our first Astronomer Royal .	365	5	48	57.5
Halley, in his Astronomical Tables . .	365	5	48	54.8
Lacaille, in his Tables	365	5	48	49
Bessel, in 1830, gives for 1800	365	5	48	47.8

CHAPTER V.

THE MOON. ◐

THE Moon, the constant attendant of the Earth in her annual course round the Sun, is by far the nearest to us of all the heavenly bodies, being situated at an average mean distance of only 238,650 miles. To her we are indebted, not merely for illumining by her presence our dark winter nights, but likewise for that more important phenomenon, the tides of the ocean, in the production of which she has the greatest influence, and it is not unlikely that this extraordinary luminary exercises an effect upon the Earth in other ways, of which we are not at present fully cognizant.

The interval of time occupied by the Moon in performing one *sidereal* revolution round the earth,* or the time which elapses between her leaving a fixed star until she again returns to it, is found by the latest and most accurate investigation, to be 27d. 7h. 43m. 11.461s., whence we find the mean *tropical*

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* Strictly speaking the centre of the Earth is not the point round which the Moon revolves; but both bodies have a revolution round their common centre of gravity. This point is situated at an average distance of 2,690 miles from the centre of our globe, or about 1,270 miles beneath the surface, and subject to a variation of rather more than 165 miles, one way or the other, in consequence of the variable distance between the Earth and the Moon. The perturbation in the place of the Earth, or rather its reaction on the place of the Sun, owing to this motion round the centre of gravity, may affect the Sun's longitude more than five seconds of arc, and his latitude about 0.7″.

revolution 27d. 7h. 43m. 4.614s., since the equinox will have receded in a sidereal period 3·758″, a space which the Moon would require 6·847″ to traverse with her average mean motion.

The phenomena, termed the *phases* of the Moon, do not recur in the space of a *sidereal* revolution, for it is evident that the real motion of the Earth in that interval, giving rise to an apparent motion of the Sun, in the direction in which the Moon revolves, must cause the period between two conjunctions or oppositions to be longer than either the sidereal or tropical revolutions, the Moon having to traverse an arc equal to the angular movement of the Earth in the sidereal period, before she is again in a line (to speak roughly) with the Earth and Sun. The lunar month, or as it is usually called by astronomers, the *synodical* revolution of the Moon, is consequently *longer* than the sidereal period, and exceeds it by 2d. 5h. 0m. 51·41s., which is the time required by that body to describe, with her mean angular velocity of 13·1764° per day, the arc traversed by the Sun since the previous conjunction. Hence we find the duration of the *synodical* period to be 29d. 12h. 44m. 2·87s.

The lunar phases depend on the position of the Moon with respect to the Sun, or what amounts to the same thing, her distance from conjunction, which is termed in astronomical language, the *age* of the Moon. Being an opaque spherical globe, reflecting the Sun's light, she can only appear fully illuminated when opposite that luminary, and in all other positions her illuminated disc appears less than a circle. Soon after conjunction with the Sun, she may be seen as a very narrow crescent, a little above the western horizon at sun-set, for being then between the Earth and Sun, her illuminated surface is in a great measure turned from us. As she advances in her orbit, the dark part gradually diminishes until the Moon is 90° from conjunction, which is called the first quarter, and then the bright and unilluminated parts are equal. After this point, the illuminated surface increases till the Moon is in opposition, when it is said to be *full*, and presents to us her whole enlightened disc. The bright part then begins to diminish and again occupies one half of her surface when the Moon is 90° from the conjunction, at the last quarter, becoming narrower as she approaches it, till a thin crescent above the eastern horizon shortly before sun-rise is all that remains. These *phases* are consequently recurrent after the interval of a *synodical* revolution, and depend upon the position of the *visible*, in reference to the *enlightened*, hemisphere.

The eccentricity of the lunar orbit is considerable, and from this cause, the distance between the Earth and the Moon, at the perigee, may be no more than 225,560 miles, while at apogee it may increase to 251,700 miles, the ellipticity of the orbit therefore producing a variation in the length of the radius vector, or true distance from the Earth, of rather more than 26,000 miles. The mean inclination of the orbit to the ecliptic is, according to recent determination, $5° \, 8' \, 55{\cdot}46''$, but this is subject to a variation, one way and the other, of rather less than $23'$: the latest *tables* of the Moon giving the greatest inclination $5° \, 20' \, 6''$, and the least, $4° \, 57' \, 22''$. The line of nodes of the lunar orbit revolves round the ecliptic in 18yrs. 218d. 21h. 22m. 46s., in a retrograde direction, which is at the rate of $1\frac{1}{2}°$ in each sidereal period, or somewhat more than $3'$ daily. This retrogression of the nodes is caused by the action of the Sun, which modifies the central gravity of the Moon towards the Earth. It is not, however, an equable motion throughout the whole of the Moon's revolution; the node, generally speaking, is stationary when she is in quadrature, or in the ecliptic; in all other parts of the orbit it has a retrograde motion, which is greater the nearer the Moon is to the syzigies, or the greater the distance from the ecliptic. The preponderating effect at the end of each synodic period is, however, retrocessive, and gives rise to the revolution of the line of nodes in between eighteen and nineteen years. Hence it is necessary to distinguish between the *mean* place of the node which supposes a regular movement of 3′ 10″ daily, contrary to the order of signs and its *true* place at any time. The backward movement of the line of nodes was discovered by the ancients, but first explained by Newton.

The line of apsides or major axis of the lunar orbit has, from a similar cause, a direct motion on the ecliptic and accomplishes a whole revolution in 8yrs. 310d. 13h. 48m. 53s., so that in 4yrs. 155d. the perigee arrives where the apogee was before. This motion of the line of apsides, like the movement of the nodes, is not regular and equable throughout the whole of a lunar month, for when the Moon is in syzigies the line of apsides advances in the order of signs, but is retrograde in quadratures. But the preponderating effect in several revolutions tends to advance the apsides, and hence arises their direct revolution in between eight and nine years.

The apparent diameter of the Moon, at her mean distance from the Earth, is 31′ 19·8″, but the eccentricity of her orbit causes a variation of about 4′ 44″, the maximum being 33′ 32″, and the minimum 28′ 48″. According to Professor Mädler, the real diameter of the Moon is 2159·6 English miles; the recent measures of Dr. Wichmann make it 2162 miles, agreeing so nearly with the former value, that we may conclude we know the dimensions of the lunar orb very exactly. Taking the diameter at 2160 miles, which cannot be far from the truth, the circumference will be 6786 miles, and the bulk of the Moon will be to that of the Earth as 1 to 49¼. Dr. Wichmann could not detect a sensible difference between the equatorial and polar diameters.

Some of the best determinations of the mass of the Moon depend upon the amount of *lunar nutation*, which, as we have seen, is a periodical fluctuation in the position of the Earth's axis, arising from the variable direction of the line of nodes of the Moon's orbit. The Baron Lindenau, from his researches on nutation, concluded the mass to be 1-87·7 of that of the Earth; Professor Henderson has more recently given 1-78·9. There are various other methods of ascertaining the mass of our satellite, as, for instance, the observation of the change in the Sun's longitude due to her attraction on the Earth. Mr. Airy's method of observing the positions of Venus near her inferior conjunction, already mentioned, which is similar in principle to the last, and the investigations of her effect upon the tides.* Roughly speaking, we shall be near the truth if we assume the mass of the Moon to be 1-80th of that of the Earth.

The most casual observer of the Moon can hardly fail to have remarked, that she always presents very nearly the same face towards us, and a little reflection will convince him that the cause must lie in the near equality of her periods of axial rotation and sidereal revolution round the Earth. Were these periods exactly equal, we should have the same hemisphere turned towards us without the slightest variation; but the orbital period is subject to small irregularities, while the time of axial rotation remains constant, and for this reason a phenomenon termed the *libration* takes place, whereby we occasionally see a little more of one edge of the Moon than usual, either on the eastern or western sides of her equatorial regions. Galileo was the first astronomer who remarked this periodical variation in the visible surface of the Moon, and the circumstance reflects no little credit on his zeal and attention, for his instrumental means are well known to have been very small, notwithstanding the numerous discoveries we owe to him. Generally speaking,

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* By this method Laplace concluded the mass of the Moon to be 1-73d of that of the Earth.

the Moon revolves on her axis in the period of one mean sidereal revolution.

The axis of the Moon is not quite, though very nearly, perpendicular to the plane of her orbit, which allows of our seeing a little more of the polar regions at certain times than at others, a phenomenon called the *libration in latitude.* The angle between the lunar equator and the plane of her path round the Earth is, according to Nicollet, 1° 28′ 47″, or, according to the more recent and elaborate researches of Dr. Wichmann, 1° 32′ 9″.

By the *parallactic libration* we understand the difference in the position of a spot as viewed from the centre and surface of the Earth.

Professor Bessel and Dr. Wichmann have made some researches respecting the existence of a *physical libration*, or a real variation in the time of axial rotation of the Moon, such as would give rise to an apparent change in the position of the spots, periodical or otherwise; but there does not at present appear to be sufficient reason for suspecting any inequality of this nature.

The full Moon which falls nearest to the Autumnal Equinox has long received the name of the *Harvest Moon*, from the fact that the difference between the hours of her rising on two successive evenings is then at a minimum, and the long duration of moonlight, thus afforded soon after sun-set, is most advantageous to the farmer at this critical season. This near coincidence in the times of several successive risings takes place every lunar month, when the Moon is in the signs Pisces and Aries, but it has only been remarked when she is at full in these signs, and this can only happen in August or September. The least possible difference between two successive risings in this latitude is about seventeen minutes. When the Moon is in Libra, and at the same time near the descending node of her orbit upon the ecliptic, the difference between the times of rising on two evenings is the greatest possible, and in London will amount to about 1h. 16m.

The theory of the lunar motions is, perhaps, the most difficult with which the astronomer has to deal, and it has accordingly occupied the attention of the most eminent mathematicians, from the time of Sir Isaac Newton to the present day. To bring it to the exact and elaborate form in which it now is, has required the utmost efforts of the observer as well as the physical astronomer, for it is a curious fact, that some of the most important of the smaller inequalities, as they are termed, of the Moon's mean motion, have been first detected by actual observation, and subsequently reconciled with the theory of gravitation as expounded by Newton. The larger inequalities are of such magnitude, that they were discovered with the rude instruments employed by Hipparchus in the second century before the Christian era. It would lead us beyond the limits and plan of the present work, were we to enter into any explanatory account of the lunar perturbations generally, which, after all that can be said respecting them, are not easily intelligible without a knowledge of the mathematical processes by which they have been detected and reduced to calculation. We shall, therefore, content ourselves with a brief notice of the most important inequalities affecting the mean longitude of our satellite.

The most considerable is that termed the *Evection*, the discovery of which we owe to the famous astronomer Hipparchus, in the second century before the Christian era. It depends upon the angular distance of the Moon from the Sun, and the mean anomaly of the former, and goes through its variations in a period of about 31d. 19h. 30m. At its maximum it may influence the Moon's longitude one way or the other about 1° 20′. It diminishes the equation of the centre in syzigies, and increases it in quadratures.

Another large inequality is called the *Variation*, the discovery of which has usually been attributed to Tycho Brahe, though M. Sedillot and others have claimed the merit of its first recognition for the Arabian astronomer, Aboul Wefa, who lived in the ninth century. It depends solely on the angular distance of the Moon from the Sun, and its period is half a synodic revolution, or about 14d. 18h. The effect of this inequality is greatest in the octants, and disappears in syzigies and quadratures, the longitude of the Moon being altered thereby rather more than half a degree when the equation is at a maximum. The *Variation* was the first lunar inequality explained by Sir Isaac Newton upon the theory of gravitation.

The *parallactic inequality* arises from the sensible difference in the Sun's disturbing force, when the Moon is travelling over that semi-circumference of her orbit lying near the Sun, and when she is in the further semicircle. Small as is the change of distance at these times, the perturbation depending upon it is sufficiently large to produce an inequality, which at its maximum may alter the Moon's longitude about two minutes of arc. The period during which it passes through all its variations is one synodical revolution, or 29d. 12h. 44m.

The *Annual Equation* is an inequality caused by a variation in the angular motion of the Moon, which becomes slower as the Earth and Moon are approaching the Sun, and accelerates as they recede from him. The motion of our satellite is slower than the mean motion during the time the Earth is moving from perihelion to aphelion, and more rapid as she passes from aphelion to perihelion, or in the present position of the line of apsides, the Moon moves slower between the end of December and June, than between the end of June and the end of December. The period of this inequality is the anomalistic solar year, and its maximum effect upon the Moon's longitude amounts to 11′ 10″.

The *Secular Acceleration* of the Moon's mean motion is caused by a change in the eccentricity of the Earth's orbit, which has been slowly diminishing for many ages. It was discovered by Dr. Halley from a comparison of the periodic time of the Moon, deduced from recent observations, with that indicated by the Chaldean observations of eclipses at Babylon in the years 719 and 720 before the Christian era, and the Arabian observations in the eighth and ninth centuries, the result of which showed that the periodic time is now sensibly shorter than at the epoch of Chaldean eclipses. The cause of this diminution was not understood until the celebrated Laplace showed that it was similar in its origin to the much larger and more rapid fluctuation of period, which takes place according to the position of the Sun with respect to the line of apsides of the lunar orbit. The mean motion of the Moon is increased by this inequality, at the rate of rather more than *ten seconds* in one hundred years. As the diminution of eccentricity of the Earth's orbit is not a permanent change, though extending over a period whose duration is hardly yet calculable, so the acceleration of the Moon's mean motion is a cyclical inequality, and a time will arrive when it must altogether cease. After this remarkable equation had been detected by Dr. Halley, great doubts existed in some minds as to the possibility of explaining it on the theory of gravitation. The elucidation which the subject has received at the hands of Laplace is, therefore, the more remarkable, and affords one of many instances where suspicions of the failure of Newton's law have ultimately tended only to its more striking confirmation.

The *Tables* at present in general use for predicting the positions, eclipses, and other phenomena of our satellite, are those calculated by the French astronomer Burckhardt, and published at Paris in 1812. They are founded principally upon the observations taken at our National Observatory at Greenwich, an establishment which was instituted with an especial view to the improvement of the lunar theory, and thereby, of the art of navigation. Burckhardt's tables are used in the preparation of the Nautical Ephemerides annually issued by the governments of Great Britain, France, and Prussia. The late Baron Damoiseau was the author of two sets of lunar tables, which are based upon elements not very different from those employed by Burckhardt. The first set, according to the centesimal division of the circle, appeared in 1824, and the second, agreeably to the old or sexagesimal division, in 1828. Since the investigation of the elements of the existing tables, the lunar theory has been greatly improved by the laborious researches of M. Plana of Turin and Professor Hansen of Seeberg, and several inequalities of long period have been discovered, which almost entirely reconcile the differences between the observed and tabular places of the Moon. But the most important work undertaken for perfecting our knowledge of her movements, and one which is hardly equalled for magnitude and intricacy in the history of astronomy, is the reduction of all the observations of the Moon taken at the Royal Observatory, Greenwich, between the years 1750 and 1830, which has been brought to a completion within the last few years, under the superintendence of the Astronomer Royal. There are about 8000 observations in all, and, for the attainment of the object in view, it was necessary to reduce the whole again, with the best modern elements, to compute the tabular places in duplicate, the tables themselves having been modified and extended so as to accord as nearly as possible with M. Plana's theory, and finally to determine the pricipal elements of the Moon's motion, from the whole mass of observations. Few persons who have not had an opportunity of viewing the manuscripts themselves can form any adequate idea of the enormous labor attending this valuable work. Twelve computers on an average were engaged eight hours a-day for several years, the reductions having been commenced in earnest in August 1841, and the last sheets of the second large volume containing the results having passed through the press in the spring of 1848. Professor Hansen has undertaken a complete revision of the lunar theory, having at his command, where necessary, the Greenwich reductions of the 8000 observations, and the British Government has lately provided funds to aid this distinguished mathematician in his important inquiry.* The Astronomer Royal communicated to the Royal Astronomical Society several years since, the most prominent conclusions at which he had himself arrived after discussing the Greenwich observations.

The naked eye readily discerns that the disc of the full Moon is not uniformly bright: light and dark regions alternate upon it, giving the idea of continents and seas analogous to those on our own globe. In fact, the earlier selenographists considered the dull grayish spots to be water, and termed them the lunar seas, bays, and lakes. They are so called to the present day, though we have strong evidence to show that if water exist at all on the Moon, it must be in very small quantity. On applying the telescope, with suitable magnifying powers, we perceive on every part of the surface, even in the midst of the so-called oceans and seas, annular spots evidently of a volcanic character, with extensive chains of mountains and steep isolated rocks, forming altogether a very rugged and desolate appearance. The

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* As one of the early fruits of this investigation, we may mention the discovery of two inequalities in the motion of our satellite, resulting from the attraction of Venus, exercised directly in one instance and indirectly in the other. Great importance is attached to these discoveries, because, when their influence is taken into account, the positions of the Moon, calculated from theory, are almost precisely identical with those given by observations, which renders it certain that our knowledge of the movements of our nearest celestial neighbor is very nearly perfect.

craters are exceedingly numerous; in some places they are thickly crowded together, small volcanoes having formed on the sides of the larger ones,—in other regions they are comparatively isolated. Their dimensions are far greater than those of the largest volcanoes on the Earth, the breadth of the chasm occasionally exceeding one hundred miles, while the sides of the mountain attain a very considerable elevation. The best time for viewing a crater is when it is just clear of the dark part of the Moon, or when the Sun is just above its horizon: we can then trace the shadows thrown by the sides of the mountain upon its interior and exterior surface, and, by measuring the lengths of these shadows, we may approximate to its true altitude. Some of the steep isolated rocks throw their shadows for many miles across the plains surrounding them.

The positions of the lunar spots upon the surface are usually given in *selenographic longitudes and latitudes.* In the large work of Professor Mädler are found the results of a great number of observations for fixing the exact places of the principal mountains and craters, first in longitude and latitude, and afterwards in the form of co-ordinates, to facilitate the construction of the lunar chart. The first quadrant contains *west* longitude and *north* latitude; the second, *east* longitude and *north* latitude; the third, *east* longitude and *south* latitude; and the fourth, *west* longitude and *south* latitude.

To distinguish the various spots from each other, two nomenclatures have been adopted by Hevelius and Riccioli respectively. The former made use chiefly of the names of places upon the Earth, the latter introduced the names of celebrities of all ages in science and literature; and this method is the one adopted by Professor Mädler, the greatest selenographer of the present day, and, in fact, universally followed by astronomers. Amongst the English names thus appropriated are those of Newton, Flamsteed, Bradley, Maskelyne, Airy, Dollond, Cook, Herschel, Ramsden, Sabine, Wollaston, &c., and the names of nearly all the foreign astronomers and mathematicians of eminence in past and present times are found on Mädler's large chart of the Moon. This nomenclature is certainly open to more than one objection. "The neutral ground of mythology and classic antiquity," to use Sir John Herschel's expression, would perhaps have been the safest and most lasting foundation. It is true many mythological names occur already on the lunar maps; but it is perhaps to be regretted that they have not been more extensively employed, to the exclusion of modern names altogether. When another rigorous telescopic survey of the Moon's disc is undertaken, as it probably will be some years hence, we think it is unlikely that an alteration will be found necessary.

One of the most remarkable of the lunar spots is that called Tycho, which is readily distinguished in the southern part of the Full Moon by the number of luminous rays or streaks of light which diverge from it, particularly in a north-easterly direction. Tycho is the Mons Sinai of Hevelius, and lies in 12° east longitude and 43° south latitude: it is an annular mountain or crater of not less than fifty-four English miles diameter. The height of the western border above the interior level is, according to Mädler, 17,100 feet, and of the eastern border rather more than 16,000 feet. A mountain, very nearly one mile high, marks the centre of the crater. Tycho is surrounded on all sides by a great number of craters, peaks, and ridges of mountains, lying so close together that in some directions it is impossible to find the smallest level place. It is, as above remarked, the origin of a number of luminous streaks or rays, which extend therefrom over fully the fourth part of the Moon's disc; the brightest ones branch off in a north-easterly direction, and there are others very conspicuous on the western side of the crater. These rays become visible as soon as the Sun is elevated from 20° to 25° above their horizon. The color is, perhaps, a little whiter or more silvery than the general lunar surface. Many opinions respecting the nature of these appearances have been advanced by Cassini, Schröter, Herschel, and others, and they have been variously styled mountains, streams of lava, or even roads: there is nothing on the Earth's surface bearing the slightest analogy to them. Perhaps the idea first started by Mr. Nasmyth is the most probable, that they have been caused by a general volcanic upheaving of the crust of the Moon in former times, which has produced an appearance on the lunar surface similar to that of a pane of glass broken by a sharp-pointed instrument. The mere fact of their diverging from the great crater Tycho, proves that it was the focus of the volcanic outbreak, whenever it may have occurred. A sharp eye will easily detect the appearances we have described on the full Moon, without the assistance of a telescope.

Another very beautiful annular mountain, the converging point of similar luminous streaks, is that known as *Copernicus*, whose selenographic place is in longitude 20° E. and latitude 9° N. The diameter of the crater is somewhat larger than in the former case, or rather more than fifty-five miles. The highest point is about 11,250 feet above the surrounding plain. It is readily discernible on the full Moon, but is most favorably viewed when the Sun's rays have just reached its eastern side about the time of quadrature or first quarter, the shadows of the western side of the crater being then thrown on the interior level, that of the central peak on the same level towards the eastern side, while the shadow of this side of the mountain darkens for some distance the exterior plain on the rugged edge of the Moon. Generally speaking, these shadows are extremely well defined and very black.

The spot itself is most advantageously seen in these latitudes about the first quarters in the spring, when the Moon has a high northern declination, but the divergent streams of light will be best observed near the time of full Moon. They vary in breadth from three to ten miles; the principal ones branching off from the crater towards the north-east.

Kepler is a conspicuous annular mountain, the focus of similar rays of light, in longitude 38° E. and latitude 8° N. The crater itself is about twenty-two miles in diameter, and the altitude of its eastern edge above the level of the interior is found to be more than 10,000 feet. This mountain is situated on the Oceanus Procellarum, the largest of the lunar *seas.*

Tycho, Copernicus, and Kepler, are the principal mountains of the class termed by Professor Mädler "Strahlenbergen," or the craters which form the radiating point of the streaks or rays, which appear so remarkable on the surface of the full Moon.

Eratosthenes is a very beautiful annular mountain placed at the extremity of the long range called the Apennines, which cover a surface of more than 16,000 square miles. It is the Insula Vulcania of Hevelius, "the mighty key-stone of the Apennines," as it is aptly termed by Mädler. The crater is not less than thirty-seven miles in diameter; its centre is occupied by a steep rock 15,800 feet in altitude above the level surface of the interior. The outside of the circular mountain is about 3300 feet above the plain, on the western border, while on the eastern side the height is more than twice as great. Eratosthenes is a beautiful spot about the time of first quarter, when the long range of mountains running off from it in a semicircular form, and their shadows thrown upon the broad plain west of the crater, are most interesting objects in a telescope of adequate power. The selenographic place is in longitude 11° 4′ E. and latitude 14° 4′ N. It is, consequently, situated to the N. W. of Copernicus already described. The highest of the Apennine range is a mountain called *Huyghens*, which is somewhat more than 18,000 feet in altitude. *Bradley* is another lofty peak of the same range, and, according to Mädler, attains an elevation of 13,500 feet.

Manilius is a beautiful annular mountain on the north side of the Mare Vaporum, and is the best determined point on the lunar surface. M.M. Bouvard and Nicollet made an extensive series of observations on this spot, for determining the amount of libration and the position of the Moon's axis. The selenographic place was found to be in longitude 8° 47′ W. and latitude 14° 27′ N. The average altitude of the edge of the crater appears to be 7600 feet, and the breadth of the same a little over twenty-five miles.

Pico is a remarkably steep isolated rock in the Mare Imbrium, and appears particularly bright when viewed under favorable circumstances. The summit rises full 7000 feet above the surrounding plain. The position of this mountain is in longitude 9° 2′ E. and latitude 45° 5′ N.

The following Table exhibits the altitude in English feet of the principal lunar mountains, calculated from the observations of Professor Mädler:

		Selenographic position	
	Altitude in feet.	Longitude.	Latitude.
Newton	23,800	16° E.	77° S.
Curtius	22,200	3° W.	67° S.
Casatus	20,800	35° E.	74° S.
Posidonius	19,800	29° W.	31° N.
Short	18,700	10° E.	74° S.
Moretus	18,400	7° E.	70° S.
Calippus	18,300	10° W.	39° N.
Mutus	18,300	30° W.	63° S.
Huyghens	18,000	2° E.	20° N.
Clavius	18,000	15° E.	58° S.
Blancanus	18,000	21° E.	63° S.
Kircher	17,600	43° E.	67° S.
Hainzel	17,500	32° E.	41° S.

	Altitude in feet.	Selenographic position. Longitude.	 Latitude.
Catharina	17,400	23° W.	17° S.
Theophilus	17,300	26° W.	11° S.
Tycho (W. border)	17,100	12° E.	43° S.
Picard	17,000	54° W.	14° N.
Pythagoras	16,900	60° E.	63° N.
Werner	16,600	3° W.	28° S.
Macrobius	16,200	45° W.	21° N.

Out of the twenty lunar mountains whose altitudes exceed three English miles, or about 16,000 feet, fourteen are situated south of the Moon's equator. This hemisphere appears more generally mountainous than the northern one. The height of the rock to which the name of our illustrious Newton has been assigned, is not much less than the heights of some of the loftiest summits of the Andes, though the diameter of the Earth is to that of the Moon as 3·7 to 1, and consequently a mountain of proportionate altitude on our globe would stand 16½ miles above the surface.

We subjoin the breadths in English miles of some of the larger craters or annular mountains on the Moon's surface, as inferred from the observations of Professor Mädler. It will be remarked that the six broadest cavities are in the *third* quadrant, south of the lunar equator:

Name of Mountain.	Breadth of Crater or Cavity in English miles.	Selenographic. Longitude.	 Latitude.
Bailly,	149	65° E.	65° S.
Clavius,	143	15° E.	58° S.
Schikard,	127	55° E.	44° S.
Ptolemy,	115	3° E.	9° S.
Schiller,	113	38° E.	52° S.
Phocylides,	96	56° E.	52° S.

Of 148 craters, whose diameters were measured by the same astronomer—

2	were between	1	geographical mile and	2
7	"	2	geographical miles and	3
16	"	3	"	4
19	"	4	"	5
17	"	5	"	6
18	"	6	"	7
11	"	7	"	8
9	"	8	"	9
12	"	9	"	10

And 36 were above 10 geographical miles in diameter.

The lunar *seas*, as they are termed, are thirteen in number, the names selected by the latest selenographers being as follow:—

Mare Australe.
Mare Crisium.
Mare Fœcunditatis.
Mare Trigoris.
Mare Humboldteanum.
Mare Humorum.
Mare Imbrium.
Mare Nectaris.
Mare Nubium.
Oceanus Procellarum.
Mare Serenitatis.
Mare Tranquillitatis.
Mare Vaporum.

The *Mare Crisium* is 280 miles in diameter from N. to S., and rather more than 350 from E. to W. There is a decided greenish tinge about it, which is very peculiar. The *Mare Imbrium* is the largest of the dark circular spots on the Moon's surface—the measures of Professor Mädler giving for the breadth, in a meridional direction, 680 miles, and from east to west, 750 miles. It is therefore five times larger than the Mare Crisium. The *Mare Nubium* has a light gray tinge, and is not so dusky in appearance as some other spots near it. The *Oceanus Procellarum* is by far the largest of the lunar seas, and covers a surface of 90,000 square geographical miles. Its prevailing color is gray, but is not so dark as in the Mare Crisium, though more so than the greenish plains of the Mare Humorum, &c. The Mare Serenitatis is an elliptical spot, having the longer axis from S.W. to N.E.; its average diameter is about 430 miles, the tinge greenish as in some other cases. The *Mare Tranquillitatis* is of a clear gray color.

All these so-called seas are covered with annular mountains, craters, and rocks. They are best seen under very small optical aid.

Besides the thirteen great seas and oceans, we have the *Sinus Iridum*, or Bay of Rainbows, a most beautiful spot on the northern border of the Mare Imbrium, which will be most advantageously observed when the Moon is between nine and ten days old. At this time, the summits of the semi-circular range of rocks inclosing the bay are strongly illuminated, while a strong greenish shadow marks the valley at its base. There is also the *Sinus Medii* in the centre of the Moon's disc, the *Sinus Æstium*, with several other bays and lakes of lesser note.

Near the *North* Pole of the Moon is a mountain rather more than 9000 feet high, the summit of which must have continual sunshine, while the plain at its base will have an alternation between day and twilight. The nearest mountain to the *South* Pole is called Malapert, in latitude 87½°. When the Moon is near the first quarter, the neighborhood appears a fine line of points of light. The southern polar district is much more mountainous and rugged than the opposite one.

If a lunar atmosphere exists, it must be one of excessive rarity and of no great extent, otherwise it would give rise to phenomena which could not fail to attract the attention of the observer. Astronomers have long held a divided opinion on this subject, and it is still a *quæstio vexata.* The latest selenographer, Professor Mädler, is of opinion that there may be a thin atmospheric envelope of variable extent.

Some authorities adduce an argument in favor of the presence of a lunar atmosphere, from a curious appearance occasionally noticed when the Moon passes before a star—a phenomenon technically known as an *occultation.* It most frequently happens that the star disappears instantaneously on coming in contact with the Moon's limb, and re-appears as suddenly and completely when emerging from behind her disc. But this is not invariably the case. It has been remarked that instead of vanishing entirely at the moment of contact, the star is sometimes seen *projected on the Moon's disc* for several seconds of time, and a similar appearance takes place (though, we believe, more rarely) before the final emersion from the other limb. About twenty years since, a good deal of interest was excited among astronomers generally in reference to this matter, and some occultations of the bright star in Taurus (Aldebaran) were closely watched at the principal European observatories, with the view of bringing the question to some satisfactory solution; but the result of these and other more recent observations have proved very far from conclusive. To illustrate this by a single example. At the Royal Observatory, Greenwich, some of the observers perceived nothing unusual either at the immersions or emersions of Aldebaran: the star disappeared and re-appeared instantaneously. Others, on the contrary, saw it distinctly projected upon the Moon's disc for a second or two before it was finally hidden behind her; and these persons were observing with similar instruments, and from the same station as the former. Professor Powell has suggested that the phenomena may be accounted for theoretically on the laws of irradiation; but there still remains the difficulty of explaining why some astronomers should see the stars projected, while others see nothing of the kind. Supposing that a lunar atmosphere exists, the projections might be ascribed to the refraction of the rays of light from the star in passing through it; and we might even go farther, and explain how it happens that they are not always noticed, if we admit, with Professor Mädler, that the atmosphere is of variable extent, and may occasionally contract within very small limits. Yet there will still be the same difficulty of clearing up the anomaly, that out of a number of practised observers, at the same place and time, some should regard the immersions and emersions as instantaneous, and others be convinced of a projection of the star upon the Moon's disc, or of its " hanging" for a few seconds upon her limb. These facts appear to point to the instruments employed, and to the observers themselves, for a satisfactory explanation of the whole.

Several instances are on record where a star, instead of disappearing finally when first in contact with the Moon's limb, has run along it and re-appeared several times, evidently between the mountains upon the edge of her disc. On the 7th of March, 1794, Professor Koch saw Aldebaran disappear and reappear three times, about thirty seconds or so intervening between the immersions and emersions. Another observation of a similar kind was made by Mr. Rümker at Hamburg, on the 19th of February, 1820. A star of the seventh magnitude appeared to run with extreme rapidity along the summits of the mountains on the Moon's edge, by which it was eclipsed from time to time. This "magnificent spectacle" continued nearly ten minutes, after which the star entirely vanished.

Occultations by the Moon of the planets Jupiter and Saturn are phenomena of great interest, though not of frequent occurrence.

The existence of active volcanoes upon the Moon is a subject which has been a good deal discussed, particularly within the last seventy years. Hevelius, when he was engaged upon his *Selenographia*, remarked that the spot called by him *Mons Porphyrites*, but now known as *Aristarchus*, appeared reddish, and seemed to burn, or rather to emit flames, whence he conjectured that its nature was similar to that of Vesuvius or Ætna, or the other volcanoes upon the Earth's surface. In 1787

Sir William Herschel announced that he had observed three volcanoes in actual operation in different parts of the Moon. The principal one was situated about 4′ from the northern limb. It was closely watched on the 19th and 20th of April. The diameter of the burning part was three seconds of arc, or about three miles. All the adjacent parts appeared to be illuminated by the eruption. The other volcanoes were much nearer the centre of the Moon. They exhibited no well-defined luminous spots, but resembled "large, pretty faint nebulæ, that are gradually much brighter in the middle." After the publication of these observations, the attention of astronomers generally was directed to the subject. Luminous appearances have been repeatedly noticed in the dark part of the Moon, when not more than three days from conjunction, during the partial obscuration of her surface in a lunar eclipse, and when her dark body has been seen projected on the Sun, during an eclipse of that luminary. The bright spot thus observed is almost invariably upon the *Mons Porphyrites* of Hevelius, or the *Aristarchus* of Riccioli, and by far the greater number of observations have been made soon after or before new Moon, when this part of the disc is far distant from the boundary of the illuminated surface, but at the same time in a position to receive a great deal of *earth-light.* Shortly before the lunar eclipse of August 2, 1822, Flauguergues remarked that Aristarchus seemed, as usual, more brilliant than the general surface of the Moon, its color being a very decided yellow. As the penumbra approached, it appeared grayish, and more so when the spot was fully covered by the dark shadow; but still it was clearly discernible, though the spots known as *Kepler* and *Copernicus* vanished as soon as they were immersed in the shadow. During more than two hours, while the Moon was undergoing eclipse, the appearance of Aristarchus was the same; the light was so distinct and striking that an observer might readily suppose he saw a lunar volcano. Flauguergues, however, adopts the opinion of Mechain, Olbers, and other astronomers, who consider this phenomenon due to the illumination of the flat summit of Aristarchus by the "lumière cendrée,"* as it is termed; it is probable that this particular spot is of a nature to reflect the light more readily than others, which would account for its being so repeatedly observed as a brilliant point. The flickering flame-like motion which is occasionally remarked can be due only to certain conditions of the Earth's atmosphere. When the sky is perfectly clear, and the air still, the summit of the mountain is seen steadily illuminated; but under less favorable circumstances, the light has all the wavering motion which a volcanic eruption might be supposed to induce.

During the total eclipse of the Sun, on the 24th of June, 1778, Don Antonio de Ulloa saw upon the disc of the Moon a luminous point, which was, strangely enough, conjectured to be a trough or canal cut through the body of the Moon, through which the Sun's light was visible. This is an explanation very unlikely to meet with the concurrence of astronomers. It is far more probable, as Flauguergues conjectures, that the phenomenon was owing to the phosphorescence of Aristarchus, particularly as a diagram of the position of the brilliant point upon the Moon's dark body agrees tolerably well with that of the spot.

After what has been here stated, the reader will see that there is no absolute necessity to admit the existence of active volcanoes upon the Moon in order to account for the appearances which have been observed upon her disc from the time of Hevelius to the present day. It is only necessary to suppose that, from the peculiarly reflective nature of the spot

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* By the "Lumière Cendrée" is understood the light derived first by the Earth from the Sun, afterwards reflected from the Earth to the Moon, and finally from the Moon to the Earth.

Aristarchus, that part appears brighter than the rest of the lunar surface when the Earth is shining strongly on those regions, while, if we admit a kind of phosphorescence in the spot, which causes it to emit during darkness the light it had previously imbibed during sunshine, we may explain without much difficulty the brilliant points recorded as having been observed when the Moon is immersed in the Earth's shadow, or is seen projected upon the Sun. The prevailing opinion amongst astronomers at the present time is consequently adverse to the existence of active lunar volcanoes.

Hevelius was the first astronomer who paid much attention to the delineation of the telescopic appearance of the Moon. His *Selenographia*, published in 1647, is a detailed description of our satellite, and contains, besides a general chart, about forty special charts for different phases, all drawn and engraved by himself. The optical power, however, employed in their formation was so small, that they have long since been superseded by others bearing greater pretensions to accuracy. Father Riccioli of Bologna published a lunar map in 1651, the various spots being distinguished by proper names, instead of the geographical ones, &c., assigned by Hevelius, and this nomenclature has been closely followed, as already remarked, by succeeding astronomers. The celebrated Dominic Cassini formed a chart of the Moon's surface in 1680, and about the year 1749, Tobias Mayer of Göttingen published one, which, though smaller than Cassini's, is more accurate, and, in fact, the best that was in the possession of observers up to the year 1824. The indefatigable Schröter of Lilienthal was the author of a large work, printed in 1791, and entitled "*Selenotopographic Fragments*," in which are given special charts of many of the principal spots upon the Moon. This work is now become somewhat rare. Schröter evinced great perseverance in his examination of our satellite; but it appears he was not always fortunate in his description of particular tracts upon the surface. In 1824, the first part of what was intended to be an elaborate work upon this subject was published by W. G. Lohrmann of Dresden. The charts are stated by Mädler to be very exact, and it is most unfortunate that their appearance was interrupted, so that instead of twenty-five maps, as intended, we are only in possession of four.

In 1837, the very elaborate and excellent chart of the Moon by M.M. Beer and Mädler was placed in the hands of astronomers, and, from its extent and minuteness of detail, eclipsed all others. The chart accompanies the fine work of M.M. Beer and Mädler upon the Moon, in which they have given us the results of a most laborious examination of the various spots. The large map is three feet in diameter; but a smaller one, of about one foot diameter, was also published, and is quite sufficient for recognizing the principal mountains, &c., exhibited by ordinary telescopes. The larger chart loses much of its utility without the accompanying description. This great work of M.M. Beer and Mädler will doubtless be regarded as the standard work upon the Moon for many years to come; and when another examination of the surface of equal extent and precision has been made half a century hence, it will be most interesting to compare the results with those of the German astronomers, as such comparisons may lead to conclusions as unexpected as they would prove important in the physical history of our satellite.

In addition to general and special *charts* of the Moon, *models* of various craters and chains of mountains have been executed with the help of powerful telescopes and micrometers; and a Hanoverian lady, Frau Hofräthinn Witte, has extended this modelling on a small scale to the whole visible surface of the Moon. Sir John Herschel gave a description of this beautiful model of Madame Witte's at the meeting of the Royal Astronomical Society in November 1845: only two copies are in existence,—one was exhibited on this occasion; the other is deposited in the Royal Museum at Berlin. The positions and general outlines of the lunar craters and mountains were first laid down from Mädler's great work upon a twelve-inch globe composed of mastic and wax, and the details were afterwards filled in by Madame Witte from her own observations with a Fraunhofer telescope, placed upon the roof of her dwelling-house. In order to exhibit the relative heights of the various mountains upon this small globe, they are laid down twice as high as they should be in proportion to the diameter. It is to be regretted that all attempts to multiply copies of this elaborate and beautiful work have hitherto failed.

A model in plaster of Paris of the region about the crater Maurolycus has been constructed by Mr. Nasmyth of Manchester, and is in the possession of the Astronomical Society of London, as also a smaller model of the fine crater Eratosthenes and its vicinity.

The appearance of the heavenly bodies to the inhabitants of the Moon, if any, are widely different from those we witness ourselves. The Earth appears to them a great globe more than 2° in diameter, and, so to speak, is a fixed object in their heavens, only altering her place by the amount of the libration, or oscillating to and fro in a space of 15° 8′ of longitude, and 13° 6′ of latitude. The stars and planets, therefore, pass behind her, and occultations of these objects by the Earth must be interesting phenomena to the lunarians. Our globe, moreover, reflects a vast amount of light for their benefit, and exhibits to them all the varied phases which are presented to us in the course of a lunar month, but in inverse order. Thus, when the Moon is at the *first* quarter, the Earth will be in her *last* quarter, when our satellite is *full* to us, we are *new* to them, or they have the Earth in conjunction with the Sun. These remarks apply only to those parts of the lunar surface which are turned towards our globe, for the inhabitants of the opposite side never see the Earth at all, and those who are located on the apparent borders of the lunar disc only now and then obtain a glimpse of it in their horizon, for which they are indebted to the librations in longitude and latitude which we have already noticed.

At the lunar equator the solar day is of a constant length, and about equal to 354h. 22m., or 14d. 18h. 22m. of our mean solar time. At a latitude of 45°, the longest day is 357h. 19m., and the shortest 351h. 26m. The difference, of course, increases as we approach the poles, and in 88° of latitude the longest day is 449h. 28m., or 18d. 17h. 28m., and the shortest 259h. 16m., or 10d. 19h. 16m. of our time. The mean length of a day at the Moon is equal to half a *synodic* revolution round the Earth. On the summit of the mountain known as Huyghens, which, according to the measurement of Professor Mädler, has an altitude of 18,000 feet, the mean length of a day exceeds by 18h. the average length on the surface at that latitude, whereas the loftier summit of Chimborazo, on our own globe, only experiences an increase of 20m. on the mean length of a day on the plains. In those parts of the Moon which remain always invisible to us, night must be totally dark,—no earthshine can reach them, and the brightest objects in their heavens will be the planets Mars and Jupiter, which can afford no more light to the lunarians than they do to us.

Pytheas, of Marseilles, who lived about 330 B.C., is said to have been the first to point out the influence of the Moon upon the ebb and flow of the waters of the ocean, yet his theory seems to have obtained little credence at the time, and the astronomer gained nothing by its divulgement. Kepler claims priority in the production of a treatise upon this subject, in which he showed that the action of both Sun and Moon is to be considered in accounting for the phenomenon, but it was not till Newton's *Principia* appeared that the *modus operandi* was explained. Owing to the much greater proximity of the Moon, her influence preponderates over that of the Sun, though the latter has still sufficient power to bring about a considerable variation in the heights of the tides according to his position with regard to the Moon. As our satellite, in the course of a *lunar* day (about 24h. 50m.), passes successively over the meridian of every place upon the Earth's surface, the waters of the ocean are drawn after her by the attractive influence exercised upon them, the greatest wave arriving on any particular meridian a short time after the Moon has passed over it, since her action is not instantaneous. So also the Sun, in the course of a *solar* day, produces a much smaller wave, which will coincide or otherwise with the lunar one, according to his position in respect to the Moon.

Now if we bear in mind that the Moon not only attracts the waters upon the surface of our globe, but has a similar influence upon the Earth itself, it will not be very difficult to account for what at first sight may appear a very singular phenomenon—that the tidal wave is produced simultaneously upon those parts of the Earth which are furthest from the Moon, or have her at a maximum depression below their horizon, as well as upon those parts which have her nearest to them, or on their visible meridian; in other words, soon after our satellite has culminated at any place, whether on the upper or lower meridian, the waters in the neighborhood are most elevated above their ordinary level. It is then from the circumstance of the Moon having a more powerful influence upon the Earth itself than upon those seas which are furthest from her that the waters are left behind, so to speak, to the amount of the difference in the attraction of the Moon upon them, and upon the intervening land.

The interval elapsing between two maxima of the tidal wave at any place, is rather more than twelve hours, or about half the lunar day of 24h. 40m. Hence, in the course of a day, we have *high* water and *low* water twice. There are several circumstances tending to vary the amount of elevation of the waters, as the change in the distances of the Sun and Moon from the Earth, and in their declinations at different times. The tides which occur at the syzigies are usually called the *spring* tides, and those at the quarters the *neap* tides. The highest tide takes place generally when the Moon is in perigee and on the equator. Local winds, and other causes of a similar kind, tend greatly to throw uncertainty upon any deductions relating to the height of the tides; but their general theory is now well understood,—the Astronomer Royal, Dr. Whewell, Sir John Lubbock, and others of our own countrymen having devoted much time and labor to the subject.

CHAPTER VI.

ECLIPSES OF THE SUN AND MOON.

THE eclipses of the Sun and Moon, particularly of the former, are amongst the most imposing phenomena of the heavens, and have been observed and studied from the remotest ages of antiquity.

The term *eclipse* is applied in the case of an obscuration of either of these luminaries. When the Moon, in the course of her monthly revolution round our globe, comes precisely into a line with the Earth and Sun at opposition, she must be immersed in the shadow of the former, and, as her light is reflected from the Sun, an eclipse or darkening of her disc must take place. This eclipse may be *total* or *partial* only, according as the Moon passes centrally or otherwise through the Earth's shadow; in other words, according to her distance from the node at the time of syzigy. If this distance exceed a certain number of degrees no eclipse can take place; within another known limit a partial obscuration may occur; and, if the argument of latitude is still less, the Moon must be entirely immersed in the shadow about the nodal passage, and a total eclipse will be the result.

Again, if the Sun, Moon, and Earth are in the same line at conjunction (*i.e.*, with the Moon between the Sun and Earth), or nearly so, the dark body of the Moon will intervene between the Earth and Sun, and cause a total or partial obscuration of the latter, or, as occasionally happens, if the Moon passes exactly between these two bodies at syzigy, but so far from the Earth as to have a less apparent diameter than the Sun, a phenomenon termed an *annular* eclipse will take place, a small portion of the bright surface of the Sun appearing like an annulus or ring round the dark body of the Moon.

It is evident, therefore, that the phenomenon called an eclipse of the Moon, is produced by causes entirely different from those which operate in an eclipse of the Sun. A solar eclipse would be more properly termed an *occultation* of the Sun by the Moon.

If the plane of the Moon's orbit exactly coincided with the ecliptic, there would inevitably happen an eclipse of the Sun and one of the Moon in every lunation, but as its inclination thereto exceeds 5°, the Moon's latitude at the time of conjunction or opposition will frequently be so great as to cause her to pass above or below the limits within which eclipses may happen, and, consequently, none will take place. The occurrence of these phenomena depends, therefore, upon the distance of the Moon from her node, or her latitude in conjunction and opposition.

According to the latest tables of the Sun and Moon formed by Carlini, Damoiseau, and Burckhardt, in order that an eclipse of the Sun may take place, the greatest possible distance of the Sun or Moon from the *true place* of the ascending or descending node of the Moon's orbit is 18° 36′; and an eclipse is impossible if the Moon's latitude exceed 1° 34′ 52″, while, if it be less than 1° 23′ 15″, an eclipse must necessarily take place; between these limits the occurrence of one at any station is doubtful, but depends upon the parallaxes and apparent semidiameters of the two bodies at the moment of conjunction.

Employing the same tables, it is found that an eclipse of the Moon may occur if her distance from the true place of the node at the time of opposition does not exceed 12° 24′: the greatest possible latitude is 63′ 45″; if it be less than 51′ 57″ an eclipse is certain; between these limits it is doubtful, but depends, as in the former case, upon the actual value of the semi-diameters and horizontal parallaxes.

The greatest number of eclipses that can happen in any one year is seven, and, of these, five may be solar and two lunar, or three solar and four lunar. The average number is four, and the least two: in the last case both will be solar. The variation in the number of eclipses is easily explained. During the time the Earth occupies in passing through the solar ecliptic limits, a new Moon must necessarily take place, and therefore a large solar eclipse; but, at the full Moon immediately preceding, it may happen that the Earth had not got within the lunar ecliptic limits (which are less than those of the Sun nearly in the proportion of two to three), while, at the next full Moon, our globe may have passed beyond them, which accounts for the non-occurrence of any lunar eclipse that year. Again, with regard to the *greatest* number of eclipses, we observe that twelve lunations occupy about 354d. 36m., which is nearly *eleven* days less than the mean length of the solar year. Consequently, if an eclipse—say one of the Sun—should happen before the 11th of January in any particular year, and there should occur at that and the following node two solar and one lunar eclipse at each, then, at the twelfth lunation, which will take place before the end of a solar year, the Earth, in consequence of the retrograde movement of the Moon's line of nodes, may have got within the solar ecliptic limits, and a fifth solar eclipse may occur within the year. If we had supposed the first eclipse to be *lunar*, then we should have three of the Sun and four of the Moon, or seven in all, as above remarked.

We have seen that the eclipses of the Sun and Moon depend upon the position of the latter luminary, in respect to her node at the time of new and full Moon, and it is therefore evident that if any cause should operate to bring about a similarity in their conditions after the lapse of certain intervals, the eclipses will become cyclical phenomena. It so happens that such a cause does operate, arising from the near commensurability of 223 mean synodical revolutions of the Moon on which the phases depend, and 19 synodical revolutions of her nodes, the former extending to 6585·32 days, and the latter to 6585·78 days. The agreement, it will be observed, is not exact, otherwise a recurrence of all eclipses under the same condition must take place in every period of rather more than eighteen years, but the difference, amounting to less than half a day, is so small that it is found that eclipses do occur in something like regular order after the completion of nineteen synodic revolutions of the Moon's nodes. A knowledge of this fact, as far as regards the length of the interval, may perhaps have enabled the ancient astronomers to foretell the occurrence of a great eclipse, since it is quite certain they did so in more than one instance before the true nature of eclipses was understood, and the eighteen year cycle is said to have been known to the Chaldeans under the name of *saros*.

ECLIPSES OF THE SUN.

A solar eclipse may be *partial*,—that is, a portion only of the dark body of the Moon may intervene between the Sun and the observer on the surface of the Earth; it may be *total*, if the apparent diameter of the Moon exceed that of the Sun, and the former body passes nearly centrally before that of the latter; or it may be *annular*, when the Sun's apparent diameter is greater than that of the Moon, traversing his globe as before. If the centres of Sun and Moon exactly coincide in the latter case, the eclipse is said to be *central* and *annular*, the Sun appearing for a moment only as a brilliant ring or annulus on the dark ground of the heavens, of *uniform breadth* in every part. Total eclipses are perhaps the most grand and imposing, and central and annular eclipses amongst the most beautiful of celestial phenomena. The former have been viewed in all ages with awe and astonishment; the gradual diminution in the light of the great ruler of the day, its sudden total extinction, the almost supernatural appearance of the heavens and surrounding objects during total darkness, the visibility of the stars in daytime, and other phenomena accompanying a large eclipse, are all calculated to inspire the mind with feelings of reverence for the Great Being whose power they proclaim, while they must at the same time impress upon it a feeling of admiration for that sublime science by the laws of which man is able to foretell the occurrence of eclipses, not to the day or the hour only, but to the very minute,—not merely a few years beforehand, but for centuries in advance.

Total eclipses of the Sun in any particular locality are phenomena of very rare occurrence. Thus, in London, none had been observed between the 20th of March, 1140, and the 22d of April, 1715, though in the interval the shadow of the Moon had repeatedly passed over other parts of Great Britain.* The next total eclipse visible in England will take place on the morning of the 19th of August, 1887, and large eclipses will happen on March 15th, 1858, March 6th, 1867, December 22d, 1870, and May 28th, 1900.

In order to give the reader some idea of the appearances he may expect to witness in a total, or very large eclipse of the Sun, we shall here particularize some of the most remarkable phenomena to which astronomers have drawn attention, while at the same time we describe the more usual characteristics of a solar eclipse. And, in the first place, it may be observed, that the determination of the precise time when the limbs of the Sun and Moon appear to touch each other, or, as it is techni-

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* According to Dr. Halley.

cally called, the moment of first contact, is one of great importance, inasmuch as the longitudes of places may be thereby ascertained, from comparative observations, with a high degree of accuracy. Careful and practised observers will seldom differ more than two or three seconds, especially if the instrumental means employed at different stations are pretty nearly the same as regards optical capacity. The angle from the apparent north point of the Sun's limb, where the contact with the Moon's dark body takes place, is always calculated beforehand from the solar and lunar tables, and the astronomer will have his eye directed to the precise spot some minutes previous to the computed time of the commencement of the eclipse. It has happened once or twice during these preparatory moments that an appearance resembling a faintly illuminated limb of the Moon has been perceived near the border of the Sun, which would tend to establish the visibility of a portion of the lunar disc as a bright object, before the actual contact of limbs: this has been noticed in England and America during the present century. The occurrence of first contact is sometimes indicated by the appearance of one or more prominent points upon the Sun's limb, possibly attributable to the mountains on the apparent edge of the Moon. As the eclipse progresses, flashes of light are occasionally remarked upon the lunar disc, and in one instance a solar spot, situated near the Moon's edge, seemed to be suddenly illuminated. Luminous appearances of a more permanent character have been witnessed upon her surface, either in form of a bright spot or a narrow stream of light. The visible edge of the Moon's disc has frequently been observed to project beyond the solar cusps, in the first instance by Hevelius, and many times during the last and present centuries. As the total obscuration approaches, the remaining portion of the Sun's illuminated disc gradually changes color, becoming either reddish or of a fainter color than before. One observer of the total eclipse of July 7, 1842, states that the thin crescent of light was suddenly changed to a line of luminous points, which appeared to wave from the extremities to the centre of the crescent, like "*a device in gas* swept over by a strong breeze," and similar appearances have been more or less perfectly observed by others. The diminution of light, though gradual, is not usually very great until a few minutes previous to the total obscuration of the Sun, when the color and general appearance of terrestrial objects change rapidly, and an unnatural gloom prevails. As the last trace of the Sun vanishes, darkness *instantaneously* supervenes, and this sudden transition is described by all who have been fortunate enough to witness it as a most imposing, nay, awe-inspiring phenomenon.

The Moon's surface is sometimes partially illuminated by a faint doubtful kind of light during the totality, and on one occasion the spots were distinctly observed by Vassenius at Gottenberg. M. Arago and Mr. Airy also bear witness to the uniform illumination of the disc, but could see no inequalities of light, either of the nature of a dark tract or bright spot: hence it would appear that this *lumière cendrée*, as it is termed, which is reflected from the Sun to the Earth, afterwards from the Earth to the Moon, and finally from the Moon to the Earth, is of variable intensity, and sometimes is entirely overpowered by what M. Arago calls the *lumière atmosphérique*. The most beautiful appearance peculiar to a total eclipse is that of the *corona*, or ring of light of variable extent, surrounding the dark body of the Moon, and very closely resembling the "glory" with which painters encircle the heads of saints. It was first generally remarked during the eclipse of 1715, and was particularly described by Halley, Louville, &c.; but a similar luminous ring is referred to by observers at a much earlier period. It must be borne in mind that we are at present treating only of *total* eclipses, and this *corona* has therefore no connection with the *annulus*, which is formed in a central and annular eclipse, to be noticed further hereafter. In July 1842, the attention of astronomers was especially directed to the appearance of the *corona*. Mr. Airy, who made a journey to Turin for the purpose of witnessing the great eclipse, describes it as a ring of peach-colored light, and possibly with somewhat of a radial appearance, though not sufficiently marked to interfere with the general annular structure. Mr. Baily, on the contrary, says the *corona* had the appearance of brilliant rays, and that he was unable to trace the well-defined shape of a ring at the outer border. The rays were vivid and *flickering*. At Montpellier, many persons suspected a rotatory motion of the *corona*, and M.M. Otto Struve and Schidlofsky, who observed the eclipse at Lipesk in Russia, tell us it was always in a state of violent agitation. Neither Mr. Airy nor Mr. Baily remarked any material deviation from a uniform breadth in the ring; but at various stations in France, and likewise by one observer at Milan, long jets of light, called *aigrettes* by M. Arago, were particularly noticed. Persons differed much in their estimations of the breadth of the *corona:* some considered it hardly more than one eighth of the Moon's diameter, or about four minutes of arc, while others traced the streams of light three or four degrees from the limb of the Moon. These discordances must be in some measure due to atmospherical conditions, whatever be the true cause of the appearance of a *corona*. The color of the light was equally the subject of doubt. Mr. Airy, as we have seen, thought it was peach-colored: Mr. Baily says it was perfectly white—and other observers at Narbonne, Lipesk, &c., were of the same opinion. M.M. Laugier and Mauvais, at Perpignan, judged the aureola to be yellowish, as viewed with the telescope, but colorless to the naked eye; and Professor Majocchi, at Milan, says it appeared to him white, "with a tendency to yellow." The intensity of the light at

Lipesk is stated to have been such that the eye was scarcely able to support it; yet at Milan, Vienna, Perpignan, and various other places in France, Italy, and Germany, it was precisely similar to that of the Moon. M. Arago suggests that the much greater altitude of the Sun at the total phase above the horizon of Lipesk than at Perpignan, and other stations in the south of Europe, may possibly serve to explain, partially at least, this wide difference. The Sun was nearly 30° higher at Lipesk than at Perpignan. The precise time of the first formation and final disappearance of the *corona* is also variously given by astronomers who witnessed this eclipse. Generally, however, it is stated to have been visible some few seconds *before* the extinction of the Sun's light, and after its re-appearance. At Montpellier the white aureola was perceived five or six seconds before totality came on, and about the same time at Salon, Marseilles, Pavia, &c. At Alais, where the eclipse was not quite, though nearly, total, the *corona* was distinctly seen.

We have yet to mention another most remarkable and beautiful phenomenon, which was witnessed by several eminent astronomers during the total eclipse of 1842. It consisted of rose-colored flames or prominences at various parts of the Moon's limb, while the Sun was entirely covered. At Vienna, Professor Schumacher remarked three of these protuberances which continued steadily visible, without the flickering peculiar to the corona. They were of a rose-red color, and between one and two minutes in altitude.

Mr. Airy, from the Superga, near Turin, saw three of these small flames, of a full lake-red, and brighter than the rest of the ring or corona: the distance between the first and third was about 40° on the Moon's limb. They were visible without the telescope shortly before the re-appearance of the Sun. Mr. Baily, at Pavia, also saw three protuberances "apparently emanating from the circumference of the Moon, but evidently forming a portion of the corona." Their color was judged to be red, with a tinge of lilac or purple. M. Arago, at Perpignan, saw two only on the northern limb, rose-colored on the whole, but greenish blue in some points. M. Mauvais, at the same place, witnessed the gradual increase of a small reddish spot to conspicuous "mountains," perfectly well defined, but not of a uniform color. They might be compared to the snowy tops of the Alpine mountains illuminated by the setting Sun. There were three distinct prominences, the last of which became perceptible about 1m. 10s. after the Sun had disappeared. Similar phenomena were recorded by observers at Toulon, Marseilles, Montpellier, Narbonne, and other places in France. At Lipesk, in Russia, M. Schidlofsky saw the rose-colored mountains, and also remarked that a considerable portion of the Moon's limb was strongly tinged with red. At Padua many persons saw the "flames" with the naked eye. Professor Santini noticed *two* "pyramids of fire," which he thought of a strong violet hue. M. Conti saw them long after the Sun had reappeared. M. Biela, observing at the same place, counted *three*, and agreed with the distinguished astronomer Santini as to their purple color. On the first glimpse of the Sun, these points seemed to run into one narrow border, and vanished altogether after a few seconds.

Similar phenomena to those we have described, before the time of totality comes on, are also remarked as the eclipse diminishes.

We have confined this brief account of the principal phenomena of a solar eclipse, in a great measure, to that which took place in July, 1842, because it is the latest of which particulars are fully published, and was observed by many of the most experienced astronomers of the day. It is, however, to be remarked, that very few novel appearances were noticed, the relations of previous eclipses containing references to most of the phenomena recorded in that year. Thus, the corona surrounding the Sun and Moon during totality is mentioned by several eye-witnesses of the eclipses of 1706, 1715, 1778, 1806, &c.: its color in 1706 was golden, in 1715 it appeared of a pearl-white, tinged with the hues of the rainbow, according to Dr. Halley, and on other occasions, it has been described as reddish, pale yellow, and peach-colored. A flickering or unsteadiness of the corona, giving the idea of a whirling motion, was remarked as early as the year 1628, and also in the eclipses of 1706, 1778, and 1816. The rose-colored flames or prominences, projected on the light of the corona, were seen during the total eclipse of May 3d, 1733, by Vassenius, at Gothenburg, who has left us a very clear account of them. They were three or four in number, of a reddish tinge; the most conspicuous one occupying a position on the Moon's limb about midway between the north and west points, or, as we should now say, at an angle of position of about 315°. Two other observers of the same eclipse witnessed a similar appearance, though less completely. Possibly the words used by Julius Firmicus, in reference to the total eclipse of A.D. 334, July 17, at Constantinople, may apply to the so-called "red flames" of modern astronomers.

During the total obscuration of the Sun, stars of the first and second magnitude, and the brighter planets, become conspicuous in the heavens, and on some occasions stars of a fainter class have been detected when the atmospheric circumstances happened to be unusually favorable. During the total eclipse of 1842, the planets Mars and Venus were distinctly visible at many stations in Italy and Germany, and Mercury was perceptible, according to one observer, in Russia. The bright stars, Capella, Aldebaran, Betelgeux, Castor, and Pollux, were amongst those noticed in different places. In some localities, as many as ten were counted. The color of the sky, and of objects surrounding the observer, is frequently recorded to have changed in a remarkable manner, as the time of total extinction of the Sun's light approached. So early as A.D. 840, this circumstance is mentioned. Dr. Halley, in describing the great eclipse of 1715, says, as the totality came on, the color of the sky changed from its usual azure blue to a livid purplish hue, and the darkness of the eclipse was attended by a chill and damp of which every one was sensible. During the eclipse of July 1842, much attention was paid to the natural phenomena accompanying it, but observers vary a good deal in their descriptions. In France the color of surrounding objects became yellowish, or of a light olive tinge, and in a sea-horizon a broad band of an orange color was formed. At the commencement of totality, the figures of persons standing near assumed a pale cadaverous aspect according to some authorities, while others describe them as greenish. In Italy, generally a greenish hue covered the whole landscape at this moment, gradually changing to violet as the darkness deepened. At Novare, the heavens, up to an altitude of 50°, were of a rosy tinge, like that of the Aurora Borealis. One observer describes the faint illumination of objects in his neighborhood as resembling that afforded by ignited spirits of wine. While the vast plains surrounding Milan presented a deep green hue, at Cremona the landscape seemed as though it were illuminated by a Bengal light. These varied accounts are probably to be ascribed in some degree to optical causes depending on the observers themselves.

During the eclipse of 1842, nearly the whole population of some of the principal cities of southern France and Italy, which were upon the central line, turned out to view the rare phenomena of a total deprivation of the Sun's light in the daytime. At Pavia, Mr. Baily says, "there was an universal shout which made the welkin ring," at the conclusion of the eclipse ; and M. Arago, who observed at Perpignan, says nearly twenty thousand persons covered the terraces, ramparts, and other eminences about the place, and that an astounding shout from this multitude announced the extinction and reappearance of the Sun's rays. At Milan, Padua, &c., the excitement was equally great. "Long live the astronomers !" was the cry in the former city, when the rose-colored flames burst forth on the bright ground of the corona during the total obscuration. Two hundred years previously, many of the inhabitants of Paris hid themselves in caves on the mere announcement of an eclipse of the Sun, which was total in that city ![*]

The sudden extinction of the Sun's light in total eclipses is not without its effects upon the animal creation, and naturalists, who have confined their attention to terrestrial observations during the totality, relate some curious instances of the alarm and astonishment exhibited, not only by the more sagacious animals, but by birds, and even insects. In July, 1842, in the south of France, horses attached to vehicles came to a decided stand, and no exertions of their drivers, though backed by the whip, could induce them to proceed until the Sun had again appeared.[†] Cattle in the fields congregated together immediately after total darkness came on, as if in apprehension of an attack. Dogs, in particular, appear to have been sensible of some unnatural event, howling piteously during the deprivation of the Sun's rays, or hastily seeking some place of safety. At Montpellier the swallows, which were numerous before the commencement of the total phase, suddenly disappeared until it had formed, and in one place it is said a great number of birds

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[*] Arago—"Annuaire du Bureau des Longitudes"—1846.

[†] An exception must be made in respect of the horses employed in the public *diligences*, which, singularly enough, betrayed no signs of alarm, but, as M. Arago observes, "paid as little attention to the phenomenon as the railway locomotives."

fell upon the earth. That this circumstance has happened in previous eclipses there can be no doubt: it is distinctly mentioned by Clavius as having occurred at Coimbra during the total eclipse of August 21, 1560, when the gloom is said to have been greater than that of night. The stars were distinctly visible, and the birds, "*mirabile dictu*, fell from the air dead upon the earth from fright at so horrible a darkness." In 1842, the birds in the trees near Lodi suddenly ceased singing at the moment when the total obscuration came on; but M. Piola says he did not notice that any of them fell, though he was stationed under one of the trees at the time. M. Arago relates an instance where three linnets were placed in a cage outside a window early on the morning of the eclipse, and on examination, after the phenomenon, one of the three was fonnd to be dead, having probably killed itself by striking against the bars of the cage in a moment of terror. At Milan the bees quitted their hives in great numbers soon after sun-rise, but returned to them in haste immediately the last rays of the Sun had vanished.

The last total eclipse of the Sun, on the 28th of July, 1851, was observed under very favorable circumstances by many English astronomers in Norway and Sweden. The author observed near the town of Engelholm, about eighteen miles from Helsingborg, on the Sound, where the eclipse was total for about 1m. 40s. The moment the Sun went out, the corona appeared; it was not very bright, but this might arise from the interference of an extremely light cloud of the *cirrus* class, which overspread the Sun at the time. The corona was of the color of tarnished silver, and its light seemed to fluctuate considerably, though without any appearance of revolving. Rays of light, the *aigrettes*, diverged from the Moon's limb in every direction, and appeared to be shining through the light of the corona. In the telescope many rose-colored flames were noticed; one far more remarkable than the rest on the western limb, could be distinguished without any telescopic aid ; it was curved near its extremity, and continued in view *four seconds after the Sun had disappeared*, *i.e.*, after the extinction of *Baily's beads*, which phenomena were very conspicuous in this eclipse, particularly before the commencement of the totality. In this case they were clearly to be attributed to the existence of many mountains and valleyse along the Moon's edge, the Sun's light shining through the valley and between the mountain ridges, so as to produce the appearance of luminous drops or beads, which continued visible some seconds. The color of the "flames" was a full rose-red at the borders, gradually fading off towards the centres to a very pale pink. Along the southern limb of the Moon, for forty degrees or upwards, there was a constant succession of very minute rose-colored prominences, which appeared to be in a state of undulation, though without undergoing any material change of form. An extremely fine line, of a deep violet color, separated these prominences from the dark limb of the Moon. The surface of our satellite during the total eclipse, was purplish in the telescope ; to the naked eye it was by no means very dark, but seemed to be faintly illuminated by a purplish-gray light of uniform intensity on every part of the surface.

The aspect of nature during the total eclipse, was grand beyond description. A diminution of light over the Earth was perceptible a quarter of an hour after the beginning of the eclipse, and about ten minutes before the extinction of the Sun the gloom increased very perceptibly. The distant hills looked dull and misty, and the sea assumed a dusky appearance, like that it presents during rain. The day-light that remained had a yellowish tinge, and the azure blue of the sky deepened to a purplish-violet hue, particularly towards the north. But, notwithstanding these gradual changes, the observer could hardly be prepared for the wonderful spectacle that presented itself when he withdrew his eye from the telescope, after the totality had come on, to gaze around him for a few seconds. The southern heavens were then of a uniform purple-gray color, the only indication of the Sun's position being the luminous corona, the light of which contrasted strikingly with that of the surrounding sky. In the zenith, and north of it, the heavens were of a purplish-violet, and appeared very near, while in the north-west and north-east broad bands of yellowish-crimson light, intensely bright, produced an effect which no person who witnessed it can ever forget. The crimson appeared to run over large portions of the sky in these directions irrespective of the clouds. At higher altitudes the predominant color was purple. All nature seemed to be overshadowed by an unnatural gloom, the distant hills were hardly visible; the sea turned lurid red, and persons standing near the observer had a pale livid look, calculated to produce the most painful sensations. The darkness, if it can be so termed, had no resemblance to that of night. At various places within the shadow, the planets Venus, Mercury, and Mars, and the brighter stars of the first magnitude, were plainly seen during the total eclipse. Venus was distinctly visible at Copenhagen, though the eclipse was only partial in that city; and at Dantzic she continued in view ten minutes after the Sun had reappeared. Animals were frequently much affected. At Engelholm a calf which commenced lowing violently as the gloom deepened, and lay down before the totality had commenced, went on feeding quietly enough very soon after the return of daylight. Cocks crowed at Helsingborg, though the Sun was only hidden there thirty seconds, and the birds sought their resting-places as if night had come on.

One of the most famous eclipses of the Sun recorded in history, is that which put an end to the war between Cyaxeres, King of the Medes, and Halyattes, King of the Lydians, described by Herodotus, and said to have been predicted by Thales, of Miletus, the celebrated philosopher. The contending armies were so alarmed at the sudden change of daylight into total darkness, that they threw down their arms and concluded a peace upon the spot. The precise time of this interesting event has long been disputed by chronologists, and the solar eclipses of B.C. 606, 592, and particularly that of 584, have been fixed upon as the phenomenon mentioned by Herodotus; but since the improvement of the tables of the Sun and Moon during the earlier part of the present century, several astronomers have occupied themselves in the inquiry; and our countryman Mr. Baily, Professor J. Oltmanns, and M. Saint Martin, have pointed out an eclipse on September 30, B.C. 609,* which they consider to have been the one in question. According to the *Tables* it was total in Lydia, where the battle was fought, and the description left us is only reconcilable with the phenomena of a total eclipse, annular ones being evidently incompetent to produce entire darkness. The central phase happened about four hours after sunrise. Recent investigations, however, have shown that the secular movement of the Moon's node used in the tables is erroneous, to the amount of more than 1½′, and this would cause a considerable difference in the position of the node in B.C. 609, and might very possibly throw the path of the Moon's shadow beyond the probable position of the contending armies. We think it is likely that a new calculation, involving the late corrections to the lunar elements, will show that the eclipse of Thales took place in B.C. 584, and not in the year assigned by the above astronomers. This is an interesting question, and deserves the attention of some skilful computer.

Another total eclipse of the Sun, supposed to have been

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* Reckoning according to the manner of astronomers.

that of August 3, B.C. 430, had its effect upon terrestrial affairs, and but for the intervention of Pericles, would have seriously interfered with the expedition undertaken by the Athenian fleet against the Lacedemonians. The date answers to the second year of the eighty-seventh Olympiad, the first of the Peloponnesian war. Thucydides, who was contemporary, says the stars were seen in the middle of the day. According to Plutarch, in his Life of Pericles, the commander of the vessel was greatly alarmed at the darkness, which took place as he was on the point of setting sail; but the Athenian General was luckily able to explain the phenomenon, which he illustrated in a manner that seems to have allayed the fears of the captain, and so prevented the delay of his expedition.

The total eclipse, known as that of Agathocles, which occurred on the 15th of August, B.C. 309, was also investigated by Mr. Baily. In this case neither the date nor the locality were open to much uncertainty, and the phenomenon consequently appeared to him to afford a favorable opportunity for checking the solar and lunar tables, instead of using them as the means of settling the date and limits of the eclipse. Diodorus Siculus says the stars were seen, so that no doubt can exist as to the *totality* of the Eclipse; but Mr. Baily found an irreconcilable difference between the tables and the historical statement, a space of about 180 geographical miles appearing between the most southerly position that we can assign to the fleet of Agathocles, and the limit of the total phase. To obviate this discordance, it is only necessary to suppose an error of about three minutes of arc in the computed distance of the centres of Sun and Moon at conjunction, a very inconsiderable correction for a date anterior to the epoch of the tables by more than twenty-one centuries.

ECLIPSES OF THE MOON.

In consequence of the ecliptic limits of the Sun exceeding those of the Moon, there are more eclipses of the former luminary than of the latter, but owing to the comparatively small tract of the Earth's surface to which a solar eclipse is visible, the eclipses of the Moon are more frequently seen at any particular place than those of the Sun. In point of interest and astronomical importance, however, they fall very far short.

Eclipses of the Moon are either partial or total. The *magnitude*, if partial, and the continuance of obscuration, if total, depend upon the direction of her transit through the Earth's shadow, which is sufficiently broad at the distance of the Moon to allow of her being hidden by it one hour and fifty minutes, when a central passage through it takes place.

The shadow of the Earth consists of a dark cone, surrounded by a lighter shade, termed the penumbra, which arises from a portion only of the Sun's rays being obscured. At that part of the conical shadow where the Moon traverses it, the diameter is between three and four times greater than her mean distance from the Earth, or, roughly speaking, 800,000 miles. An eclipse may continue as long as five and a half hours, reckoning from the first to last penumbral contact.

It is not possible to ascertain, with any degree of accuracy, the time when the Moon first enters into the penumbra, for the darkening effect upon her disc is so slight that it requires some minutes to elapse before sufficient shade is produced to attract attention. Neither does the moment of contact with the dark shadow admit of exact observation, and hence lunar eclipses are not of so much astronomical importance as eclipses of the Sun, as they afford but very imperfect determinations for differences of longitude.

When the Moon is totally immersed in the shadow, she does not, except on some rare occasions, become invisible, but assumes a dull, reddish hue, somewhat of the color of tarnished copper. This arises from the refraction of the Sun's rays in passing through the Earth's atmosphere. During the eclipse of July 23, 1823, M. Gambart states he could distinctly see all the lunar spots, the general surface being of a deep red color. In that of September 11, 1802, Schröter remarked that the Earth's shadow was very bright (*sehr helle*), and of a light gray color; the penumbra was not perceptible. Sir John Herschel observed the eclipse of December 26, 1833, during his voyage to the Cape of Good Hope, in latitude 26° 30′ south; the Moon continued conspicuously visible to the naked eye, while totally immersed in the Earth's shadow, and of a swarthy copper color, which changed to bluish green at the edges as the eclipse passed off. Sir J. Herschel thinks this remarkable phenomenon arose from the "accidental absence of clouds over a large portion of that annulus of the Earth's atmosphere grazed by the Sun's rays at the time." The total lunar eclipse of March 8th, 1848, was characterized by similar phenomena. The spots upon the surface were distinctly seen by many observers, even at the middle of the eclipse, and the general color of the Moon was a full, "glowing" red. Her appearance was so singular that many persons doubted her being eclipsed at all. Perhaps it may be worthy of remark, in connection with these facts, that the *aurora borealis* was seen in vivid streamers in various parts of England, Ireland, and the Continent.

Instances of an analogous kind might be easily multiplied; but the few we have mentioned will be sufficient to warn the reader of what he may expect to witness in a lunar eclipse.

The earliest observations of lunar eclipses on record date in the year 719 and 720 B.C., reckoning according to the manner of astronomers, and were taken at Babylon by the Chaldeans in the reign of Mardokempadius. Ptolemy has preserved these ancient observations in his Almagest. The first of three eclipses took place in the twenty-seventh year of the era of Nabonassar, the first of the reign of Mardokempadius, on the 29th of the Egyptian month *Thoth*, answering to the 19th of March, B.C. 720, in our mode of reckoning. The eclipse commenced about an hour after the rising of the moon, the greatest phase about 2h. 30m. before midnight. It appears to have been total at Babylon. The second eclipse is dated in the twenty-eighth year of Nabonassar's era, on the night between the 18th and 19th of the month *Thoth*, at midnight, or on the 8th of March, B.C. 719 ; this was a partial eclipse. The third took place in the same year, on the 15th of the month *Phamenoth*, corresponding to September 1st, B.C. 719 of our era. It began soon after the moon rose at Babylon, and continued three hours ; the magnitude was six digits on the northern limb, according to Ptolemy. Three other ancient eclipses fix the commencement of the important era of Nabonassar in the year B.C. 746, and have likewise indicated the existence of an acceleration in the mean motion of the Moon, which was first detected by our countryman Dr. Halley.

An eclipse in the nineteenth year of the Peleponnesian war, the fourth of the ninety-first Olympiad, produced very disastrous consequences to the Athenian army, through the ignorance of their general, Nicias. It is mentioned by Thucydides, Plutarch, and others, and took place on the 57th of August, B.C. 412, being total at Syracuse, according to calculation upon modern tables.

The lunar eclipse of March 1, 1504, proved of great service to Columbus, when his fleet was reduced to extremities for want of supplies. The islanders of Jamaica having refused to supply him, he threatened them with a deprivation of the Moon's light, as a punishment for their obstinacy. His threat was treated at first with indifference ; but when the eclipse actually commenced, the barbarians vied with each other in the production of the necessary supplies for the Spanish fleet. Baron de Zach has satisfactorily shown that this eclipse must have occurred on the above date. It was observed at Ulm, in Germany, by Stoffler, and at Nuremberg by Bernard Walther, and began about six o'clock in the evening, at Jamaica, which perfectly accords with the words of Columbus in describing the phenomenon.

CHAPTER VII.

THE SUPERIOR PLANETS.

MARS. ♂

WE now arrive at the planet Mars, which, in several respects, has a closer analogy to our own globe than obtains in the other members of the solar system. He usually shines with a full, red or fiery light, and, when in opposition and perihelion, is a very conspicuous object in the midnight sky.

The mean distance of this planet from the Sun is 145,205,000 miles, but in consequence of the eccentricity of its orbit, the distance varies between 131,656,000 miles, when the longitude is about 332·4°, and 158,754,000 miles, when its heliocentric position is about 152·4°, so that the difference between the perihelion and aphelion distances amounts to 27,098,000 miles. The sidereal period of Mars is 686d. 23h. 30m. 41s., and the mean synodic period, or interval between two oppositions, is 779d. 23h., or rather more than two of our years.

The apparent diameter of the planet varies considerably. About the time of conjunction it is little more than four seconds of arc, while in opposition and perihelion it may attain more than thirty seconds. The real diameter is probably not less than 4500 miles.

The phase of Mars does not undergo such great alteration as we have observed in the inferior planets. About the opposition, he appears perfectly round, while, as he recedes from that point, his illuminated disc gradually diminishes until he arrives at quadrature, when the form resembles that of our Moon a day or two before the last quarter, so that the planet is generally seen *gibbous*, but never less than a semicircle, which is a sufficient proof that, receiving its light from the Sun, the orbit must be exterior to our own. The phases of Mars were discovered by Galileo soon after the telescope was invented.

When viewed under proper optical power, the surface of this planet presents outlines of continents, and seas similar to those on the Earth, and usually, white spots are discernible near the poles, which, from their alternate diminution and increase, as the Sun possesses greater or less power on the surface, are conjectured to be masses of snow. The color of the continents is a dull red, that of the seas greenish, as, by contrast with the former, they should be. It is this prevailing color of the land which gives the planet that ruddy light by which it is at all times readily distinguished from the other members of the system, and from the fixed stars. By observing the spots upon the surface, the time of the axial rotation of Mars has been determined. The elder Cassini made it 24h. 40m., a very near approximation to the truth. Sir W. Herschel paid great attention to his observations of this planet, and fixed the time of revolution at 24h. 39m. 21·67s., mean solar time, remarking that he did not consider this determination liable to a greater error than 2·34s. Professor Mädler, however, from observations between 1830 and 1834, infers the time of rotation to be 24h. 37m. 20s., or two minutes less than it is given by Sir W. Herschel. In 1781–3, the latter astronomer measured the positions of the bright polar spots on Mars, with the view of ascertaining the obliquity of his ecliptic, or the angular inclination of his equator to the plane of the orbit. He found these spots were not exactly at the poles, but that the circles of their motions were situated at latitudes 75° or 80°, the luminosity extending occasionally as far south as the sixty-fifth parallel on Mars. By a great number of observations, Sir W. Herschel found that the axis of Mars is inclined to his orbit at an angle of 61° 18′, or 59° 42′ to our ecliptic, the north pole being directed to longitude 347° 47′. The obliquity on the globe of Mars is therefore 28° 42′, so that his seasons are possibly not very different from our own.

A very extensive atmosphere has been thought to surround the planet; and to this dense envelope has been attributed the ruddy appearance he presents to the naked eye; but recent observations, and particularly those of Sir James South, go far to disprove its existence. The attention of astronomers had been closely directed to this subject after the announcement of an observation by Cassini in 1672. He affirmed that in the month of October he saw the star called ψ in Aquarius become so faint, when six minutes distant from the planet's disc, that it could not be discerned in a three-feet telescope. This star is of the fifth magnitude, and consequently visible to the naked eye. In alluding to this observation, Sir W. Herschel gave one of his own, which tended to show that the atmosphere of the planet, though moderately dense, could not be so extensive as Cassini had inferred, since he could trace a very small star (of the thirteenth or fourteenth magnitude) within a very short distance from the planet's limb.

Astronomers have not yet succeeded in discovering a satellite to this planet, although some of the most perfect telescopes have been brought to bear upon it. Being situated at a greater distance from the Sun than our globe, we might imagine it would stand more in need of an attendant to illuminate its otherwise dark nights, and regulate the tides upon its oceans. If one exist it is possibly very small and close to the planet, which would account for its having so long escaped detection.

In the absence of a satellite to afford us a more exact value, we can only be said to have *approximated* to the mass of the planet. The French calculator, Burckhardt, assigns 1·2680337, which is adopted by astronomers at the present day, and indicates that the mass of our neighbor is seven times less than that of the Earth.

Dr. Maskelyne, formerly Astronomer Royal, examined this planet with the view of ascertaining whether there is any sensible difference between the equatorial and polar diameter; but could perceive none. Sir W. Herschel considered the ratio of the equatorial to the polar diameter as 16 to 15; but an extensive series of observations, recently taken with the best instruments to be found in observatories, gives the compression much less, or the ratio of the diameter as 51 to 50, which is probably nearer the truth. It is only at the oppositions, or about once in two years, that we see the disc of Mars fully illuminated, consequently, the proper times for determining the difference of diameter, or for any observations upon the appearance of the surface, are not of very frequent occurrence.

A method of determining the amount of the solar parallax from observations of Mars at places differing greatly in latitude has been put in practice by several astronomers; though not very successfully. It is with a view to the application of this method that observers are furnished in the *Nautical Almanac* with a list of stars lying near the path of the planet about the times of opposition. The differences of declination between the stars and planet are to be repeatedly measured on the same night at the various stations, either with a micrometer or on the divided circle of an equatorial instrument. Suppose one of the observations in the northern and another in the southern hemisphere. The differences of declination measured at the two places and reduced accurately to the same moment after correction for refraction, will exhibit a discordance, which, supposing the observations exact, must be equal to the sum of the parallaxes of the planet at the two stations. Hence, knowing the geocentric latitudes, we easily ascertain the amount of the horizontal parallax of Mars. But as we also know the relative distances of the Sun and planet from the Earth at the time, a very simple proportion gives us the value of the solar parallax. Cassini, from observations of a similar kind, found it 10·1″; La Caille, 10·2″; and Du Sejour, 9·47″.

The most ancient observation of Mars that has come to our knowledge is one reported by Ptolemy in his Almagest, Book x., Chap. 9. It is dated in the fifty-second year after the death of Alexander the Great, and four hundred and seventy-sixth of Nabonassar's era, on the morning of the 21st of the month *Athir*, when the planet was above, but very near, the star β in Scorpio. The date answers to B.C. 272, January 17, at 18h. on the meridian of Alexandria.

An occultation of the planet Jupiter by Mars is recorded, on the 9th of January, 1591. Such a phenomenon would be extremely interesting, if viewed with the powerful telescopes so common at the present day.

The tables employed in predicting the geocentric places of Mars were published at Eisenberg in 1811 by the Baron Von Lindenau, and are chiefly dependent upon observations taken at our Royal Observatory. They are capable of correction, though sufficiently exact for most practical purposes: the error in longitude in 1847 exceeded half a minute of arc. It is understood that new tables of the movements of this planet, founded on the Greenwich observations, are in course of preparation by the computers employed upon the *American Nautical Almanac*, a work which has recently been commenced under the auspices of the Government of the United States.

CHAPTER VIII.

THE MINOR OR ULTRA-ZODIACAL PLANETS.

BETWEEN the orbit of Mars and that of the next of the older planets (Jupiter), there occurs an interval of no less than 350 millions of miles, in which no planet was known to exist before the commencement of the present century. Three hundred years ago Kepler had pointed out something like a regular progression in the distances of the planets as far as Mars, which was broken in the case of Jupiter, and he is said to have suspected the existence of another planet in the great space separating these two bodies. The question attracted little further attention until Uranus was brought to light by Sir William Herschel in 1781, when several German astronomers revived the opinion held by Kepler, and, guided by an empirical law of distances published by Professor Bode of Berlin, even approximated to the period of the supposed latent body. According to this law, the distance of a planet is about double that of the interior one, and half that of the one immediately exterior to it, and, roughly speaking, this rate of progression of the planetary distances is found to hold good with these exceptions. Mars is situated at a distance of about twice that of the Earth, but very much less than half that of Jupiter; and again, Jupiter is located at half the distance of the exterior planet Saturn, but considerably more than twice that of Mars. If, therefore, another planet existed between the orbits of Mars and Jupiter, the progression in Bode's law, instead of being interrupted at this point, might perhaps be found to hold good as far as Uranus, and for this reason an association of astronomers was formed under the auspices of the Baron de Zach of Gotha, and a regular plan of search was devised, with a view to the discovery of the planet, which was put in practice about the end of the last century. The result of this systematic examination of the heavens will presently appear.

CERES.

Professor Guiseppe Piazzi, the celebrated Director of the Observatory at Palermo, repeatedly sought for a star numbered in Wollaston's catalogue, Mayer 87, but, finding none in the position there assigned, he observed all the stars of similar brightness in the vicinity. On the 1st of January, 1801, or about the time when the search for the supposed latent body was begun, he determined the place of an object shining as a star of the eighth magnitude, not far from the position of the missing one. On the following night the place was sensibly altered, the instrument employed by Piazzi showing a retrograde movement in right ascension with a northerly one in declination. It does not appear that any notice of this discovery was given until the 24th, when letters were despatched to several astronomers, in which Piazzi states that he had detected a *comet* in 51° 47′ of right ascension and 16° 8′ north declination. Owing probably to delays of post, no observations were made at any observatory, except Piazzi's, before the conjunction of the stranger with the Sun; but on the publication of the whole series of positions observed at Palermo, the eminent mathematician and astronomer Professor Gauss of Göttingen, undertook the determination of the orbit of Piazzi's star by methods which he had recently devised, and announced that it revolved round the Sun in about 1652 days, at a mean distance of 2·735, —that of the Earth being called 1. This distance agreeing so closely with that indicated on Bode's law for the planet supposed to exist between Mars and Jupiter, astronomers were very soon induced to regard Piazzi's "comet" as in reality a new primary planet, fulfilling, in a remarkable manner, the conditions in respect to distance from the Sun, which had been found to hold good for the other members of the planetary system.

Piazzi named his planet *Ceres Ferdinandea*, in honor of his patron the King of Naples; but the *Ferdinandea* has been dropped by common consent, and the planet is now known as *Ceres*.* The very neat and significant symbol ⚳ was adopted by astronomers, on the suggestion of the Baron de Zach.

The detection of Ceres, on her reappearance after conjunction with the Sun, was a matter involving some little difficulty, and one that occupied the attention of the principal observers on the continent. Bode mapped down all the stars of his great catalogue lying near the expected path of the planet, according to the calculations of Professor Gauss, and in the morning hours of October, November, and December, 1801, he sought for it with his 3½ feet telescope by Dollond. Dr. Olbers at Bremen, and Baron de Zach at Gotha, were similarly engaged. On the night of December 7, a suspicious object was remarked by the latter astronomer near the computed place, but he was not able

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* Laplace, writing to Baron de Zach in 1802, states that he had mentioned the discovery of the Sicilian astronomer to Bonaparte, "who, in the midst of his great occupations, took a lively interest in the progress of the sciences, and particularly of astronomy." Bonaparte thought *Juno* was a preferable name to Ceres, and Laplace says he held the same opinion, since it appears natural to place Juno near Jupiter. He adds that a Latin name was better than a Greek one, the German astronomers having already suggested Hera ('Ηρα), the Greek name of Juno, for Piazzi's planet. On this subject the discoverer observes—" J' espere que les astronomes qui sont gens paisibles, ne consenteront jamais à appeller leur divinites du nom d'une déese si inquiéte, jalouse et vendicative comme Junon."

to decide whether he had really seen the planet until the 31st of that month, when he had the satisfaction of observing it again, and finding no star in the position noted on the 7th. Dr. Olbers found it on the 1st of January, 1802, and, on the 13th of February, it was seen at our Royal Observatory by Dr. Maskelyne. The calculations of Professor Gauss mainly contributed to the re-discovery, and, in fact, he has been considered by some astronomers as the second discoverer of the planet, which they imagine would have been lost but for the manner in which the future course was predicted by the profound mathematician of Göttingen. Professor Bode says a friend of his could discern the planet without a telescope in March, 1802, when its brightness was about equal to that of a star of the seventh magnitude; but generally Ceres is just beyond unassisted vision, and would be more properly termed an eighth magnitude.

The minuteness of the planet has prevented any exact determination of the real diameter. Schröter thought it exceeded 1600 miles, while Sir W. Herschel's measures gave only 163 miles, and this last measure is certainly much nearer the truth than the former. Observers have remarked a haziness surrounding the planet, which is attributed to the density and extent of its atmosphere. The light is very slightly tinged with red. The mean distance from the Sun in 1850, is 263,713,000 miles, and the length of a sidereal revolution 4·6033 years.

PALLAS.

In order to find Ceres the more readily, Dr. Olbers examined particularly the configurations of the small stars lying near her path. On the 28th of March, 1802, after observing the planet, he swept over the north wing of Virgo with an instrument termed a "Cometen Sucher," and was astonished to find a star of the seventh magnitude forming an equilateral triangle with 20 and 191 of Bode's Catalogue, where he was certain no star was visible in January and February preceding. In the course of less than three hours he found the rigbt ascension had diminished and the north declination increased. On the following evening, as soon as twilight permitted, he looked again for his star: it no longer formed an equilateral triangle with the stars above mentioned, but had moved considerably in the direction indicated by the previous night's observations. On the 30th, after again observing the planet, Dr. Olbers wrote to Bode at Berlin, and to Baron de Zach, giving an account of his discovery. "What a singular accident," he exclaims, "was it by which I found this stranger in the same place, or only about twenty-six minutes (of space) north of the position where I had observed Ceres on the 1st of January." It was truly a fortunate circumstance. In the letter to Professor Bode, Dr. Olbers suggested *Pallas* as a name for a new member of the system. The elements of the orbit were quickly determined by Professor Gauss, who found the most remarkable peculiarity consisted in the great inclination of its plane to the ecliptic, owing to which the planet passed far beyond the limits of the ancient zodiac. The orbit was found to be an ellipse of not much greater eccentricity than that of Mercury, with a mean distance nearly *the same as in the case of Ceres.* Dr. Olbers pointed out that the orbits of the newly-discovered planets approached very near each other at the descending node of Pallas, a circumstance which induced his remarkable conjecture as to the common origin of these bodies. He thought a much larger planet had, in remote antiquity, existed near the mean distance of Ceres and Pallas, and that, by some tremendous catastrophe, this body had been shivered in pieces,—the two small planets being amongst the fragments. At the time this hypothesis was started it was certainly a bold one, but we shall presently see it is materially strengthened by the discoveries of later years.

When nearest to the Earth in opposition, Pallas shines as a full seventh magnitude, with a fine yellowish light, as we can testify from observations under very favorable circumstances in March, 1848. Some astronomers have noticed a haziness round the planet, but not so strongly marked as with Ceres: this appearance is considered due to extensive atmosphere. Sir W. Herschel thought the diameter of Pallas a little over seventy-five miles, while Schröter made it 770 at least. These discordances prove the great difficulty and uncertainty of such observations. Dr. Lamont, from two nights' measures with the powerful telescope at the Royal Observatory, Munich, found the diameter 670 miles, which is probably a fair approximation to the truth. The mean distance of the planet from the Sun is 264,256,000 miles, and the time occupied in one sidereal revolution 4·6175 years, or 1687 days.

JUNO.

Professor Harding of Lilienthal occupied himself in the formation of charts of small stars lying near the paths of Ceres and Pallas, with a view to assist the identification of these minute bodies. On the 1st of September, 1804, at ten o'clock in the evening, he noticed an object shining as a star of the eighth magnitude, near the stars 93 and 98 in Pisces, of Bode's great catalogue. The position was in right ascension 2° 24′ and north declination 0° 37′. On the evening of the 4th he re-examined the neighborhood, and soon discovered that the star had altered its place. The right ascension had diminished, and the declination was now south. On the 5th and 6th he observed it more accurately, and finding that the positions deduced from the observations confirmed the retrograde motion indicated by the estimations on September 1st and 4th, he announced the discovery to Dr. Olbers, at Bremen, on the 7th, who saw it the same evening. Professor Harding named his planet *Juno*, and chose for a symbol ⚵, representing a sceptre crowned by a star.

Juno usually appears like a star of the eighth magnitude, of a somewhat ruddy color. Her period of revolution round the Sun is 4·3594 yrs., and her synodic period about 474 days. The mean distance from the Sun is 254,312,000 miles. This planet was detected with a telescope of about thirty inches focal length, and two inches aperture, which would not show the belts of Jupiter, as the author has been assured by Sir James South, who saw the instrument at Göttingen.

VESTA.

Dr. Olbers, following up his idea respecting the origin of the zone of planets, considered, from the mutual intersection of the orbits of the three already found in Virgo and Cetus, and the explosion must have taken place in one or other of those regions, and consequently all fragments should pass through them. Provided with an ordinary night-glass, he examined every month the small stars in Virgo and Cetus, whichever constellation was nearest the opposition. On the evening of the 29th March, 1807, soon after eight o'clock, while occupied in sweeping over the north wing of Virgo, as a part of his plan he discovered an object shining like a star of the sixth or seventh magnitude, west of Flamsteed's 20 Virginis, which he knew at once to be a planet, inasmuch as the previous examination of the vicinity had indicated no star in the position of the stranger. He satisfied himself that it was really in motion on the same evening, and continuing his observations until the 2d of April, he obtained sufficient evidence to justify the public announcement of his discovery of another new planet. Accordingly, on the following day, he wrote to Professor Bode of Berlin, the editor of the *Astronomische Jahrbuch*, and to Baron de Zach of Gotha, who conducted a most valuable periodical, entitled *Monatlieche Correspondenz.* In his letter to Berlin, Dr. Olbers particularly mentions that his second discovery was not the result of accident, but of a systematic search for a body of this nature, guided by considerations already noticed. He adds, he should certainly have found the planet a fortnight earlier if moonlight and unfavorable weather had not interfered with his observations, and remarks in conclusion, that neither Schröter and Bessel, with thirteen-feet and fifteen-feet reflecting telescopes, nor he himself, with an excellent achromatic by Dollond, could perceive any difference in appearance between this planet and a fixed star; it shone with a somewhat reddish but very bright light, without planetary disc, or any surrounding nebulosity. At the request of Dr. Olbers, Professor Gauss undertook to name the planet, and decided upon *Vesta*, a name highly approved of by the discoverer. The symbol chosen is ⚶, to represent an altar with the sacred fire burning upon it. Professor Mädler has carefully measured the diameter of Vesta with the famous telescope by Fraunhofer, erected at the Observatory of Dorpat in Russia. A mean of several nights' measure makes the real diameter about 295 English miles.

Vesta performs her revolution in 3·6284 yrs., at a mean distance of 225,000,000 of miles. Her orbit is little more eccentrical than that of Ceres. Near her opposition to the Sun she appears the brightest of all the minor or ultra-zodiacal planets, and a person with good sight may often distinguish her without a telescope. The reddish tinge noticed by the astronomers at Lilienthal soon after the discovery of the planet is probably due to some peculiarity in the specula of their instruments; but it is well known persons differ widely in their appreciation of colors in the heavenly bodies. Some observers consider Vesta perfectly white; while the author has repeatedly examined her under various powers, and always received the impression of a pale yellowish cast in her light.

Dr. Olbers continued his systematic examinations of the small stars in Virgo and Cetus between the years 1808 and 1816, and was so closely on the watch for any moving body, that he considered it very improbable a planet could have passed through either of these regions in the interval without being detected. No further discovery being made, the plan was relinquished in 1816.

ASTRÆA.

After Dr. Olbers had discontinued his search for planets, the subject appears to have attracted little attention until M. Hencke, an amateur astronomer, at Driessen in Prussia, entered upon it with a zeal and diligence that could hardly fail in producing some important result. For fifteen years it is understood this gentleman had occupied himself in a strict survey of the zone of the heavens comprised within the charts published by the Royal Academy of Berlin. These charts contain all stars to the ninth magnitude inclusive, 15° on each side of the equator, and are complete for about two thirds of the hour of right ascension. M. Hencke extended these maps by the insertion of smaller stars, and his immediate object being the discovery of a new planet, he previously examined the configuration of the stars, so that by obtaining a close acquaintance with certain parts of the heavens he could readily detect any moving body on its passage through them. The 8th of December, 1845, was destined to be the epoch of M. Hencke's first discovery. While engaged on the evening of that day in comparing Professor Knorre's map (Hour iv. of right ascension) with the heavens, he noticed what appeared to be a star of the ninth magnitude, between two others of the same brightness in Taurus, which had not been noted in his previous examinations. Without waiting for any further observations, M. Hencke wrote to Professors Encke and Schumacher, stating his reasons for supposing that he had detected a new planet. On the 14th of December the astronomers of the Observatory at Berlin found the stranger in a position where no star appeared on Professor Knorre's excellent chart, and the motion was easily perceived the same evening. Information of the discovery reached this country in letters from Professor Schumacher on December 19, and the planet was observed on the 24th. M. Hencke having requested the celebrated Prussian astronomer Encke to name his new planet, the Professor fixed upon *Astræa.* The period of revolution is found to be 1511 days, and the mean distance of the planet from the Sun 245,622,000 miles.

Astræa will not be seen without a tolerably good telescope; and, however powerful may be the instrumental means employed, it is necessary to have a pretty exact knowledge of her position in respect to the neighboring stars, to guard against observing a wrong object. At the opposition in 1847 she was not brighter than a star of the tenth magnitude, and no charts of the heavens hitherto published contain stars of so faint a class. Two months after opposition she had diminished into a twelfth magnitude, and was therefore observable only in the most powerful telescopes. Under the most favorable circumstances, or when the planet comes into opposition and perihelion at the same time, it will but little exceed in brightness a star of the ninth class.

HEBE.

Encouraged by his success, M. Hencke continued his search for planetary bodies, extending and verifying the Berlin Academical charts, and by frequent comparison with the heavens acquiring an extensive knowledge of the configurations of the smaller stars in certain regions about the equator and ecliptic. On the evening of the 1st of July, 1847, he noticed an object shining as a star, a little less bright than the ninth magnitude, which was not marked on Dr. Bremiker's chart for the seventeenth hour of right ascension, nor observed in M. Hencke's previous search about the neighborhood. At midnight, on July 3, it had retrograded in right ascension, leaving no doubt of its planetary nature, and showing by the direction and amount of its motion that it formed another member of the ultra-zodiacal group. Information of the discovery was circulated by M. Hencke on the following day, and the planet was soon recognized at the principal observatories of Europe. The illustrious mathematician and astronomer, Professor Gauss, was deputed by the discoverer to select a name for the stranger, and it was soon known as the planet *Hebe*, with a cup for the symbol, emblematic of the office of the goddess in mythology. There is decidedly a ruddy tinge about this planet from which Astræa is free. The mean distance from the Sun is about 231,089,000 miles, and the time occupied in one sidereal revolution 3·7761 years. The orbit is very eccentrical, and inclined more than 14° to the plane of the ecliptic.

IRIS.

The next two members of this remarkable group in order of discovery were found by the author at the observatory erected by Mr. Bishop in the grounds of his private residence in the Regent's Park, London. So early as April, 1845, a search for a planetary body was commenced, but in consequence of other classes of observation, then more particularly followed up, no extensive or systematic plan of examination of the heavens was attempted. In November, 1846, a rigorous search was undertaken, the Berlin Academical charts being employed as far as they extend, while ecliptical charts, including stars to the tenth magnitude inclusive, were formed for other parts of the heavens, where the ecliptic falls beyond the declination limits (15° N. to 15° S.) of the Berlin maps.

On the evening of the 13th of August, 1847, after nine month's close observation on the above system, an object resembling a star of the eighth magnitude was discovered in the immediate vicinity of 63 Sagittarii, which had not been noticed at any former time. Its planetary nature being immediately suspected it was attentively observed, and in less than half an hour the motion in right ascension was detected. In the course of an hour the planet had retrograded two seconds of time, a sufficient change of place to be indubitable. An announcement of the discovery was given to astronomers generally on the following morning, and observations were soon obtained at most of the European observatories. The name fixed upon for this new member of the solar system is *Iris*, which appears to have met with general approbation amongst astronomers. The symbol is due to Professor Schumacher, and is composed of a semicircle representing the rainbow, with an interior star, and a base line for the horizon. As an attendant upon Juno, the name was not inappropriate at the time of discovery, when Juno was traversing the 18th hour of right ascension, and was followed by Iris in the 19th.

Several observers have remarked decided variations in the light of this planet which are not accounted for by change of distance from the Earth and Sun, and which there is strong reason to suppose, in a great measure, independent of atmospheric conditions. If Olber's hypothesis with regard to the origin of this zone of planets be correct, these variations may possibly be caused by axial rotation.

The period of revolution of Iris is 3·6844 yrs., or 1346 days, and the corresponding mean distance from the Sun 227,334,000 miles. No approximation to the diameter of the planet has yet been obtained.

FLORA.

Continuing the plan of observation already described, the author noticed at 11 P.M. on the 18th of October, 1847, an object resembling a star of the eight or ninth magnitude, which had not been previously visible in the position it then occupied. Its right ascension was 5h. 3m. 39s., and its north declination 14° 4′, it was therefore situate in the constellation Orion, or on the borders of Orion and Taurus. Clouds covered the heavens soon afterwards, and precluded further observation until about 3 A.M. on the 19th, when the micrometer speedily revealed a direct motion in right ascension of about two seconds of time in the four hours elapsed since the discovery, and the declination had also changed a little, the object having slightly approached the equator. The alteration of position was quite large enough to prove the nature of the stranger, and it was announced to astronomers on the same morning as the ninth member of the group of small planets, not far from its stationary point. At the suggestion of Sir John Herschel, the new planet received the name *Flora*, and a flower, the "Rose of England," was chosen as the symbol. The period of revolution is shorter than that of any other of her companion-planets, being about 1193 days only. Flora, therefore, comes after Mars in order of mean distance from the Sun, and approaches nearer to the Earth than the rest of the group to which she belongs. The semi-axis major of the orbit, or mean distance, is 209,826,000 miles. The planet is somewhat ruddy, but without any hazy appearance, such as might be supposed to arise from an extensive atmosphere. On more than one occasion, when viewing it under high magnifying powers, the author has fancied he could perceive a measurable disc, but cannot place implicit confidence in the observation. At the time of the opposition in 1847, the light of the planet was equal to that of a star of the eighth magnitude. Flora and Iris were discovered with an equatorially-mounted achromatic telescope, having an object glass of seven inches aperture, and about eleven feet focal length; the power employed being about 45.

METIS.

In the year 1848 another member of this interesting group was brought to light by Mr. Graham at the private observatory of Markree Castle, Ireland, under the direction of Mr. Cooper. Having formed a chart of the stars near the equator in the 14th hour of right ascension, on a more extended scale than that of the Berlin charts, he remarked on the 25th of April a star of the tenth magnitude in a position where none had been visible before, and noted it down for re-examination. On the following evening this object was found to have retrograded one minute, thus leaving no doubt of its planetary nature. On the 27th the discovery was announced to several astronomers in this country and on the Continent, and speedily became generally known through the circulars issued by Professor Schumacher. The position of the planet at the time it was first detected, was in right ascension 14h. 56m. 38s., and south declination 12° 35′, or in the zodiacal constellation Libra.

The name selected for this planet is *Metis*, with an eye and star for a symbol.

We are indebted to Mr. Graham, the discoverer, and to Dr. Luther, of Berlin, for our knowledge of the form of the orbit. Their calculations assign a periodic time of 1347 days, or 3·686 years, the corresponding mean distance from the Sun being 227,387,000 miles.

The planet is fainter than either of the two discovered in England in the previous year, and a good telescope will be required to show it well.

HYGEIA.

On the 12th of April, 1849, Dr. Annibal de Gasparis, assistant astronomer at the Royal Observatory at Naples, while comparing Steinheil's chart for hour xii. of right ascension with the heavens, perceived a star of between the ninth and tenth magnitude in a position which he had found vacant at previous examinations of this region. Unfavorable weather prevented his observing it on that evening, but on the 14th he ascertained that it had sensibly changed its place, and was, therefore, a new planet, the amount of its motion showing that it must belong to the group of small planets between Mars and Jupiter. The position on the 14th was in A. R. 182° 59′ N. P. D. 97° 28′. The discovery was announced to astronomers generally by M. Fabri Scarpellini, Secretary of the *Correspondenza Scientifica* at Rome, and Professor Schumacher as usual issued his printed circular from Altona on the 11th of May. Professor Capocci, Director of the Neapolitan Observatory, named the new planet "Igea Borbonica;" but it is universally termed *Hygeia*, the unnecessary appendage "Borbonica" being dropped, as was the case with the complimentary additions to the names of the planets of Piazzi and Olbers.

The elements of Hygeia are not yet very exactly known. We are certain, however, that the mean distance is greater than in the orbit of any other member of this group, the best calculations making it about 300,322,000 miles, corresponding to a revolution in 5·594 yrs., or 2044 days. Between the mean distances of Flora and Hygeia, those of all the other small planets are included.

At no time since the discovery has Hygeia equalled in brightness an ordinary ninth magnitude, consequently good telescopes are required to observe her well. We know nothing at present respecting her diameter.

PARTHENOPE.

On the occasion of the discovery of Hygeia, it appears Sir John Herschel had suggested that *Parthenope* would be a very appropriate name as memorializing the site of the discovery; the nymph having given her name to the city now called Naples. Signor de Gasparis states that he used his utmost exertions to realize for Sir John Herschel a Parthenope in the heavens, and his endeavors were crowned with success on the 11th of May, 1850. On the evening of that day he found an object shining as a star of the ninth magnitude in A. R. 230° 22′, and N. P. D. 100° 35′, which he soon ascertained to be a new planet from its motion in right ascension. He gave immediate notice of his discovery, and before the end of the month the planet was observed at many of the European observatories.

The elements of Parthenope have been calculated by several astronomers, but it is not to be expected that we can know them with any degree of accuracy in so short a time after the first detection of the planet. The latest results indicate a mean distance of 233,611,000 miles, and a corresponding period of 1401 days, or 3·838 years.

VICTORIA.

On the evening of the 13th of September, 1850, the author noticed a star of the eighth magnitude in the constellation Pegasus, near another smaller one frequently examined on previous occasions, without any mention being made of its bright neighbor. Its peculiar bluish light satisfied him at once as to its planetary nature, and the micrometer was introduced to ascertain the difference of right ascension between the two objects, and to obtain satisfactory proof of the discovery of a new planet,—for the eleven known members of the extra-zodiacal group were all in different positions, according to calculation. In less than an hour the brighter star had moved westward about two seconds of time, so that no doubt could be entertained in respect to its nature and position in the Solar System; this amount of retrograde motion in an hour being such as a planet of the group between Mars and Jupiter would exhibit in the direction of the stranger.

The name selected for the *twelfth* member is *Victoria*, which we think is perfectly consistent with conventional usage amongst astronomers in reference to small planets; the rule hitherto followed requiring a female name, taken either from the Greek or Roman Mythologies. The name has been readily accepted, as far as we are aware, by all the principal astronomers of Europe. The symbol is a star surmounted by a laurel branch.

The period of Victoria is 1302 days, and her mean distance from the Sun 222,373,000 miles, which places her between Flora and Vesta. The orbit is more eccentrical than that of Flora, though less so than that of Iris. At her maximum brilliancy she will be seen with very small optical power, resembling a bluish star of the eighth magnitude; at other times, when her distance from us is much greater, the light will hardly exceed that of a star of the eleventh class.

EGERIA.

The discovery of Victoria (which afforded the first instance on record of the detection of three planets by the same observer), was quickly followed by that of another small planetary body by Dr. Annibal de Gasparis, at the Royal Observatory, Naples. In this case, a star map was not the means of bringing to light the little wanderer, but its existence was indicated by a series of observations in zones of declination, which the able and energetic astronomer had instituted for the express purpose of finding new planets. On the 2d of November, 1850, Dr. Gasparis met with the *thirteenth* member of the extra-zodiacal group, in the constellation Cetus, or in that region of the heavens which Olbers had considered the most convenient for his periodical examinations, since the nodes of Ceres, Pallas, &c., appeared to lie in that direction. This planet was much fainter than Victoria, and probably, in its most favorable position in respect to the earth, it will not excel in intensity of light a star of the ninth magnitude.

M. Le Verrier, having been deputed by the discoverer to name his prize, has proposed *Egeria*, the councillor of Numa Pompilius. The period of a sidereal revolution is 1505 days, and the mean distance from the Sun 244,940,000 miles. The orbit is more inclined to the plane of the ecliptic than that of any other planet, Pallas alone excepted; its eccentricity is very nearly the same as in the orbit of Vesta.

IRENE.

The next member of the group of small planets in the order of discovery was found by the author in the constellation Scorpio, on the 19th of May, 1851, and four days later by Dr. Gasparis, at Naples. It appeared like a star of between the eighth and ninth magnitudes, with a full blue light, and seemed to be surrounded by a faint nebulous envelope or atmosphere, which could not be perceived about stars of similar brightness. The nature of this object was satisfactorily established within half an hour from the first glimpse of it on the 19th of May; repeated examinations of the vicinity on previous occasions, having indicated no star in the position of the stranger. At the recommendation of Sir John Herschel the new planet was named *Irene*, in allusion to the peace prevailing at the time in Europe; the symbol proposed being a dove with an olive branch and star on head.

The discovery of this planet is too recent to allow of any exact knowledge of its path in space, but the most trustworthy calculations hitherto published assign it a mean distance of 246,070,000 miles, and a corresponding period of revolution of 4·15 years.

EUNOMIA.

On the night of July 29, 1851, another small planet was discovered by Dr. Gasparis at Naples, in hour xviii. of right ascension, a little below the ecliptic. It shone as a fine star of the ninth magnitude; but owing to its low situation in the heavens, was not so generally observed during its first apparition as some of the other newly-found bodies. Dr. Gasparis named his planet *Eunomia*, who, in classical mythology, was one of the Seasons, a sister of Irene.

The period of Eunomia is 1574 days, or 4·308 years, and her mean distance from the Sun is about 252,300,000.

We have already alluded to the near approximation of the orbits of the small planets at the points of mutual intersection, a circumstance which induced Olbers and many other astronomers to consider these bodies as the fragments of a large planet formerly revolving at about the same mean distance from the Sun, which had been shivered into pieces by some great internal explosion or an external shock. The idea of the German astronomer has been so strongly countenanced by the discoveries of the last five years, that we cannot fairly reject it until another theory has been advanced which would account equally well for the peculiarities observed in this zone of planets, however unwilling we may be to admit the possibility of such tremendous catastrophes, and notwithstanding the great difference in the mean distances of Flora and Hygeia, the innermost and outermost of the zone. Yet it is singular that this group appears to separate the planets of small mass from the greater bodies of the system, the planets which rotate on their axes in about the same time as the Earth, from those which are whirled round in less than half that interval, though of ten times the diameter of our globe; and it may yet be found that these small bodies, so far from being portions of the wreck of a great planet, were created in their present state for some wise purpose, which the progress of astronomy in future ages may eventually unfold.

CHAPTER IX.

JUPITER. ♃

JUPITER is the next planet in order of distance from the Sun and the largest in the system, presenting a bulk more than twelve hundred times greater than that of the Earth. He revolves round the Sun in an orbit but slightly inclined to the plane of the ecliptic, at a mean distance of 495,817,000 miles, in a period of 4332 days, or a little less than twelve of our years. Owing to the eccentricity of the orbit, the planet is nearer the Sun by 47,760,000 miles when its heliocentric longitude is about 11° than when it is situated in the opposite point of the ecliptic, or the radius-vector varies in length between 471,937,000 miles and 519,697,000 miles. The apparent diameter of Jupiter is about 47″ at the oppositions, and 30″ or rather more, near the times of conjunction. The real mean diameter is 88,780 miles, according to the observations of Professor Struve, but the difference between the polar and equatorial diameters is considerable, and will strike the eye the moment the planet is seen in a telescope under proper magnifying power. The most recent measures make the ratio of the polar to the equatorial diameter as 947 to 1000. Professor Struve considered it much more unequal, and his numbers would assign 92,130 for the equatorial, and 85,430 for the polar diameter. The mean circumference of the planet exceeds 2,789,000 miles.

On examining the surface of Jupiter with telescopes, we see no appearance of regular continents or seas as on the surface of Mars; but dark streaks, or, as they are termed, *belts*, are found to cross his disc, presenting similar forms to some of the modifications of cloud in our own atmosphere. Occasionally these belts retain nearly the same form and positions for months together, while at other times they undergo great and sudden changes, and, in one or two instances, have been observed to break up and spread themselves over the whole disc of the planet. Generally there are two belts much more strongly marked than the rest, and retaining a higher degree of permanence, one situated a little north and the other a little south of the planet's equator. The prevailing opinion amongst astronomers in reference to the nature of these phenomena is, that they are produced by disturbances in the planet's atmosphere, which occasionally render its dark body visible, and, as the belts are found to traverse the disc in lines uniformly parallel to Jupiter's equator, we are naturally led to the conclusion that these disturbances are connected with the rotation of the planet upon its axis, which, as we shall presently see, is performed with wonderful rapidity. The belts were first observed by Zuppi and Fontana, at Naples, soon after the invention of the telescope.

In July, 1665, Cassini of Paris remarked a black spot of considerable apparent magnitude on the upper edge of the southern belt of Jupiter, which remained visible two years. This spot, or one supposed to be identical with it, has repeatedly appeared since the time of Cassini, but at very irregular intervals. On the 11th of December, 1834, a remarkable spot was discovered on the northern belt by the observers at Cambridge. It was black and well defined; about two thirds of its breadth was above the belt, and one third upon it. On the 13th of the same month two spots were distinctly visible on the north belt, both well defined, but the following or eastern one (that of the 11th) being the larger. For some time these spots remained wholly unchanged, but, in 1835, they gradually faded away; the principal one was seen at Cambridge for the last time on March 19th. Cassini noticed that the spot in July, 1665, appeared to traverse the disc from east to west: it was very conspicuous near the centre of Jupiter, and gradually faded away as it approached the western limb: the motion seemed quickest when the spot was near the centre, and became slower towards the edge of the planet. Hence he inferred that it adhered to the surface and was carried across the disc by the rotation of Jupiter upon his axis, an hypothesis which would account fully for the appearances observed. By closely watching the movements of the spot, the same astronomer ascertained that the time of revolution of the planet was about 9h. 56m. The spots of 1834–5, were carefully observed at Cambridge, and by the German astronomers M.M. Beer and Mädler. Mr. Airy, on discussing the observations taken at Cambridge, deduces 9h. 55m. 21·3s. for the time of diurnal rotation, and M. Mädler 9h. 55m. 29·9s. This enormous globe, exceeding in diameter that of the earth eleven times, is, therefore, whirled round upon its axis in less than ten of our mean solar hours. A particle at the equator of Jupiter must consequently move with a velocity of more than 450 miles per minute, and it is easy to conceive how materially this rapid rotation would contribute to the generation of heat upon the surface of the planet, and in other ways tend to compensate for the effects we might expect to follow from the great distance of Jupiter from the Sun, which, without some alleviating agency, would appear to render the planet an unfit abode for sentient beings. But it is further worthy of remark that the axis of rotation is very slightly inclined to the plane of the orbit, a circumstance which would produce one constant climate at any particular spot upon the surface of this immense globe, the regions in the immediate neighborhood of the poles alone excepted. The inclination of Jupiter's equator to his ecliptic, *i.e.*, to the plane of his orbit, is 3° 4′ 5″, and the ascending node of the equator in 1850, is in longitude 314° 45′.

Jupiter is attended by four satellites or moons, which were discovered by Galileo, at Padua, on the 8th of January, 1610. There has been a good deal of disputation concerning the claims of other astronomers to the honor of having first observed these interesting objects: our countryman, Harriot, was held to be the discoverer by Baron de Zach, who was certainly mistaken, as the facts brought to light respecting Harriot, by Professor Rigaud, have undoubtedly proved. Simon Marius asserted positively, in his *Mundus Jovialis*, that he had remarked the satellites on the 29th of December, 1609, at Ansbach, in Bavaria, a point which was warmly disputed by Galileo, who termed Marius the " usurper of the system of Jupiter." M. Delambre considered that the *Mundus Jovialis*, so far from establishing the claim of Marius to the discovery, bore internal evidence to the contrary. At this distance of time it is safest, in forming an opinion, to be guided by the publications of each astronomer, and it is quite certain that the announcement of the existence of four Jovian satellites, by Galileo, in his *Nuncius Siderius*, preceded the first notification by Marius nearly two years. The earliest observations of Harriot date October, 1610, or nine months later than those of Galileo. It is quite possible that the Italian and German astronomers may have discovered the satellites about the same time and entirely independently of each other, but the general opinion at the present day is in favor of priority on the part of Galileo.

The newly discovered secondary planets were named *Sidera Cosmica*, or *Medicea*, by Galileo, in honor of his patron, Cosmo de Medici, and to distinguish them from one another, he proposed to give them the family names of the ruling house at

Florence. Simon Marius, on the contrary, suggested mythological names—Io, Europa, Ganymede, Callisto. Modern astronomers, however, have not thought it necessary to resort to any such special nomenclature, but identify the satellites as the first, second, third, and fourth, in order of their distance from the primary.

The *first* satellite presents an apparent diameter of 1·015″ at the mean distance of Jupiter from the Sun, whence we find the real diameter to be 2440 miles. Its average distance from the centre of the planet is 278,500 miles, and the period of a sidereal revolution is 1d. 18h. 27m. 33·50s.

The *second* satellite appears under a diameter of 0·911″, or its real diameter is 2190 miles; it is the smallest of the four, according to the observations of the eminent Russian astronomer, Professor Struve. The mean distance from the planet is 443,300 miles, and the time occupied in one sidereal revolution is 3d. 13h. 14m. 36·4s.

The *third* satellite is seen under an angle of 1·488″ at the mean distance of Jupiter, whence its true diameter is 3580 miles, considerably greater than that of the planet Mercury. It is the largest of the satellites, as the measures of Schröter and Struve have shown. The distance from the centre of the primary is 707,000 miles, and the time of a sidereal revolution 7d. 3h. 42m. 33·4s.

The apparent diameter of the *fourth* satellite is 1·273″, and its real diameter 3060. The distance from the planet amounts to 1,243,500 miles, corresponding to a sidereal revolution of 16d. 16h. 31m. 49·7s.

The satellites shine with the brilliancy of stars of between the sixth and seventh magnitude; but owing to their proximity to the planet, which overpowers their light, they are invisible to the naked eye. There are some few instances on record where persons possessed of extremely good vision have fancied they could perceive one of these little moons without optical aid, but on applying the telescope, it has been found that *three* of the satellites have approached so near together as to appear like one—just perceptible to the unassisted eye. A very small optical power suffices to exhibit the satellites clearly as stars, but to see them with measurable discs requires the very best instruments yet constructed, and high magnifyers.

If we adopt the values of the diameters resulting from the observations of Professor Struve, we shall find that, as viewed from the equator of Jupiter, the first satellite would appear by far the largest, its apparent diameter being greater than that of our Moon, or about 36′. The second and third would seem to be 19′ in diameter, while the fourth would subtend an angle of only 9′, or about one quarter of the apparent diameter of the first. The second and third satellites might, therefore, be totally eclipsed by the first, and the fourth by all the others. The diameter of the Sun, as seen from Jupiter, in perihelion, is 6½ minutes of arc, so that total eclipses or occultations of the Sun are of common occurrence to the equatorial inhabitants of the planet, some portion of the surface necessarily suffering an entire deprivation of the solar light every time the first, second, or third satellite passes through the interior part of its orbit.

The configurations of the satellites of Jupiter are continually varying: sometimes their attendants are all situated on one side of the planet, though more frequently one, at least, is to be found in each direction. Some few instances are on record when all four have been invisible for a short time; such was the case on 2d November, 1681, old style, according to an observation by Molyneux, and the same phenomenon has been witnessed on more than one occasion during the present century. It is not so rare an occurrence to find only one satellite visible. The amateur astronomer will find the tables of configuration of the satellites, given in our *Nautical Almanac* of great service to him in fixing upon the proper times for viewing these little moons in their most interesting positions relative to the primary.

Sir William Herschel, by a long series of observations upon the satellites, inferred that they rotate upon their axes in the time of one *synodical* revolution round Jupiter, thus presenting an analogy to our own satellite. He was led to this conclusion on remarking the great changes in the relative brightness of the satellites in different positions, which were found to follow such a law as was reconcilable only with this hypothesis. The orbits of the satellites, as seen from the Earth, are projected into very eccentrical ellipses in most situations; but when our globe is in the line of nodes of any satellite its apparent path is a straight line. The real paths of the first and second satellites do not differ sensibly from circles: those of the third and fourth are very slightly elliptical. The line of apsides of the *third* revolves in about 137 years, and that of the *fourth* in about 516 years. The line of nodes of the three exterior satellites revolve in a *retrograde* direction, as is the case with the nodes of the lunar orbit; the period for the *second* is 30 years, for the *third* 140, and for the *fourth* 520 years.

The eclipses and occultations of the satellites, and transits of the satellites and their shadows, over the disc of Jupiter, have long attracted considerable attention, as well on account of the interest attaching to their phenomena, as for their utility in practical astronomy.

The shadow of the planet extends into space through a distance of more than half the interval which separates the Sun from the Earth; and, in consequence of the smallness of the orbital inclinations of the satellites, the *first*, *second*, and *third* suffer an eclipse in every revolution round the primary; the fourth sometimes escapes altogether, or may suffer a partial eclipse only, a circumstance arising from the plane of its orbit being rather more inclined than with the others. The first entrance of a satellite into the shadow of Jupiter is called the *immersion;* when it is just clear of the shadow, the *emersion* is said to take place. Soon after the conjunction of the planet with the Sun, the shadow is projected on its western side, and at this time, both the immersions and emersions of the *third* and *fourth* satellites may be observed, and occasionally those of the *second*, but the emersions only of the *first* are visible, since it is so near the planet as to enter into the shadow behind the disc. About the oppositions, the immersions and emersions take place very near the limb of Jupiter: as he moves onward towards the Sun's place, the shadow is projected on his eastern side; the immersions only of the *first* satellite are then visible, because on leaving the shadow it is occulted by the planet, while the immersions and emersions of the *third* and *fourth* satellites, and, more rarely, those of the *second*, may be observed to the east of the planet.

One of the most important results to which the observations of the eclipses of Jupiter's satellites have conduced, is the detection of the measurable velocity of light, due to Olaus Römer, a Danish optician and astronomer, about the year 1675. It had been remarked that the calculations always gave the times of the eclipses with errors of contrary signs when Jupiter was nearest to, and farthest from, the Earth. In the former case the eclipse occurred *before* the computed moment; in the latter, the predicted time was invariably too early. These circumstances led Römer to suspect that the anomaly arose from the light having a greater distance to travel when Jupiter was in apogee than when he was nearest to the Earth, or about the times of opposition, and, on comparing the observations together, it was inferred that light actually travelled at the rate of nearly 200,000 miles in a second, or that it would require 16m. 36s. to traverse the diameter of the Earth's orbit. The corrections applied to the observed times on this hypothesis rendered them perfectly accordant with one general theory of the satellites' movements, which before had failed to prove satisfactory. The eclipses are highly useful, also, for determining approximate differences of longitude between distant stations on the Earth's surface. We say *approximate*, because there are difficulties in the way of their exact observation, which preclude the possibility of obtaining very accurate results from them.

The theory of the motions of Jupiter's satellites has been fully developed by the celebrated mathematician, Laplace, and was published in his *Mécanique Celeste.* It is beyond the plan of this work to enter into any details on so complicated a subject; but there are one or two points in connection with the relative movements of the satellites which deserve especial notice. It appears that this singular relation subsists between the mean motions of the three interior ones—the mean angular velocity of the first satellite added to twice that of the third gives a sum exactly equal to three times that of the second, wherefore, if three times the mean longitude of the second satellite be subtracted from the mean longitude of the first, *plus* twice that of the third, the remainder will be always constant, or as we find from observation, 180°. This curious arrangement has a most important effect in the system of the planet. It is thus seen, that for a long period to come, if the first and third satellites present their unilluminated sides to the planet, or are undergoing eclipse simultaneously, the second must be so situated as to afford considerable light to its inhabitants, and the same will occur in regard to the third satellite, if the first and second are in such positions as to reflect no light on the planet.

The occultations of the satellites, which take place when they pass behind the disc of the planet, generally require much more powerful instruments for their satisfactory observation than the eclipses. With a telescope of adequate power, we may trace the gradual disappearance of the satellite, from the first contact with the limb of the planet to its final obscuration behind the disc, and, as viewed with such an instrument, these phenomena are highly interesting. The occultations of the *fourth* satellite are usually visible throughout, *i. e.* from disappearance to re-appearance; those of the *third* also are frequently observable; but it happens much more rarely that the complete phenomenon can be observed in regard to the *second* satellite, while the immersion and emersion of the *first* can only be visible a day or two before or after the opposition of Jupiter, as at all other times either the immersion or emersion must happen while the satellite is obscured in the planet's shadow. Thus it most usually occurs, that from conjunction to opposition, the *re-appearances* only of the first and second satellite can be observed, and the *disappearances* only from opposition to conjunction.

Perhaps the most interesting of all the phenomena of the Jovian system, are the transits of the satellites and their shadows over the disc of the planet, which occur when they are moving from east to west. With powerful telescopes the satellites are seen projected upon the disc, sometimes as lucid spots sensibly brighter than the general surface of the primary; while, on other occasions, they have been observed as dark spots,—which can only be accounted for by admitting that such spots really exist on the satellite itself, since the illuminated part of their disc must be turned towards the Earth at these times. Schröter and Harding noticed these varied appearances repeatedly; and, so long ago as the middle of the seventeenth century, Cassini had discovered that the satellites were sometimes visible during their passage across Jupiter's disc, though he could perceive no trace of them on other occasions. Professor Bond, of Cambridge, U. S., has detailed some curious observations made by him with the great telescope under his direction, on the transit of the *third* satellite and its shadow. On the 28th of January, 1848, it was seen as a *black spot*, well defined, and again on the 11th of March. On the 18th of the latter month it entered upon the disc as a very bright spot, more brilliant than the surrounding surface: twenty minutes later it had decreased in brightness, so as to be hardly perceptible, and in a few minutes a dark spot appeared suddenly in its place, and was seen nearly two hours and a half. It was conspicuous enough to be easily measured with a micrometer, being perfectly black and nearly round. This spot is stated to have been observed *on* the satellite. The same astronomer has also seen the first and fourth satellites like dusky spots projected on the disc of Jupiter, and the same appearance has been repeatedly noticed in this country during the transits of the fourth satellite. The shadows are uniformly black and larger than the satellites themselves: they are consequently more readily perceived, though powerful instruments are required for the proper observation of either satellites or shadows at these times. Before the opposition of Jupiter to the Sun the shadow *precedes* the satellite, but *follows* it after the opposition.

The mass of Jupiter is much greater than that of any other planet, and an accurate knowledge of it is therefore of considerable importance in astronomy. We cannot predict the true positions of the small planets without taking into account the influence of Jupiter upon their movements, and this action is very sensible for some of the larger bodies of the system. Newton, Lagrange, and Laplace, considered the mass of the Sun to be to that of the planet nearly as 1067 to 1. Bouvard, in his Tables of Jupiter, assumes it as 1070 to 1. The calculations of Professor Encke in 1826, relative to the disturbances produced by the planet on the elements of Vesta, indicated the necessity of a very sensible increase on the received mass, which appeared to be more nearly as 1050 to 1, a result confirmed in the same year by the computations of M. Nicolai of Manheim, relative to another of the minor planets—Juno. The most accurate method of determining the mass of Jupiter, viz., by observing the elongations of his fourth or most distant satellite, had not been put into practice at this time with such improved means as modern observatories afford; but, about the year 1834, Mr. Airy undertook a series of observations at Cambridge, which established the ratio of the masses, as 1048 to 1. The latest researches on this subject are those of Professor Bessel of Königsberg, who, in an extensive course of observations on the satellites, concluded that the Sun's mass exceeds that of Jupiter 1047·87 times, and this result is now very generally adopted.

The most ancient observation of Jupiter which we are acquainted with is that reported by Ptolemy in Book x. chap. 3, of the Almagest, and considered by him free from all doubt. It is dated in the eighty-third year after the death of Alexander the Great, on the 18th of the Egyptian month *Epiphi*, in the morning, when the planet eclipsed the star now known as δ Cancri. This observation was made on the 3d of September, B.C. 240, about 18h. on the meridian of Alexandria.

A similar occultation of a star by Jupiter was witnessed by Pound on the morning of the 22d of November, 1716, when α Geminorum, or, as it is more usually termed, Castor, was eclipsed by the planet.

The tables in use at present for predicting the places of this planet were calculated by M. Bouvard of Paris, on the theory of Laplace. They are quite exact enough for all practical purposes; but we have the means of improving them when necessary.

Very elaborate tables for predicting the phenomena of Jupiter's satellites have been calculated by several astronomers. Those now employed in the computation of the nautical ephemerides of Great Britain, France, and Prussia, were constructed by the late Baron Damoiseau, and published by the French Board of Longitude in 1836.

CHAPTER X.

SATURN. ♄

THE next planet in order of distance from the Sun is Saturn, one of the most interesting of the heavenly bodies, as presenting an extraordinary manifestation of creative power and wisdom. He is attended by no fewer than eight satellites, and is moreover surrounded by several luminous *rings*, which must reflect considerable light on some parts of the planet's surface.

The sidereal revolution of Saturn occupies about 10,759 mean solar days, or 29½ of our years. His mean distance is 909,028,000, but in consequence of the eccentricity of his orbit the distance from the Sun varies between 857,986,000 miles and 960,070,000 miles, or the planet is nearer the Sun by more than 102,000,000 miles, when it is situate in 89° longitude, where the perihelion point falls, than when it is located in the opposite part of the ecliptic.

The figure of Saturn appears to be a perfect ellipse, though it has long been supposed to resemble a parallelogram, " with the four corners rounded off, so as to leave both the equatorial and polar regions flatter than they would be in a regular spherical figure." This motion was first advanced by Sir W. Herschel after examining the planet in reflecting telescopes of ten, twenty, and forty feet focal length. Actual micrometric measures by Professor Bessel in 1833 gave results unfavorable to this deviation from an elliptical outline, and a recent series of observations at our Royal Observatory, by the Rev. R. Main, has fully confirmed the measures of the German astronomer. It may be stated, therefore, that the form of Saturn does not deviate visibly from an ellipse, the major axis of which, in the direction of the planet's equator, subtends an angle of 17·053″ at Saturn's mean distance, while the minor axis is seen under an angle of 15·394″. The compression is thus found to be 1-10·28th or the equatorial diameter is to the polar as 1000 to 903. These numbers depend on Professor Bessel's observations with the grand heliometer at Konigsberg. The Greenwich measures make the ellipticity 1-9·23d, or one tenth greater than Professor Bessel's. Many years ago Mr. Airy showed that the Herschelian form of Saturn could not be accounted for by theory; and it is understood that Sir John Herschel, after a consideration of the results obtained at Greenwich, has fully admitted the necessity of giving up the idea which he had held in common with Sir W. Herschel, respecting the unusual figure of the planet. The distortion is evidently owing to some optical cause, probably connected in some way with the interference of the ring; yet Professor Struve thought the planet Jupiter exhibited a similar deviation from an elliptic outline, until he had convinced himself, by careful measurement, that such was not really the case. The true diameter of Saturn at his equator, by a mean of the most accurate and recent observations, is about 77,230 miles; and if we adopt a mean value for the polar compression from the measures at Konigsberg and Greenwich, we shall find the diameter in the direction of the poles of Saturn to be about 69,300 miles. The planet is consequently nearly ten times the diameter of the Earth, and exceeds it in bulk nearly one thousand times.

Though belts are frequently observed with good telescopes upon the surface of Saturn, they are far more indistinct than those of Jupiter. *Spots* are of rare occurrence. One was seen by Sir W. Herschel in June, 1780, for several days, and M.

Schwabe of Dessau saw one on the 8th of November, 1847, on the southern edge of a dark belt, somewhat to the north of the equator, projecting a little into the bright central zone, which was sufficiently distinct to allow of micrometrical measures of distance from the limbs of the planet. In 1793, Sir W. Herschel saw a quintuple belt, and availed himself of its visibility to determine the time of axial rotation of Saturn, which had not been previously ascertained. This he accomplished by very frequent and careful examination of the appearance of the belts, remarking when it was best seen, how far the belts were separated, and making other observations on their figure, &c.; from a combination of which he concluded that the same configuration recurred after 10h. 16m. 0·4s., which he inferred to be the time occupied by Saturn in one rotation upon his axis, or the length of a Saturnian day. This great astronomer satisfied himself that the belts had undergone no relative change of any consequence during the hundred revolutions through which he watched them, and further concluded that the error of the period he had deduced must be very much less than two minutes. The axis of Saturn is inclined to his orbit 63° 10′, or 61° 50′ to the plane of the ecliptic. His seasons, therefore, are probably more diversified than those of Jupiter. Sir William Herschel considered he had sufficient evidence to show that the planet is surrounded by a very dense atmosphere, an inference drawn not only from the changes in the number and appearance of the belts from year to year, but depending also on observations of the closer satellites, when about to be occulted by the planet; the nearest satellite was observed to hang upon the disc about twenty minutes, and the next satellite about fifteen minutes longer than they should have done were there no refraction. Periodical changes of color in the polar regions of Saturn, and the appearance of large dusky spaces of a cloudy character in these parts, which Sir W. Herschel repeatedly noticed, were likewise thought to strengthen the supposition of the existence of an atmosphere of considerable density. The general color of the planet's surface is a very pale yellow or yellowish white.

When Galileo turned his newly constructed telescope upon this planet, he saw that the figure was not round as in the case of Jupiter, but at first conceived it to be oblong, though on further examination he thought the planet consisted of a large globe, with a smaller one on each side. Continuing his observations, he remarked that this appearance was not constantly the same, the appendages on each side of the central globe gradually diminishing until they vanished entirely, and left the planet nearly round, without anything extraordinary about it. He informed Kepler of these circumstances in November, 1610. Hevelius observed Saturn very attentively about the year 1655, and described the various phenomena which had been noticed by Galileo. Huyghens, who possessed telescopes of greater power than those of the Italian astronomer, was the first who gave a correct explanation of these varied appearances, attributing them to a luminous ring surrounding the globe of Saturn, the greater apparent diameter of which he considered to be to that of the globe as nine to four. The discovery of the Ring of Saturn was announced by Huyghens in his *Systema Saturnium*, a small work published at the Hague in 1656; and many drawings of the supposed figure of the planet, taken before the improvements in optical means revealed the true nature of the phenomena which had attracted the attention of Galileo, are appended to this account. Huyghen's telescopes, though much better than those of his predecessors, were yet of insufficient power to exhibit all the phenomena of the ring. The first mention of a division separating it into two concentric rings is usually supposed to be due to the celebrated Dominic Cassini, astronomer at the Observatory of Paris, soon after the foundation of that establishment by Louis XIV., or in the year 1675. But it is on record that two English amateurs, Dr. Ball and Mr. W. Ball, of Minehead, North Devonshire, had noticed the duplicity of the ring in October, 1665, giving them a priority of ten years in this interesting discovery.

The ring of Saturn may be described as broad and flat, and is situated precisely in the plane of the planet's equator; it is therefore inclined to the ecliptic at an angle of 28° 10′ 27″, and intersects it in longitude, 167° 31′ 52″ and 347° 31′ 52″, which points are called the *ascending* and *descending* nodes of the ring respectively. It is owing to this inclination of the plane of the ring to the ecliptic and to the orbit of the primary, that this appendage is sometimes observed as a broad ellipse, and at others as a straight line, but just discernible in the most powerful telescopes hitherto constructed. For when the heliocentric longitude of Saturn is either 167° 32′, or 347° 32′, the plane of the ring passes through the Sun, which consequently can only illuminate the thin edge; and it is for this reason invisible to ordinary telescopes. It will disappear also when the plane passes through the Earth, or when the Sun shines on that part of the surface which is turned from us. Generally the ring *disappears* twice, for the motion of Saturn is so slow in comparison with that of the Earth, that our globe passes twice through the plane of the ring before it is carried past the plane of the ecliptic. Thus, in 1848, after the north surface had been visible nearly fifteen years, the ring became invisible on April 22d, when the Earth was in its plane, and the Sun above it: it reappeared on the 3d of September, when the Sun was in the same plane, passing south to the same side as the Earth; and consequently, when the southern illuminated surface was turned towards us. On the 12th of the same month, the Earth passed to the northern side, while the Sun still shone on the southern surface, and the ring therefore disappeared a second time. It continued to present to us its unilluminated surface until the 18th of January, 1849, when the Earth passed to the southern side of the plane of the ring, which had been turned towards the Sun since the 3d of September. We shall continue to see the *southern* surface until a few months before Saturn arrives in the opposite part of his orbit, or at the ascending node of the ring, which will take place towards the close of the year 1861, and after the occurrence of similar phenomena to those we have just described, the *northern* surface of the ring will become visible, and continue so until the year 1877, which may witness a series of disappearances and re-appearances similar to those of 1848 and 1849. After the plane of the ring has passed through the Sun, the surface illuminated by him becomes broader and broader until Saturn is distant 90° from the nodes on the ecliptic, or is situate in longitude 257·5°, or 77·5°, or about the middle of Sagittarius and Gemini, in which positions we see the rings most open, the minor axis being almost precisely half the greater one. These times are the most favorable for the examination of the division of the ring, which may then be traced nearly all round, the only interruption being caused by the globe of Saturn. The belts also appear at their greatest curvature, and the shadow of the ring upon the surface of the planet, and of the planet itself upon the ring are distinctly visible in good telescopes. The apparent major axis of the ring at Saturn's mean distance is about 39″, and the diameter of the globe about 17·5″, consequently the surface of the ring covers either the north or south pole of the planet for some little time, about the periods just referred to, since, as we have observed, the minor axis is then very nearly equal to half the major axis, or is nearly 19·5″. The opposite pole is, then, for the same reason, projected upon the surface of the ring.

We have already noticed the discovery in England and France of the *double* ring of Saturn during the latter half of the seventeenth century, and we shall now describe in some detail the observations which have been made by various astronomers tending to prove that the Ring is at least a *triple* one, and possibly may be more correctly termed *multiple.* M. Lalande mentions, in the last edition of his "Astronomie," that the well known English optician, Mr. Short, had informed him orally of his having noticed the *outer* ring of Saturn divided by several black lines: this was with a telescope of twelve feet focal length. M. Laplace, in his "Theory of Saturn's Ring," published in the memoirs of the Paris Academy for 1787, mentions the same circumstance, and infers that the outer Ring must be formed of several smaller ones nearly in the same plane,—that of the planet's equator; in which situation he concluded they are retained by the attraction of the equatorial parts, which, as we have already seen, are more prominent than the polar regions. M. Lalande gives a figure representing the appearance noticed by Mr. Short. Both M. Delambre and M. Biot, in their treatises on Astronomy, refer to these divisions; but it does not appear that they had any further evidence than is furnished by M. Lalande. The observations of Mr. Short were probably made about the year 1760. In a paper read before the Royal Society of London in December, 1791, Sir W. Herschel mentions having seen, between the 19th and 26th of June, 1780, "a second black list" upon the ring, close to the *inner* side, and on the preceding arm only. This appearance was visible with three reflecting telescopes, and could hardly arise, therefore, from optical illusion. On the 29th of the same month, no such division of the inner ring was perceptible. The visibility of a dark line on one side only, Sir W. Herschel thought might be accounted for by supposing the opening very narrow and the rings eccentric.

In December, 1823, Professor Quetelet, at Paris, noticed the outer Ring of Saturn divided into two, with an achromatic telescope of ten inches aperture. This circumstance is related by Captain Kater in Vol. iv. of the "Memoirs of the Royal Astronomical Society," where he has also given the results of some observations of his own, which tend to prove the existence of such divisions. On the 17th of December, 1825, with a Newtonian reflector by Watson of six inches aperture and forty inches focus, the outer ring "appeared separated by numerous dark divisions, extremely close, one stronger than the rest dividing the ring about equally. The inner ring decidedly had no such appearance." It is added that this phenomenon was noticed only with Watson's Newtonian. On the 16th of January of the following year, Saturn was examined by Captain Kater, with a telescope of the same construction by Dollond; the outer ring was thought to be made up of several, as before mentioned, but it was not so distinct as with the smaller telescope, on December 17th. On the following night, "the outer ring appeared to be made up of several rings," but not very distinctly marked, so that some doubt attached to the observation. On the 22d January, 1828, Captain Kater could see no trace of divisions in the exterior ring, and thence concludes that they are not permanent.

On the 28th of May, 1837, Professor Encke, observing with the great telescope of Fraunhofer at Berlin, not only saw the outer ring of Saturn divided by a black line, but obtained micrometrical measures of the diameter of the division. It was found that the outer diameter of the outer ring was 40·445″, reduced to Saturn's mean distance; the diameter of the new division 37·471″, and the inner diameter of the exterior ring 36·038″. Hence it would appear that the exterior ring is not equally divided. On April 25, Professor Encke had seen the extra division, but could not measure it.

In 1838, M. Dumouchel, Director of the Observatory of the Collegio Romano at Rome, published an account of some new divisions in the ring of Saturn which had been noticed by M. de Vico with the large achromatic telescope of that establishment. Having heard of Professor Encke's observations, M. de Vico took advantage of some very fine nights in the summer of 1838 to scrutinize the appearance of the planet. On the evening of May 29, he very distinctly saw, and showed to several pupils and friends, besides the two principal rings, three other divisions or black lines, the one nearly in the middle of the exterior ring, and two upon the interior one. It is stated that the observations of following days indicated some variation in the number of zones, according as the sky was more or less favorable. About the time of meridian passage, sometimes as many as six rings were noticed, the distinction being such that it was difficult to admit any optical illusion as the cause of the appearance.

M. Schwabe, of Dessau, paid particular attention to the phenomena of Saturn's ring in the summer of 1841, employing in his examinations a six-feet achromatic telescope by Fraunhofer. On July 26th, soon after 9h., Encke's division was seen by glimpses, with powers of about 290 and 360. On August 10th, it was just perceptible on the eastern ansa, and again on the 17th. On September 10th, this division was noticed at the western side. M. Schwabe observed on thirty days; but the extra division was noticed on four occasions only, as above.

In the month of September, 1843, a very satisfactory observation of the division in the exterior ring was made by Mr. Lassell and the Rev. W. R. Dawes, with a nine-feet Newtonian reflector constructed by the former gentleman. On the 7th of that month, the sky at 9 P.M. hazy and the stars dull, the telescope was turned upon Saturn, and under a power of 450 the outer ring was distinctly perceived to be divided into two. The outline of the planet was very sharply defined with this power, and the primary division of the ring was very black, and steadily seen all round the southern side. When this was most satisfactorily observed, a dark line was pretty obvious on the outer ring. Mr. Dawes was not only perfectly satisfied of its existence, but, during the best views, obtained some estimations of its *breadth* in comparison with that of the ordinary division. The proportion appeared to him to be as 1 to 3 ; but Mr. Lassell considered it scarcely one third. Both observers, however, agreed in placing it *outside the middle* of the exterior ring. *It was equally visible at both ends.* Mr. Dawes adds, that neither he nor Mr. Lassell had any glimpses of further subdivisions. "The shading of the inner ring was very obvious, but no dark line was even suspected in that situation." Such evidence of the reality of the divisions in the exterior ring as is afforded by the observations of Messrs. Dawes and Lassell is conclusive enough, and it is fortunate that we have the testimony of these able observers in a question of such delicacy.

Professor Challis obtained some glimpses of this extra division in 1842 and 1845, with the great Northumberland telescope at Cambridge, and about the middle of September, in the latter year, the author saw what he considered to be Encke's division on the eastern arm of the ring. More recently, Mr. Lassell and the Rev. W. R. Dawes have had most satisfactory views of a dark line on the outer ring, but not exactly in the position indicated by Encke's measures.

The most recent, and, at the same time, one of the most remarkable discoveries in reference to the rings of Saturn, is that of a dusky or obscure ring nearer to the planet than the interior bright one. It appears that Dr. Galle of Berlin had noticed a gradual shading off of the inner ring towards the globe of Saturn, and had published measures of the extent of the darker part in the *Transactions of the Berlin Academy* in 1838. The memoir, however, was but little known, for in 1850, after the reappearance of the ring in a position favorable to the observation of the divisions, the dusky zone was remarked as new by Mr. Bond of Cambridge, United States, and by the Rev. W. R. Dawes at Wateringbury, near Maidstone, about the same time (in the month of November). Mr. Bond, we believe, has seen only that portion of the obscure ring which had been previously noticed by Dr. Galle at Berlin, but the English astronomer, with his excellent eye and instrument, has succeeded in making out some additional facts respecting this wonderful appendage. He sees not only that there is a dusky ring near the interior edge of the inner bright one, but that it is certainly a double one, being divided during the most favorable views by an extremely fine line. Supposing with Professor Struve that the interval between the globe of Saturn and the interior bright ring is 4·34″, Mr. Dawes estimates the breadth of the different portions of the obscure ring as follows :—

Interval between the bright ring and exterior obscure ring	0·3″
Breadth of the exterior obscure ring	1·1″
Breadth of interior obscure ring, and of the dark boundary separating the two	0·6″

By numerous measures of the breadth of the dark ring, including the whole space between the inner edge of the bright ring and the inner edge of the interior obscure one, the angle subtended was found to be 1·94″. The more distant portion of the new ring is seen much more distinctly than the corresponding portion nearest to the Earth. The projection of this ring upon the ball was noticed by the Rev. W. R. Dawes in November, 1850, and as might be expected from that eminent observer, the connection of the dark line crossing the disc, and broader at the edges than towards the centre, with the obscure portion of the ring seen on each side of the planet, was immediately discovered.

The following table exhibits the dimensions of Saturn's rings in equatorial semi-diameters of the primary, and also in English miles. They are calculated from the most accurate micrometrical measures hitherto published, and must be pretty near approximations to the true values :—

	Equatorial semi-diameters.	English miles.
Outer diameter of outer ring	4·4575	172,130
Inner diameter of outer ring	3·9232	151 500
Outer diameter of inner ring	3·8326	148,000
Inner diameter of inner ring	2·9648	114,480
Breadth of outer ring	0·26715	10,316
Breadth of inner ring	0·43391	16,755
Breadth of the principal division	0·04536	1,752
Distance of the inner ring (interior edge) from Saturn's limb	0·48238	18,628
The same from Saturn's centre	1·48238	57,243

Sir John Herschel estimates that the thickness of the rings does not exceed a hundred miles. Sir W. Herschel was convinced it must be very much less than the diameter of the smallest satellite, which he judged might be about one thousand miles.

The diameter of Encke's division, according to the observations of that astronomer, is 4·2778 equatorial radii of Saturn, or 165,100 miles ; it is therefore situated at a distance of about 3500 miles from the exterior edge of the outer ring.

The planet Saturn is attended by *eight* satellites, seven of which revolve in orbits lying nearly in the plane of the ring, and consequently of the planet's equator.

A good deal of confusion having arisen in the nomenclature of these satellites, Sir John Herschel proposed in 1847 a series of mythological names to distinguish the *seven* satellites then known, and the faint one more recently discovered having also received a classical name, we shall adhere strictly to the plan adopted by this eminent astronomer, as there can be no doubt these moons will be known hereafter by the names Sir John has assigned them. Taking the satellites in order of distance from Saturn, their names will be—Mimas, Enceladus, Tethys, Dione, Rhea, Titan, Hyperion, and Japetus; but in our description of them we shall follow the order of discovery.

Titan, the great satellite of Saturn, was discovered by Huyghens on the 25th of March, 1655, with telescopes of twelve and twenty-three feet focal length. He observed it attentively, and published tables of its movements in 1659, in his *Systema Saturnium.* These tables were afterwards improved by Halley, Cassini, and Lalande. But the most exact determination of its orbit is that recently published by the late Professor Bessel of Königsberg, which depends on his own observations with the fine heliometer at the observatory at that place. The period of one sidereal revolution is 15d. 22h. 41m. 24·86s., and the mean distance from the centre of the planet 176·55″, or 778,000 miles. This satellite shines with the brilliancy of stars of the eighth magnitude, and in powerful telescopes exhibits a very decided disc.

The next satellite in order of discovery is *Japetus*, the most distant of all, detected by the elder Cassini at Paris at the end of October, 1671, with the aid of a telescope of seventeen feet focal length. The period of a sidereal revolution, according to the latest investigations, is 79d. 7h. 54m. 40·8s., and the semi-axis of the orbit subtends an angle of 514·52″ at Saturn's mean distance from the Earth; whence we find the distance of the satellite from the centre of the planet to be 2,268,000 miles, which is nearly twice that of the furthest satellite of Jupiter. The plane of the orbit of this satellite is not nearly coincident with the plane of the ring, and consequently of Saturn's equator, as in the case of the other satellites, but is inclined thereto at an angle of 10°, the node being placed in 150° 27′ longitude upon the orbit of the planet according to the calculations of Lalande. Cassini found the longitude of this point 155°; but it appears certain that there is a retrograde motion of the line of nodes, though we are as yet without any precise determination of its amount.

Cassini noticed that this exterior satellite regularly disappeared during half its revolution, when to the east of Saturn, or following the planet in right ascension. Hence he concluded that it revolved upon its axis in the time of revolution round the primary, as in the case of our Moon. Sir J. Newton in his *Principia* also expressed the same opinion, and thought the variations in the degree of brightness of the satellite was owing to some parts of its surface being less capable of reflecting the Sun's light than others. Sir William Herschel traced the fluctuations of light during more than ten revolutions of Japetus, and found that the same phenomenon always recurred when the satellite returned to the same position in its orbit. At maximum brightness Japetus appears like a star of the ninth magnitude, but more usually the light is not greater than that of a star of the tenth or eleventh class.

The satellite which Sir John Herschel has called *Rhea* was detected by Cassini at Paris, on the 23d of December, 1672, with the help of telescopes of 35 and 70 feet focal length. Its period of revolution is found to be 4d. 12h. 25m. 11·1s., and its distance from the primary 336,000 miles, which subtends an angle of 76·16″ when Saturn is placed at his mean distance from the Earth. The plane of the orbit of this satellite is very nearly coincident with that of the plane of the ring, so that about those times when the primary is near the nodes of the ring, the orbit will appear to be a straight line; but at all other periods the apparent form of the orbit is an ellipse, which is least eccentrical at the time that the ring is most open, cr when Saturn is 90° distant from its line of nodes. Sir John Herschel has investigated the elements of Rhea from his own observations, taken with a twenty feet reflector, during his residence at the Cape of Good Hope, in the years 1835–7. The greatest equation of the centre appears to be 2° 36′, corresponding to an eccentricity of 0·02269, the perisaturnium being placed in 95° longitude. These numbers, however, will be only approximate. Generally speaking, this satellite shines like a star of the tenth or eleventh magnitudes, but at times it will more nearly resemble one of the ninth, and at others one of the twelfth magnitudes. Much depends on the position in respect to the primary, and on atmospheric conditions. To see it steadily at any time, an instrument of not less power than the ordinary five feet achromatic should be employed.

Dione was discovered by Cassini in March, 1684, with lenses varying from 34 to 220 Parisian feet in focal length. The period is 2d. 17h. 44m. 51·2s., and the distance from the centre of the primary 240,000 miles, subtending an angle of 54·54″. It is not so easily seen as *Rhea*, but will occasionally equal in brightness a star of the eleventh magnitude, though far more commonly it resembles one of the twelfth, or is even fainter still. A powerful instrument is therefore required to observe it satisfactorily. The orbit of *Dione* is stated by Sir John Herschel to be elliptical, the greatest equation of the centre being 2° 22′, and the position of the perisaturnium in longitude 42° 30′ for the year 1836. The satellite is supposed to revolve in the plane of the ring; the same remarks in regard to the apparent form of the orbit that were made in the last article will therefore apply here, and with respect to all the other satellites except *Japetus.*

Tethys was likewise detected by Cassini about the same time as Dione, or in March, 1684, with the same telescopes, or with lenses mounted without tubes in consequence of their great focal length. Her period of revolution round the primary is 1d. 21h. 18m. 25·9s., at a mean distance of 188,000 miles, which subtends an angle of 42·57″ at the average distance of Saturn from the Earth. Generally this satellite resembles a star of the thirteenth magnitude, and can therefore be well observed only in powerful telescopes. Dr. Lamont, of Munich, investigated the elements of the orbit from his own observations in 1836; he found that the eccentricity was 0·0051, giving the greatest equation of the centre 0° 35′; the place of the perisaturnium in 1836 was 357° 39′, the longitude of the ascending node 184° 36′, and the inclination of the orbit to the plane of the ring 1° 33′, the longitude of the satellite in this orbit (referred to the same plane) on the 23d of April, 1836, at 8h. 27m., Greenwich mean time, being 158° 31′. Sir John Herschel made a series of observations at the Cape of Good Hope about the same year, from which he inferred that the eccentricity of the orbit of Tethys amounted to 0·04217, giving the greatest equation 4° 50′; the perisaturnium was fixed in longitude 53° 40′, and the satellite was assumed to revolve exactly in the plane of the ring. The differences between the calculations of these astronomers are to be attributed to the difficulty attending the observations, and to the circumstance of small errors of measurement in the apparent position of the satellite with respect to the planet greatly affecting the deduced elements. It will be remarked that the three female names (Rhea, Dione, and Tethys) selected by Sir John Herschel serve to distinguish the three satellites discovered by the elder Cassini.

Enceladus, one of the closer satellites of Saturn, was first perceived by Sir William Herschel, on the evening of August 19, 1787, about its greatest western elongation; but the discovery was not confirmed till the completion of the forty-feet reflector in August, 1789. The very moment this instrument was first directed to the planet, on the 28th of that month, *six* satellites were seen, " in such situations and so bright, as rendered it impossible to mistake them." Sir W. Herschel says, this new satellite is not so conspicuous as the interior of Cassini's (Tethys). It is visible only in the most powerful telescopes to be found in observatories. Professor Struve states that with the Dorpat Refractor of nine inches aperture, the five old satellites were readily distinguished in an illuminated field, but Enceladus had only been caught occasionally in a dark field. Mr. Lassell says it is instantly seen in his twenty-foot reflector, under all tolerable circumstances, when within 40° or 50° of his greatest elongation. Sir John Herschel, on several occasions, has estimated it of the fifteenth magnitude. The author believes he has seen it more than once with a telescope having an object glass of seven inches aperture, but with this instrument it was only caught by glimpses, and could not have been properly observed. Hence we may conclude, that a telescope of less than five inches aperture will stand but little chance of showing this satellite at all.

By the observations of Sir John Herschel at the Cape of Good Hope, and those at Slough in 1789, the period of a sidereal revolution appears to be 1d. 8h. 53m. 6·8s. From the observations of Sir W. Herschel alone, M.M. Beer and Mädler find a period of 1d. 8h. 53m. 2·7s., and consider the orbit as circular in the plane of the ring, the saturnicentric longitude of the satellite on the 14th of September, 1789, at 11h. 53m. mean time at Slough, being 67° 56′ 26″. The distance of Enceladus from the centre of the primary is 152,000 miles, subtending an angle of 34·38″, when Saturn is at his mean distance from the Earth.

Mimas, the closest satellite, was discovered by Sir W. Herschel, with his forty-feet reflector, on the 17th of September, 1789. Even with this grand instrument it is described as a "very small lucid point." It is the faintest object imaginable, as may be judged from the fact, that Sir John Herschel never saw it more than once with his reflecting telescope of twenty feet focal length, employed in his great survey of the heavens recently completed. Mr. Lassell has been more fortunate, but states that the difference in the degree of visibility of Enceladus and Mimas is almost incomparable, and under all but the most favorable conditions, the latter is an object of extreme difficulty. It is only the giant telescopes that are powerful enough for observations of the satellites, and there are probably very few instruments of less than seven inches aperture, which could give the least indication of it.*

M.M. Beer and Mädler have inferred from Sir W. Herschel's observations in 1789, that the orbit is elliptical, the greatest equation of the centre being 7° 54′, and the position of the perisaturnium 104·42°. The period they assign is 22h. 36m. 17·705s., and the longitude of the satellite, as seen from Saturn on the 14th of September, 1789, at 13h. 26m. mean time at Slough, appears to have been 264° 16′ 36″. Hence we find the real mean distance of the satellite from the centre of the primary to be 118,000 miles, subtending an angle of 26·78″. When Mimas is at his greatest elongations, he appears about half the length of one of the ansæ of the ring from its extremity.

The eighth satellite of Saturn, which has received the name *Hyperion*, was discovered nearly simultaneously, by Mr. Lassell, at Liverpool, and by Professor Bond, of Cambridge Observatory, United States. Mr. Lassel caught his first glimpse of the satellite on the 18th of September, 1848, not far from the po-

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* The Rev. W. R. Dawes, with his excellent Munich refractor of 6½ inches aperture, has more than once obtained a favorable view of Mimas; but then it must be remembered that this gentleman is one of the most practised observers of delicate objects that Europe affords.

sition of Japetus, and being uncertain whether it was that satellite or not, he made a drawing of the small stars surrounding Saturn for re-examination on the next clear evening. On the 19th he was astonished to find that both stars had moved away from the positions they had occupied on the previous night, one of them having moved northward in conformity with the orbital movement of Japetus, while the fainter of the two remained in the line of the interior satellites, and seemed to have drawn rather closer to the planet. Mr. Lassell was able to establish the fact of his having discovered a new satellite on the same evening, for he perceived a very sensible change in its position relative to the stars, which was decisive as to the nature of the object. Professor Bond saw this satellite for the first time on the 16th of September, and describes it as a point of light, resembling a star of the seventeenth magnitude, in the plane of Saturn's ring. A diagram was made for comparison on another evening. On the 18th this object was seen and recorded again "with a doubt expressed as to its character." On the 19th (the same night that Mr. Lassell verified his discovery) Professor Bond ascertained that the small star partook of the retrograde motion of Saturn, and must consequently be a new satellite. Thus it appears that the discovery of this body should date from the evening of September 19, 1848, when its true nature was first determined by the English and American astronomers. We have but few instances of so close and remarkable a coincidence in the first detection of a heavenly body.

The elements of Hyperion have not yet been accurately ascertained. It appears probable, however, that the period of revolution round the primary does not differ much from 21d. 4h. 20m., the apparent mean distance from the centre of Saturn being 213·3″, indicating a real distance of about 940,000 miles. The orbit seems to be more eccentrical than in the case of any other satellite, the perihelion point falling in about 295° longitude.

With regard to the diameters of the satellites of Saturn we know but little. Titan, the most distant but one of the eight, is however by far the largest. Sir W. Herschel saw a pretty considerable disc with a power of 500, and remarked that it appeared reddish. Professor Struve has also seen it as a small round disc about 0·75″ in diameter, with the great telescope at the observatory of Dorpat in Russia. This estimation would give us 3300 miles for the real diameter of Titan, which is, perhaps, not far from the truth. The ruddy tinge may be indicative of an extensive atmosphere. The diameter of the closest satellite, Mimas, was judged by its discoverer to be about 1000 English miles, and he remarked that Enceladus was larger than Mimas, but not quite equal to Tethys. The exterior satellite, Japetus, is next in size to Titan, and much larger than the interior ones. Schröter gave measures or estimations of the diameters, from which it would appear that Titan is 2850 miles, Japetus 1800 miles, Rhea 1200 miles, and Dione and Tethys 500 miles in diameter; the numbers for the closer satellites must be received with caution.

Sir John Herschel has pointed out a curious relation between the periods of the four interior satellites of Saturn. The time of revolution of *Mimas* is half that of *Tethys*, and the period of *Enceladus* half that of *Dione*.

The eclipses of the satellites are only visible to us at those times when the Earth is near the plane of the ring, and even then, as will be readily supposed, the most powerful telescopes would be required to observe them with any degree of certainty. Occultations of the satellites by Saturn were occasionally observed by Sir William Herschel, and one satellite has been seen to eclipse another, or approach so close to it that no dark line could be seen between them. These conjunctions of the satellites were frequently witnessed by the eminent astronomer just named. The interior satellites were seen projected on the edge of the ring at the time the Earth was in its plane in the year 1789, and Sir W. Herschel made use of them as "micrometers," by which to estimate the thickness of the rings, his observations leading him to the conclusion that it was very much less than the diameter of either Mimas or Enceladus.

On the 2d of November, 1789, Sir W. Herschel observed a transit of the shadow of Titan over the disc of the planet. It appeared as a black spot, darker than the equatorial belt, and was traced from the south preceding edge of the disc up to Saturn's centre, where it arrived in about 2h. 10m. after it was first perceived on the planet's surface.

It has been notified to the American Academy of Arts and Sciences that Professor Peirce was about to enter on an investigation of the motions of the satellites, at present a great desideratum. It would materially assist the practical astronomer were he in possession of tables of the satellites, sufficiently exact to enable him to predict their phenomena within anything like reasonable limits of error.

The most ancient observation of Saturn which has descended to us was made by the Chaldeans, probably at Babylon, in the year 519 of Nabonassar's period, on the 14th of the month *Tybi*, in the evening, when the planet was observed to be two digits below the star in the southern wing of Virgo, known to us as γ Virginis. The date given by Ptolemy, who reports this observation in his Almagest, answers to B.C. 228, March 1.

An occultation of Saturn by the Moon was observed as early as the year A.D. 503, at Athens. On the 21st of February, at 11h. 44m. P.M., the planet was seen emerging from the middle of the illuminated limb of the Moon. The observation is mentioned by Ismael Bullialdus in his *Astronomia Philolaica*, and was copied from a Greek manuscript at that time, preserved in the *Bibliotheque du Roi* at Paris.

CHAPTER XI.

URANUS. ♅

PREVIOUS to the year 1781, the only planets known besides the one we inhabit were Mercury, Venus, Mars, Jupiter, and Saturn, all which are more or less conspicuous to the naked eye, and were recognized as wandering bodies from the earliest antiquity. Saturn was supposed to be the most distant member of the solar system, and very little suspicion of the existence of any exterior planet was entertained. The close examination of the heavens, commenced by Sir W. Herschel with his powerful telescopes in 1779, led however to a most remarkable discovery, which almost doubled the extent of our system.

On the 13th of March, 1781, between ten and eleven o'clock in the evening, while engaged in examining with his seven-feet reflector the small telescopic stars, near a brighter one called H in Gemini, Sir William noticed one which appeared visibly larger than the rest, and being struck with this circumstance, he applied high magnifying powers, with a view of ascertaining the true nature of the object, for the fixed stars are not proportionally magnified with high powers, as are the planets and comets. The diameter was so much increased beyond what that of a fixed star should have been, that Sir W. Herschel immediately conjectured it to be a *comet*, and it was actually announced as such to the Royal Society on the 26th of April. Perhaps one reason which induced this great astronomer to adopt this conclusion was, the apparent regular increase in the measured diameter of the object between March 13 and April 18; but we are now certain that this gradual increase must have been owing to some optical deception. At any rate, Sir William seems to have had no idea at this time of the real nature of his discovery.

On March 17 the new star was observed by Dr. Maskelyne, then Astronomer Royal, who is understood to have immediately expressed his suspicion of its planetary nature. It was seen by M. Messier, at the Paris Observatory, a month later, or on April 17, and at Berlin by Professor Bode, on July 18, after which it became an object of engrossing attention at all the observatories of Europe.

As soon as a sufficient number of positions had been obtained, astronomers attempted to represent them by a parabolic orbit, under the idea that they belonged to a comet situated at a great distance from the Sun. The assumption being found irreconcilable with the observations, M. Lexell and others calculated the orbit without this hypothesis, and speedily came to the conclusion that its true form differed but little from a circle, the radius of which was about nineteen times the Earth's mean distance from the Sun. M.M. Hennert, Mechain, Lalande, and the President de Saron arrived at very similar results. The stranger was then recognized as a superior planet, next in order of distance to Saturn, and it was inferred that the period occupied in one revolution round the central luminary must be about eighty-two years. The observations of the first period of visibility, before the conjunction of the planet with the Sun, were sufficient to prove that the plane of its orbit deviated but slightly from that of the ecliptic, and that no very great eccentricity could exist.

The reader must not imagine from what has been said of the manner in which the planet was discovered, that we are indebted to *accident* for this addition to the members of the solar system. It is very likely true that little notion of finding an exterior planet was entertained by Sir W. Herschel, when he commenced his survey of the heavens, yet it must be remembered that this great astronomer was at work on a *systematic plan*, which was followed up with a zeal and diligence no less the admiration of his contemporaries, than an example in after times.

The name for the new primary planet was a subject of some contention amongst astronomers. Sir W. Herschel, to whom belonged the right of selecting a name, termed it the "*Georgium Sidus*," in gratitude to George III., the munificent patron of the science. Continental astronomers were not disposed to receive any but a mythological name, and Cybele, Atlas, Neptune, &c., were suggested. Professor Bode soon afterwards proposed *Uranus* (the father of Saturn), and this name gradually gained ground, notwithstanding a good deal of opposition. Laplace insisted upon calling the planet Herschel in compliment to the eminent observer who had brought it to light, and in this he was followed by many cultivators of astronomy in this and other countries. The term "*Georgian*" was substituted by some persons in place of the longer name assigned by the discoverer; and the planet has been thus styled in our *Nautical Almanac*, until the appearance of the volume for 1851, when it was rejected in favor of Bode's appellation "Uranus," which for a long time past has been in universal use amongst astronomers. This change we believe to have been made with the full consent of Sir John Herschel, the son of the great discoverer.

The theory of the motions of Uranus occupied the attention of the celebrated French geometer Laplace very soon after the detection of the planet in 1781. Various inequalities of long period were discovered, the amount of ellipticity was determined, and the position of the lines of nodes and apsides.

Fixmillner, Delambre, and other eminent calculators, also occupied themselves with the numerical elements and formation of tables, in order to predict the future positions of the planet. In these computations they were not confined to observations taken since the actual discovery of Uranus by Sir W. Herschel. As soon as an approximation to the orbit had been obtained, it became a matter of great interest and importance to ascertain if Flamsteed or other observers in previous times had catalogued the planet as a fixed star, for if this were the case, the date of the observation being recovered, the position would prove of the utmost value in assigning the exact elements of the planet's orbit. A careful search was made with this object in view, and it was found that the planet had been repeatedly observed by Flamsteed at our Royal Observatory, and by Lemonnier at Paris, and was once observed by Tobias Mayer at Gottingen. Flamsteed saw the planet first on the 13th of December, 1690, and entered it in his catalogue as the 34th star in Taurus. He observed it also on March 22, 1712, and on February 21, 22, 27, and April 18, 1715. Mayer took its transit over the meridian of Gottingen, on September 25, 1756. Lemonnier observed it no less than twelve times, and had he reduced his observations as he made them, would in all probability have detected the planet. The dates are October 14, and December 3, 1750, January 15, 1764; December 27 and 30, 1768; January 15, 16, 20, 21, 22, and 23, 1769; and December 18, 1771. Thus, the planet Uranus had been observed as a fixed star at least nineteen times before its real nature was detected by Sir W. Herschel.

The length of a sidereal revolution of Uranus is about 30686·7 days, or rather more than 84 of our years, according to the recent researches of M. Le Verrier. Its mean distance from the Sun is 1,828,071,000 miles, the least distance being 1,742,738,000, and the greatest 1,913,404,000, so that the eccentricity causes a variation in length of the radius-vector of about 170,666,000 miles. The plane of the orbit is very nearly coincident with the ecliptic, the *inclination* being less than 47′.

The apparent diameter of the planet is subject to very little change during the time it is visible from the earth, and hardly exceeds four seconds of space, but at a distance = 1, this diameter would subtend an angle of 78·4″. The real diameter of Uranus is therefore about 35,000 miles. Professor Mädler thinks he has detected a very considerable ellipticity in the form of the planet, and makes the ratio of the equatorial to the polar diameter as ten to nine, the axis being inclined at an angle of about 15° 26′ to the circle of declination (1843, September 28). Other astronomers, with more powerful telescopes, have not succeeded in gaining any certain evidence of an appreciable difference in the diameters.*

The disc of Uranus appears uniformly bright, and of a pale color but no appearance of spots or belts has been perceived. For this reason, the time of axial rotation has not been ascertained, though it is probably not very widely different from that of Jupiter or Saturn. No indications of a ring or double ring have been afforded by the powerful telescopes of the present day. Sir W. Herschel hinted at the possibility of such an appendage, but seems to have had little confidence in the observations which led him to make this suggestion.

The planet Uranus is accompanied by several satellites which require very great optical power to render them visible. Sir William Herschel considered he had seen six of these little moons, and was able to approximate very closely to the periods of two out of this number, which are much more conspicuous than the rest. The periodic times of the other four were inferred, on Kepler's law, from *estimated* values of their mean

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* Mr. O. Struve has informed me orally that the grand refractor at Pulkova affords no indications of ellipticity.

distances from the centre of the primary. The two satellites with which we are best acquainted are usually denominated the *second* and *fourth*, the numbers being reckoned in order of distance from the planet.

Sir William Herschel states that he had frequently directed large telescopes to this remote object, before the year 1787, with the view of ascertaining if it were attended by satellites; but the situation of the planet, in a part of the heavens closely studded with small stars, led to such continual disappointment, that he ascribed his failure to a want of sufficient light, and for a time relinquished the attempt. At the commencement of the year 1787, Sir William found so great an advantage in the introduction of what he termed the *front view* in his powerful reflectors, when applied to the examination of the nebulæ, that he immediately concluded it would be attended with success if applied to the observations of his new planet, and accordingly began a close scrutiny of the telescopic stars near it on the 11th of January. On this, the very first evening that he attacked the planet with his improved means, he saw the two larger satellites which we have termed the *second* and *fourth;* and a month's observations sufficed not only to confirm the discovery, but to give a very fair idea of the paths pursued by these distant bodies. Accordingly, on the 11th of February, 1787, he announced his success to the Royal Society, and assigned the periodic times of the satellites 8¾ days, and 13½ days respectively. These approximations were pretty near the truth, as the following results obtained from long-continued observations will show:—

Second Satellite.

	D.	H.	M.	S.
Period, according to Sir W. Herschel's later observations, ...	8	16	56	5·2
Sir John Herschel, by a comparison of his own observations with his father's, ...	8	16	56	31·3

	D.	H.	M.	S.
Dr. Lamont, from measures taken at Munich Observatory,	8	16	56	28·55
Mr. Adams, from the combination of all the observations between 1787 and 1848,	8	16	56	24·88

Fourth Satellite.

Period, according to Sir W. Herschel's latest calculations,	13	11	8	59·0
Sir John Herschel, by a comparison of observations between 1787 and 1832,	13	11	7	12·6
Dr. Lamont, from Munich Observations,	13	11	7	5·92
The author, by comparison of observations between 1787 and 1848,	13	11	7	9·22
Mr. Adams, from the whole series of observations,	13	11	6	55·21

Mr. Adams' numbers, which depend on a discussion of all the observations of the two Herschels, Dr. Lamont, and Mr. Lassell, up to the present time, must, of course, receive the preference.

There is still a great deal of uncertainty with respect to the other satellites discovered by Sir W. Herschel at a later period than the second and fourth. The observations taken by that astronomer between the years 1790 and 1801 sufficiently establish the existence of at least four additional satellites; but it is doubtful whether they are definite enough to point out the correct times of revolution and mean distances from the planet, and hence the difficulty of identifying these objects from time to time. Sir W. Herschel assigned the following numbers, which, however, should be regarded rather as the results of calculation than as conveying any exact information respecting the true periods and elongations of the satellites, for it is evident, from a consideration of the scanty data which Sir William had to work upon, that he could not determine from them the exact elements, nor, indeed, does he affect to speak of his conclusions with any degree of confidence in either of his memoirs on the subject:—

Sat.	Revolution. d. h. m. s.	Mean distance in semi-diameters of Uranus.
I.	5 21 25 20	13·120
III.	10 23 2 47	19·845
V.	38 1 48 0	45·507
VI.	107 16 39 56	91·008

These numbers being reckoned in order of distance from the primary, it will be remarked that the orbit of the first supplementary satellite is *interior* to that of the closest of the two with which we are best acquainted; that the second on the list is intermediate, and the two others more distant from Uranus than either of the old ones.

The existence of an interior satellite is inferred from Sir W. Herschel's observations on the 15th and 16th of February, 1798. On the 15th a very small star was seen in the line of greatest northern elongation, which had moved away on the 16th. Another observation of a satellite supposed to be identical with this was obtained on the 17th of April, 1801, at 10h. 30m.: it was at a great angle in the south preceding quadrant, about 81°, and at half the distance of the *second* satellite from the planet's centre. On the following night no star was visible in the same position.

The intermediate satellite was detected on the 26th of March, 1794, and was steadily seen more than two hours. At 11h. 24m., Sir W. Herschel noticed that it was much smaller than the closest of the two older satellites, and in a line with it and the planet: its position was in 59½° in the north following quadrant. On the following evening *it had moved away.*

The existence of the first of the exterior satellites was considered to be established by an observation on the 9th of February, 1790, when a satellite was remarked at twice the distance of the fourth, and in a line with it and the planet; the angle of position being 61·5° south following. On the 12th, Sir W.

Herschel observed that the supposed satellite of the 9th was not in the place where it was then seen. Other observations of this object were made on February 26th, 1792, March 5th, 1796, and February 11th, 1798.

The sixth, or most distant satellite, was perceived by Sir W. Herschel on February 16th, 1798, at or near its greatest southern elongation: it was described as excessively faint, and the least haze rendered it invisible. On the 18th, it had moved away from this place, and had approached nearer to the primary. At 11h. 25m. P.M., mean time at Slough, the angle of position was 80·9° south preceding. Two previous observations, on February 28th, 1794, and March 28th, 1797, were supposed to refer to this satellite, but its existence was hardly established till February 1798.

Sir John Herschel repeatedly observed the second and fourth satellites between the years 1828 and 1832, but did not succeed in recovering any of the supplementary ones. Dr. Lamont commenced a course of observations on the two brighter satellites with the view of determining the mass of the planet Uranus with greater accuracy, and on one occasion, in October 1837, he discovered a very faint object, which he considered to be the most distant of the Herschelian satellites, though, for want of later observations, he could not speak positively as to the identity. Sir John Herschel used his twenty-feet reflector, with which his surveys of the heavens have been made. Dr. Lamont employed the great refracting telescope at the Royal Observatory of Munich, which has a clear aperture of ten inches, English measure.

The more recent observations of Mr. Lassell at Liverpool, and Mr. Otto Struve at Pulkova, near St. Petersburg, appear to decide the existence of at least *two* satellites within the orbit of Herschel's *second*, or the closest of the brighter ones. During the latter part of the year 1847, both observers paid particular attention to their measures of these satellites, and searched carefully for the others. Mr. Lassell repeatedly observed another one on the northern side of Uranus; and Mr. Otto Struve also detected a third satellite, which, singularly enough, was invariably observed on the southern side of the planet. In the whole series of observations at Liverpool and Pulkova, only one night is common to both, and this was so unfavorable at Liverpool, that the faint satellite of Mr. Struve might have been easily overlooked. Mr. Lassell's satellite would seem to have a periodic time of 2d. 2h. 39m. 36s., agreeably to the calculations of the Rev. W. R. Dawes, while the observations of Mr. Otto Struve's can only be satisfied by a period of 3d. 22h. 8m. 35s. Mr. Lassell noticed a satellite on September 27th, 1845, which seems very likely to have been identical with that recognized again by Mr. Otto Struve on October 8th, 1847; and, in fact, it was by assuming the observations to belong to the same object that the above period was inferred. It is probable that Mr. Lassell's satellite disappears (at least to the most powerful telescopes of the present day) when it is in the *southern* portion of its orbit, as Mr. Otto Struve's does in the *northern*, but this can only be decided from further observations.

On the 6th of November, 1847, Mr. Lassell observed a satellite at about 10″ distance from the planet, and almost precisely opposite to that of the *second* of Sir W. Herschel's list. It is shown by the Rev. W. R. Dawes that this object could not have been either Mr. Lassell's or Mr. Struve's satellite, but that its orbit is probably intermediate, its greatest distance being 15¼″. It is true, in this case, we have only a single observation to depend upon, and it may seem hazardous to form any opinion therefrom; but the night of November 6th was unusually fine, and the planet was viewed for more than two hours, during which interval this supposed satellite was *carried* *along with it.* Hence Mr. Dawes thinks it is probable that there are *three* satellites interior to the *second* of Sir W. Herschel, at apparent mean distances of 12″, 15″ and 18″. If any one of these be the same as the interior satellite of that astronomer, it would appear most likely to be that detected by Mr. Otto Struve, which revolves in 3d. 22h. 8m. 35s.

From what has been here stated, the reader will easily understand that a considerable degree of uncertainty still attaches to this question; not perhaps so much in reference to the *number* of satellites as to their relative mean distances from the primary. As Uranus is becoming every year more favorably loca ted for observation in this hemisphere, it is to be hoped that the great telescopes now found in so many observatories will clear up all doubts, and place us in possession of something like a fair estimate of the number and movements of his attendants.

The mass of Uranus has been inferred from observations of the two brighter satellites, whose elongations from the primary have been repeatedly measured, with this object in view, by Sir W. Herschel, Dr. Lamont, Mr. Lassell, and Mr. Otto Struve. The recent calculations of Mr. Adams, founded upon their data, indicate that the Sun's mass exceeds that of the planet in the ratio of about 21,000 to 1, and this result is undoubtedly a close approximation to the truth. M. Bouvard had made it as 17,918 to 1, from the perturbations of other planets by Uranus; but this being considered too large, Dr. Lamont was induced to undertake a course of observations in 1837, from which he concluded the ratio of the masses as 24,605 to 1. It will be remarked that the value assigned by Mr. Adams is intermediate to the numbers of M.M. Bouvard and Lamont.

CHAPTER XII.

NEPTUNE.

THE tables of Uranus at present employed in the calculation of the planet's apparent positions were composed by M. Bouvard of Paris, and published in the year 1821. In the formation of these tables, M. Bouvard wished to combine the ancient observations of Flamsteed, Le Monnier, &c., with the whole series between 1781 and 1820, and thus produce the means of predicting the future places of the planet, from a study of its motion through a period of 130 years. But in the course of this investigation an unexpected difficulty was encountered. M. Bouvard found it impossible to represent the whole of the observations, ancient and modern, by one elliptic orbit, even after a consideration of the disturbances due to the action of Jupiter and Saturn, as indicated by the formulæ of Laplace. At the time, there appeared to be no satisfactory explanation of this discrepancy, and the able astronomer preferred abandoning the old observations altogether, and founding his tables on the positions from 1781 and 1820, which could be fairly reconciled with an elliptic orbit, with proper allowance for the perturbations produced by known planets. This curious anomaly excited no further remark amongst mathematicians for some few years after the publication of the tables; but in the year 1828, the Cambridge observations of Uranus showed a very sensible difference between the planet's true places and those calculated from theory. The circumstance had evidently attracted M.

Bouvard's attention; for in a letter written in November, 1834, by the Rev. T. Hussey to Mr. Airy, then Plumian Professor at Cambridge, it is stated that the French astronomer had been led to suspect the existence of an exterior planet to Uranus in order to account for the discordances, an idea which had also occurred to Dr. Hussey himself. Some correspondence had taken place on the subject between Mr. Airy and Mr. Eugene Bouvard, nephew of the author of the tables, in the course of which the former gentleman expressed an opinion to the effect that, if the differences between calculation and observation arose from the action of an unseen planet, it would be a matter little short of an impossibility ever to ascertain its place in the heavens. The excessive difficulty of the problem, afterwards so unexpectedly solved, will be readily imagined after this deliberate opinion from one of the highest geometers of the day.

Early in the year 1843, Mr. Adams, of St. John's College, Cambridge, commenced an examination of the theory of Uranus, and after satisfying himself that the errors of M. Bouvard's tables could neither be ascribed to oversight in calculation, or to corrections required by the pure elliptic elements of the planet's orbit, he directed his attention to the probable effect of a more distant planet, and succeeded in obtaining an approximate solution of the *inverse problem of perturbations*, in which certain observed disturbances are given, to find the positions and path of the body producing them. In this first solution (which it must be remarked was a grand step in the inquiry), Mr. Adams assumed that the unseen planet moved round the Sun in a circular orbit, at twice the mean distance of Uranus, and his results were so satisfactory as to induce him to enter upon the subject again, starting from more complete data, and working out the problem without any hypothesis respecting the form of the orbit. An application was made to the Astronomer Royal (Mr. Airy), through Professor Challis, for some quantities furnished by the Greenwich observations of Uranus, and, in reply, the whole of the *heliocentric errors* in longitude and latitude, between 1754 and 1830, were placed at Mr. Adams' service. From these data, and the ancient observations of Flamsteed, he started afresh, and, in October 1845, communicated to Mr. Airy the result of his second, and more complete investigation. He remarked that the observed irregularities in the motion of Uranus might be explained by supposing the existence of a more distant planet, the mass and orbit of which were as follows :—

Mean distance from the Sun, assumed nearly in accordance with Bode's law	38·4
Mean longitude on October 1st, 1845	323·34°
Longitude of the perihelion	315·55°
Eccentricity of the orbit	0·1610
Mass, that of the Sun being called 1	0·0001656

The Astronomer Royal replied to Mr. Adams' communication on November 5th, 1845, observing that these numbers were very satisfactory, and further inquiring whether the assumed perturbation would explain the error in the distance of Uranus from the Sun, which had become very considerable, and was first pointed out by Mr. Airy, in 1836. From some accidental cause, no immediate answer to this query was sent; but Mr. Airy states, that had he received an affirmative reply, he should at once have exerted all the influence he might possess, either directly or indirectly, through Professor Challis, to procure the publication of Mr. Adams' theory. As it happened, it was not printed until a twelvemonth after this time.

In the summer of 1845, M. Le Verrier, the eminent French mathematician, turned his attention to the anomalous movements of Uranus, being entirely ignorant of the researches already commenced by Mr. Adams. In the "*Comptes Rendus*" of the Institute of Paris for November 10th, 1845, appeared a most valuable memoir by M. Le Verrier upon the theory of Uranus, as regards the perturbations produced by the planets Jupiter and Saturn. He determined at the expense of a vast amount of labor, the precise effects to be attributed to the action of each of these bodies, and after carefully comparing his new theory with the observations, ancient as well as modern, he announced, as the principal result of his investigation, that the anomalies in the motion of Uranus could not be explained, on the principles of gravitation, without admitting the existence of some extraneous influence.

On the 1st of June, 1846, M. Le Verrier published in the same periodical his second memoir on the planet, the first part of which contained a discussion of nearly all the existing observations of Uranus, in reference to the corrected theory of perturbations given in the former paper: the result of this great labor was to prove beyond the possibility of doubt that the movements of the planet were affected by some external action, and M. Le Verrier accordingly proceeds to examine in the second part of his memoir the various explanations of the irregularities that might be suggested. Could they be due to the failure of the law of gravitation at the great distance of Uranus? This idea the eminent mathematician rejects as too improbable, all previous suspicions of the kind having ultimately tended to confirm that law. Could they be owing to the action of a great satellite accompanying the planet Uranus? In this case the discordances should pass through regular variations of magnitude in a certain period, the extent of which would be pretty easily determined from a long and continuous series of observations. But the errors of the theory followed no such law of change. Had a comet at some past time impinged upon Uranus, and changed its orbital velocity and direction of motion? To this question M. Le Verrier replies that the observations between 1781 and 1820 could be very well represented without having recourse to any extraneous action, so that the disturbing force, of whatever kind it might be, had exercised no visible influence during that interval. But then the theory which would be reconcilable with observations between 1781 and 1820 should also be compatible either with the observations previous to the year 1781, or subsequent to 1820, yet it had been shown that neither the earlier or the later series of positions could be brought into agreement with it. A single collision with a comet would not, therefore, explain the anomalous movements of Uranus. There remained only the hypothesis of an unseen planet of considerable mass, and on this point M. Le Verrier observed it must be situated exterior to the orbit of Uranus, or it could not fail to produce some appreciable effect upon the motion of Saturn ; whereas nothing of the kind could be detected. Consequently, admitting the existence of an exterior planet, it would be necessary to place it at such a distance that the Saturnian system should not be influenced by it in any sensible degree, though not so remotely distant as to preclude the possibility of its exercising a very powerful attraction upon Uranus. M. Le Verrier, partly guided by Bode's empirical law of distances, though without adhering strictly to the indications of that law, and further observing that the perturbations in latitude produced by the disturbing body were very insignificant, proposes the following question :—"Is it possible that the inequalities of Uranus are due to the action of a planet situated in the ecliptic, at a mean distance double that of Uranus ? If so, where is the planet actually situated, what are its mass and the elements of the orbit it describes ?" This intricate problem M. Le Verrier resolves in his memoir of June, 1846. Now, if we could determine for any time the variation due to the action of a planet of unknown mass, we might ascertain immediately the direction in which Uranus would be attracted, in consequence of the continuous action of the disturbing body, and hence we should also find the position of this body amongst the stars. But M. Le Verrier shows that the problem is very far from presenting itself thus simply. The direct determination of the effect of the disturbing planet was not possible unless we could ascertain the exact orbit which Uranus would describe if uninfluenced by it, and this there are no means of discovering unless we are acquainted with the precise amount of the perturbations. It was impossible to resolve the problem into two distinct heads, the determination of the elliptic elements of Uranus, and of the planet to which the irregularities in the motion of Uranus were referable. The method adopted by the eminent mathematician, in his researches, was to assume the planet located in different parts of the ecliptic, and to calculate the amount of alteration which it would produce in the longitude of Uranus at each of these different points. The computations were executed for every tenth of a quadrant, or for every ninth degree; the results showed that in one position of the disturbing body its effect upon the longitude of Uranus would be excessively great, while in another position it would vanish entirely, and thus M. Le Verrier was led to that precise part of the heavens where it was necessary to place the perturbing body in order to represent completely the anomalous motions of Uranus. He concluded that there was only one region of the ecliptic, where the unseen planet could be located, and further, that the observed irregularities might be perfectly explained, if the existence of a planet in that region were admitted, its mean distance from the Sun being about double that of Uranus. Taking the 1st of January, 1847, as an epoch, M. Le Verrier announces as the principal result of his researches that the heliocentric longitude of the disturbing body would be 325°, and this position could hardly be in error to the extent of 10° one way or the other. In answer to a question from Mr. Airy, M. Le Verrier shows that the errors in the radii-vectores of Uranus are fully explained by his theory, or rather, we should say, disappear altogether on its application. About a week after the receipt of this reply, or on the 9th of July, 1846, Mr. Airy wrote to Professor Challis at Cambridge, inquiring whether he could undertake the search for the disturbing body, the existence of which now appeared to be placed beyond doubt. Professor Challis having at command one of the largest refracting telescopes in this country, the gift of the Duke of Northumberland to the University, Mr. Airy considered he would possess the means most likely to lead to the discovery of the planet if it were faint, as was generally anticipated by those astronomers who had seen the memoir of M. Le Verrier. In answer to Mr. Airy's inquiry the Professor expressed his intention of commencing a strict search at once; the examination to be extended over a part of the heavens 30° long, in the direction of the ecliptic, and 10° broad. The necessary observations were begun on the 29th of July, and continued during August and September.

In the *Comptes Rendus* of the 31st of August there appeared a third memoir on the inequalities of Uranus by M. Le Verrier, which is truly a most wonderful production. In the first investigation the mean distance of the disturbing planet was announced to be twice that of Uranus; in the second it is considered one of the unknown elements, and results directly from the solution of the equations, from which the position of the planet and the other orbital quantities are found. All the ancient observations of Flamsteed, Le Monnier, Bradley, and Mayer, are combined with a great number of modern positions between 1781 and 1845; and, after many unsuccessful attempts, M. Le Verrier finally completed the solution of the problem which he had propounded in June, 1846, and gave the following elements of the orbit of the latent planet:—

Mean distance from the Sun or semi-axis major .	36·154
Duration of a sidereal revolution	217·387 yrs.
Eccentricity	0·10761
Longitude of the perihelion	284° 45′
Mean longitude on the 1st of January 1847 . .	318° 47
The most probable value of the mass . . .	1–9300th

From these numbers the true position of the planet at the commencement of the year 1847 was found to be 326° 32′. Having given these important results, M. Le Verrier proceeds to limit the space over which the search for the suspected planet should be extended, to make sure of including the true position. The limits depended on the possible variations of certain quantities on which the elements of the orbit were based, and are stated to be 321° and 335° of heliocentric longitude. But M. Le Verrier expressly mentioned that he considered the positions remote from 326° 32′ as possessing little probability, and advised observers to begin their search for the latent body at the point immediately resulting from the solution of the problem, extending it on each direction as might be found necessary. He further gave it as his opinion that the planet would present a disc, of about three seconds diameter, or sufficiently large to be readily detected with some of the larger telescopes employed in observatories. Throughout the whole of this memoir M. Le Verrier speaks most confidently of the result of his prediction: he had pointed out to astronomers the only way in which the anomalous movements of Uranus could be explained; he had solved all the mathematical difficulties attending it, and finally published to the world the position and appearance of the latent planet in the heavens, thus leaving little to be accomplished in its actual discovery.

On the 2d of September, 1846, Mr. Adams addressed a letter to Mr. Airy (who happened to be absent from England), giving a further account of his researches on the irregularities of Uranus, and the results of another solution of the inverse problem of perturbations in respect to these observed anomalies. In the first attempt the mean distance of the disturbing body was supposed to be double that of Uranus; in this new investigation it was somewhat diminished, and the agreement between theory and observation was found to be more satisfactory than before. Mr. Adams then shows from calculations that the errors in the distances of Uranus from the Sun, pointed out by Mr. Airy, were destroyed or nearly so by admitting the existence of a planet with the elements he had assigned. These elements on the second hypothesis as to mean distance were as follows:—

Mean longitude of planet, 1st October, 1846	323° 2′
Longitude of Perihelion	299·11
Eccentricity	0·12062
Mass (that of the Sun being called 1)	0·00015003

The ratio of the mean distance of Uranus to that of the disturbing planet is considered to be as 0·515 to 1.

In conclusion, Mr. Adams states that he was "employed in discussing the errors in latitude, with the view of obtaining an approximate value of the inclination and position of the node of the new planet's orbit;" but he expressed doubts as to the probability of any results to be derived from them in consequence of their being very small. A rough calculation made some time before had indicated that the line of nodes would fall at about 300° and 120° of heliocentric longitude, the former being the place of the ascending node; and, further, that the plane of the orbit of the new planet would be rather largely inclined to that of the ecliptic.

On the evening of the 23d of September, 1846, Dr. Galle, one of the astronomers of the Royal Observatory at Berlin, received a letter from M. Le Verrier, containing the latest results of his analysis, and strongly urging him to employ the great telescope at his command in a search for the planet. It so happened that the Berlin Academical Chart for the 21st hour of right ascension had been completed by Dr. Bremicker, and as the map contained every star to the 9-10 magnitude inclusive, which was visible within 15° of the equator, north and south, and between 315° and 330° of right ascension, the region of the heavens to be examined on M. Le Verrier's recommendation was included upon it, and nothing but a comparison of the map with the sky was required to detect the planet, if it existed in the predicted position, and equalled in brightness a star of between the 9th and 10th magnitudes. Dr. Galle, therefore, took advantage of a fine evening on the same day that M. Le Verrier's letter arrived, and very soon discovered an object resembling a star of the 8th magnitude, near the place indicated by theory as that of the disturbing planet. This object was not marked upon Dr. Bremicker's map, and observations were therefore commenced at once, with the view of detecting any change of place. After about three hours, it appeared that the right ascension had somewhat diminished, though the alteration was hardly sufficient to justify the immediate announcement of a planetary discovery. But the following evening, at eight o'clock, the object had retrograded more than four seconds of time, and there remained no further doubt of its being a planet; nor, considering the proximity to M. Le Verrier's place, could there be any hesitation in pronouncing it the very body which had caused the irregularities in the movements of Uranus. On the 25th, Dr. Galle consequently wrote to M. Le Verrier, informing him of his discovery of the latent planet, and stating the results of some measures of its diameter by himself and Professor Encke, which assigned about 2½ seconds of space, thus confirming, in the most remarkable manner, the predictions published by M. Le Verrier on the 31st of August. The observed longitude of the planet on the 23d of September, at midnight, was 325° 52·8′, and the diurnal motion in longitude 74″, while the numbers computed from the theory were 324° 58′ and 69″. Thus the error of prediction was less than 1° in the geocentric longitude, and the close accordance of the diurnal motions showed that the distance M. Le Verrier had given could not be very far wrong. The news of this grand discovery soon spread throughout Europe: it was known in England on the 30th of September, and about the same day in Paris; but M. Le Verrier does not appear to have received any intimation till some days afterwards that our countryman had employed himself in similar researches to those, the success of which now astonished the astronomers of Europe. The investigations of the two gentlemen were consequently entirely independent of each other; both had remarked the apparent errors in the existing theory of Uranus, and sought to explain them on the same assumption, but the direct discovery, on the 23d of September, of the planet which thus gave evidence of its existence, was owing to the letter of M. Le Verrier to Dr. Galle.

We have already stated that Professor Challis commenced a search for the planet on the 29th of July, 1846. At this time the publication of the Berlin Academical Chart for hour xxi. was unknown in England, and the Professor was therefore under the necessity of forming his own map, which was to depend on observations taken in the following manner:—Employing the great Northumberland telescope erected in the grounds of Cambridge Observatory, the positions of all stars to the eleventh magnitude, inclusive, that could be conveniently taken as they passed through the field of the telescope, were first noted down; the magnifying power used gave a breadth of field about 9′. In some parts of the heavens, where the stars existed in great numbers, some few were necessarily passed over; but as it was important to secure the exact positions of every star to the eleventh magnitude, the same zone was gone over a second time, the instrument being used on another method, which allowed more time for recording the places of the stars. The observations made on the second occasion being intended to include all stars observed in the first sweep, the planet would be readily detected if any star noted down in the first examination had altered its position. But as many new stars might be observed the second time, Professor Challis proposed going over the zone once more, to make quite sure of the planet's discovery, if it really existed in the prescribed region of the sky. Observations were taken on July 30 and on August 4 and 12; the zone examined on the latter day being the same that was observed on the 30th of July. A *partial* comparison of the results on those two days showed that the plan of observation was effectual, and the search was continued till the 29th of September; but the further comparison of the observations was deferred until the close of the season, Professor Challis little suspecting, as he has since stated, that "the indications of theory were accurate enough to give a chance of discovery in so short a time." On the 29th of September, the second memoir of M. Le Verrier came under his notice; and struck with the manner in which the French mathematician limited the region to be examined, and with his recommendation to endeavor to detect the planet by its disc, Professor Challis changed his plan of observation on the evening of the same day, and out of 300 stars, singled out one which appeared to him to have an appreciable diameter, and was noted down for a second scrutiny on the next fine night. On the 1st of October the news of Dr. Galle's discovery reached Cambridge. Professor Challis had recorded the places of 3150 stars, and was making preparations for mapping them; but he was not aware at the time whether the planet was amongst them or not. Soon afterwards, on continuing the comparison of the observations of July 30 and August 12, it was found that a star of the eighth magnitude in the series of August 12 was wanting in the zone of July 30, and, according to the principle of the search, it should be the planet. This was really the case; it had advanced into the zone during the interval between July 30 and August 12. The former comparison had been extended only to the star No. 39, whereas the planet was No. 49. Thus an opportunity of announcing its discovery was lost. A further discussion of the observations showed that the planet had been observed also on August 4; so that two early places had been secured; and on carrying forward the positions from September 23d to 29th, Professor Challis ascertained that the object he had singled out on the latter evening, as presenting a measurable disc, was no other than the planet of which he was in search.

Mr. Adams communicated the results of his calculations to the Royal Astronomical Society in November, and they were printed as a Supplement to the Nautical Almanac for 1851, in December 1846. M. Le Verrier gave his analytical computations in detail, in an appendix to the *Connaissance des Temps*, but the principal conclusions had been published, as we have seen, some months before the planet was detected by the telescope.

A good deal of discussion took place with regard to a name for the newly-discovered body. Dr. Galle suggested *Janus*, which M. Le Verrier opposed, as being too significative: and after other appellations had been proposed (including the name of the illustrious mathematician whose recondite researches had led to the actual discovery of the planet at Berlin), astronomers generally called it *Neptune*, the name first mentioned by the *Bureau des Longitudes*, and approved by M. Le Verrier himself.

Such is the history of this most brilliant discovery, the grandest of which astronomy can boast, and one that is destined to a perpetual record in the annals of science—an astonishing proof of the power of human intellect.

It is very possible that there may be a considerable number of satellites attendant upon Neptune; but owing to the remoteness of the planet, astronomers have succeeded in observing with certainty only one of them, which was discovered by Mr. Lassell of Liverpool, with his great reflecting telescope, in October, 1846, or very shortly after the first detection of the planet by Dr. Galle. It was so faint as to require a sky of the utmost purity, and the full aperture of the telescope, to render it steadily visible. In the summer of 1847, Mr. Lassell ascertained that the periodic time would be about 5d. 21h., and the greatest apparent elongation from Neptune's centre about 18″, or little more than six diameters of the primary. He also discovered that the satellite is much brighter when it *precedes* than when it *follows* the planet in right ascension, a phenomenon which obtains in the Saturnian system, and seems to indicate that the time of rotation of the satellite upon its axis is equal to the periodic revolution round Neptune, as in the case of our Moon. Mr. Otto Struve found the satellite at the Central Russian Observatory of Pulkova, on the 11th of September, 1847, and in the following month it was discerned by Professor Bond of Cambridge, U. S., with a telescope of the same dimensions as that of Pulkova. The American astronomer states that he has gained pretty strong evidence of the existence of another satellite, fainter and more distant from the primary than Mr. Lassell's, but never having succeeded in procuring consecutive observations, the reality of this second discovery is not fully confirmed.

A discussion of all the observations of the satellite up to the end of 1848, shows that the orbit is inclined at an angle of about 30° to the plane of the ecliptic, which it intersects in

120° and 300° of longitude. The apparent semi-axis major, as seen at the distance 30, appears to be 16·75″, so that the real mean distance of the satellite from Neptune is 232,000 miles, or not very different from the interval which separates the Moon from the Earth. The time of a sidereal revolution of the satellite is 5d. 21h. 0m. 17s., according to Professor Bond, or exactly 5d. 21h., agreeably to an investigation by the author. Viewed from the Earth, the orbit appears an ellipse, with the longer axis three times the breadth of the lesser one; but the true path of the satellite is not far from circular, and the ellipticity of the apparent orbit is consequently owing to the small inclination of its plane to our line of vision.

The satellite is estimated to be equal in brightness to a star of the fourteenth magnitude.

The mass of the planet is not yet accurately known. The excessive difficulty attending observations of the satellite, and the manifest discordances between the measured distances of different observers, tend to throw some degree of uncertainty upon any conclusions we may deduce from them. Still, there is no doubt that we have already *approximated* to the correct value of this important element. The theoretical method has hardly received rigorous application at present, but the observations of the satellite furnish us with the following results :—

Mr. Otto Struve, from the Pulkova measures, 1-14494.

Professor Peirce, from the observations by Messrs. Lassell and Bond, 1-18780.

Professor Bond, from his own observations, 1847–48, 1-19400.

The author, by a combination of *all* the measures, 1-17900.

At present it appears probable that the mass is somewhat larger than in the case of Uranus, and perhaps we are justified in stating that it can hardly be greater than 1-15000, nor smaller than 1-20000. By assuming that the mass of the

Sun exceeds that of Neptune 18,000 times, no great error can be incurred.

Mr. Lassell, with his twenty-feet reflector, and Professor Challis, with the great Northumberland telescope, have at various times suspected traces of a ring similar to that surrounding the planet Saturn, and at present seen nearly edgeways. Professor Bond, of Cambridge, United States, who has under his direction one of the largest refracting telescopes in the world, announces that he has repeatedly seen some kind of luminous appendage to the planet, similar to what might be supposed to be the appearance of a thin flat ring, but he does not profess to say positively whether the phenomenon is really due to this cause, or whether it be owing to close satellites, which very probably exist, or to some optical illusion. It is understood that the astronomers of Pulkova, in Russia, who are in possession of an instrument precisely similar to that of Cambridge, United States, have not yet succeeded in observing any appearance such as would lead to the suspicion of a ring. The question will most likely remain undecided until the planet rises in declination in the course of a few years' time, so as to allow the gigantic reflecting telescopes to bear upon it advantageously. We find Mr. Lassell's present opinion to be less in favor of the existence of a ring than formerly.

After the discovery of Neptune, it became a matter of importance to ascertain if any observation of the planet existed in the catalogues of stars formed in past times. Professor Bessel and M. Lalande have determined the positions of a great number of stars in the northern heavens, but at the time the former astronomer was occupied with his observations, Neptune was always south of his limit of declination (— 15°), and consequently could not have been included in any of the zones observed at Königsberg. Lalande, on the contrary, might have seen the planet, and, in fact, did so on two occasions, May 8 and

10, 1795, as was discovered almost simultaneously by Dr. Petersen, of Altona, and Mr. Sears C. Walker, of Philadelphia. These observations, combined with the recent ones, have enabled astronomers to approximate much more closely to the true elements of the planets, than they could reasonably have expected to do from modern observations only. The most exact determination of the orbit is due to the American astronomer just named, who has devoted much of his time and attention to the subject. The planet's mean distance from the Sun is 2,862,457,000 miles; the eccentricity is comparatively small, and produces a variation in the length of the radius-vector of not more than 49,940,000 miles. The sidereal time of revolution is 60126·71 days, or rather more than 164½ years, which is very nearly double the period of Uranus. The planet is nearest to the Sun, or in perihelion when its heliocentric longitude is in 47° 15′, and traverses the plane of the ecliptic at the ascending node in longitude 130° 7′, the orbit being inclined to the Earth's path at an angle of 1° 47′.

The author has lately found three observations of Neptune as a star, by Dr. Lamont, at Munich, before its actual recognition as a planet by Dr. Galle, viz., on the 25th of October, 1845, and the 7th and 11th of September, 1846. The last observations were probably in consequence of a search commenced on the announcement of M. Le Verrier's remarkable results in the *Comptes Rendus* of the French Institute.*

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* The only collection of observations in which there appears now a probability of discovering an observation of the planet Neptune prior to the commencement of the present century, is that of M. Le Monnier, whose manuscripts are understood to be preserved at the National Observatory of Paris. It would be a great boon to astronomers if these valuable observations were printed; but the expediency of a search for any possible positions of Neptune is so great, that it is to be hoped we shall soon hear of an examination having been instituted. Many

The apparent diameter of Neptune which is subject to no sensible variation, is about 2·6″, but this diameter reduced to the Earth's mean distance from the Sun would subtend an angle of 76·6″ The real diameter of the planet is about 31,000 miles, or rather less than that of Uranus. These numbers depend upon careful measurements with some of the most powerful European telescopes.

observations of Uranus as a fixed star occur in Le Monnier's journals, and Burckhardt thought he had discovered there an observation of the planet Vesta.

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