SUPPLEMENTARY CHAPTERS

FERGUSON'S ASTRONOMY,

BY

THE EDITOR.

"Veneranda non alium quas aut magnificentius quaerunt, aut deditum et utilius quam de stellarum siderumque natura."

SENECA, Cap I, De Cometes.
SUPPLEMENTARY CHAPTERS

FERGUSON'S ASTRONOMY.

CHAP. I.

ON THE FIVE NEW PLANETS, THE GEOGRIUM SIDUS, CERES, PALLAS, JUNO, AND VESTA.

The great additions which astronomy has lately received, have given a new form to this interesting science, and extended our knowledge far beyond the limits of the system which we inhabit. The discovery of five primary, and eight secondary planets; the determination of the motion of our system in free space; the reference of all the celestial phenomena, and particularly of the inequalities arising from the mutual action of the planets, to the simple law of gravitation; and the consequent improvement of our astronomical tables, form a lasting monument to the industry and genius of their authors, and mark the close of the first, and the commencement of the present century, as the most brilliant period in the history of astronomy.

For several of these important discoveries, we are indebted to the powerful telescopes of Sir William Herschel, by which he detected two of the satellites of Saturn, and all the satellites of the Georgium Sidus. The success of this celebrated astronomer gave birth to a spirit of observation and inquiry which was before unknown. The heavens have been explored with the most unwearied assiduity, and this laudable zeal for the advancement of astronomy has been crowned with the discovery of Four new Planets.

These additions to the science do not merely present us with
a few insulated facts similar to those with which we were formerly acquainted: They exhibit to us new and unexpected phenomena, which destroy that harmony in the solar system which appeared in the magnitudes and distances of the planets, and in the form and position of their orbits. The six planets which formerly composed the system, were placed at somewhat regular distances from the Sun: They moved from west to east, and at such intervals as to prevent any extraordinary arrangements which might arise from their mutual action. Their magnitudes, too, with the exception of Saturn, increased with their distance from the centre of the system, and the eccentricity, as well as the inclination of their orbits, was comparatively small. In the present system, however, we find four very small planets between the orbits of Mars and Jupiter, placed at nearly the same distance from the Sun, and moving in very eccentric orbits which intersect each other, and are greatly inclined to the plane of the ecliptic. The satellites of the Georgium Sidus, too, appear to move nearly at right angles to the plane of his orbit; and what is still more surprising, the direction of their motion seems to be opposite to that in which all the other planets, whether primary or secondary, circulate round their respective centres.

On the Georgium Sidus.

From inequalities in the motion of Jupiter and Saturn, which could not be accounted for from the mutual action of these planets, it was inferred by some astronomers that there existed beyond the orbit of Saturn another planet, by whose action these irregularities were produced. This happy conjecture was confirmed on the 13th March 1781, when Dr. Herschel discovered a new planet, which, in compliment to his royal patron, he called the Georgium Sidus, though on the continent it is better known by the names of Herschel or Uranus. This new planet, which had been formerly observed as a small star by Flamsteed and Mayer, and introduced into their catalogues of the fixed stars, is situated beyond the orbit of Saturn, at the distance of 1,800,000,000 miles from the centre of the system, and performs its sidereal revolution round the Sun in 83 years, 150 days, and 18 hours. Its diameter is about 4½ times larger
than that of the Earth, being nearly 35,112 English miles. When seen from the Earth, its apparent diameter, or the angle which it subtends at the eye, is $3^\circ 32''$, and its mean diameter as seen from the Sun is $4^\circ$. As the distance of the Georgium Sidus from the Sun is twice as great as that of Saturn, it can scarcely be distinguished by the naked eye. When the sky, however, is serene, it appears like a fixed star of the fifth magnitude, with a bluish white light, and a brilliancy between that of Venus and the Moon; but with a power of 200 or 300, its disc is visible and well defined.

The want of light arising from the great distance of this planet from the Sun is supplied by six satellites, all of which were discovered by Dr. Herschel. The first satellite is $25'' 5$ distant from its primary, and revolves round it in 5 days, 21 hours, 25 minutes. The second satellite is $33'' 09$ distant from the planet, and performs its revolution in 8 days, 17 hours, 1 minute, 19.15 seconds. The distance of the third satellite is $38'' 57$, and its periodic time 10 days, 23 hours, 4 minutes. The distance of the fourth satellite is $44'' 23$, and the time of its periodical revolution 13 days, 11 hours, 5 minutes 1.5. The distance of the fifth satellite is about $1' 28'' 46$, and its revolution is completed in 38 days, 1 hour, 49 minutes. The sixth satellite is placed at the distance of $2' 52'' 92$ from the primary, and will therefore require 107 days, 16 hours, 40 minutes, to complete one revolution. The second and fourth of these satellites were discovered by Dr. Herschel on the 11th January 1787. The other four were discovered in 1790 and 1794, but their distances and periodic times have not been so accurately ascertained as the other two. It is a remarkable circumstance, however, that all the six satellites move in a retrograde direction, and in orbits lying in the same plane, and almost perpendicular to the ecliptic. M. Delambre has found that the inclinations of their orbits are $89^\circ 30'$, or $90^\circ 30'$, and the ascending node in $5^\circ 21'$, or $8^\circ 9'$, according as we adopt the first or the second inclination.

According to La Place, the first five satellites of the Georgium Sidus may be retained in their orbits by the action of its equator, and the sixth by the action of the interior satellites;

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1 See the Phil. Trans. for 1787, p. 175; 1788, p. 364.
2 See Phil. Trans. 1793, Part I, p. 17.
and hence he concludes, that this planet revolves about an axis very little inclined to the ecliptic, and that the time of its diurnal rotation cannot be much less than that of Jupiter or Saturn.  

When the Earth is in its perihelion, and the Georgium Sidus in its aphelion, the latter becomes stationary when his elongation or distance from the Sun is 8° 17' 37", and his retrogradations continue 151° 12'. When the Earth is in its aphelion, and the Georgium Sidus in its perihelion, it becomes stationary at an elongation of 8° 16' 27", and the retrogradations continue 149° 18'. The following table contains the elements of the orbit of the Georgium Sidus, and other particulars concerning this planet:

<table>
<thead>
<tr>
<th>Days</th>
<th>Hours</th>
<th>Min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tropical revolution</td>
<td>........</td>
<td>......</td>
</tr>
<tr>
<td>Mean distance from the Sun, that of the Earth being 100000</td>
<td>........</td>
<td>......</td>
</tr>
<tr>
<td>Density, that of water being 1</td>
<td>........</td>
<td>......</td>
</tr>
<tr>
<td>Quantity of matter, that of the Earth being 1</td>
<td>........</td>
<td>......</td>
</tr>
<tr>
<td>Diameter in English miles</td>
<td>........</td>
<td>......</td>
</tr>
<tr>
<td>Inclination of its orbit in 1780</td>
<td>........</td>
<td>......</td>
</tr>
<tr>
<td>Place of aphelion in 1800</td>
<td>........</td>
<td>......</td>
</tr>
<tr>
<td>Secular motion of aphelion</td>
<td>........</td>
<td>......</td>
</tr>
<tr>
<td>Eccentricity of its orbit, the mean distance being 100000</td>
<td>........</td>
<td>......</td>
</tr>
<tr>
<td>Longitude for 1784</td>
<td>........</td>
<td>......</td>
</tr>
<tr>
<td>Greatest equation of the centre</td>
<td>........</td>
<td>......</td>
</tr>
<tr>
<td>Longitude of ascending node in 1786</td>
<td>........</td>
<td>......</td>
</tr>
<tr>
<td>Secular motion of the node</td>
<td>........</td>
<td>......</td>
</tr>
<tr>
<td>Greatest aberration</td>
<td>........</td>
<td>......</td>
</tr>
</tbody>
</table>

On Ceres.

The planet Ceres, which is situated between the orbits of Mars and Jupiter, was discovered at Palermo, in Sicily, on the 1st of January 1801, by M. Piazzi, an ingenious astronomer, who has since distinguished himself by his numerous observations on the fixed stars. This new celestial body was then situated in Taurus, and was observed by Piazzi till the 12th of February, when a dangerous illness compelled him to discon-

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5 See Mécanique Céleste par L. Place, tome i., p. 381, tome iv. Préface, and p. 190, and Mém. de L'Institut. tome iii., p. 123.
tinue his observations. It was, however, again discovered by
Dr. Olbers of Bremen, on the 1st of January 1807, nearly in
the place where it was expected from the calculations of Baron
Zach. The nebula with which it was surrounded gave it the
appearance of a comet; and it was in consequence of the sugges-
tion of Professor Bode of Berlin, or of Baron Zach, that Piazzi,
and other astronomers ranked it among the planetary bodies.

The planet Ceres is of a ruddy colour, though not very
depth, and appears about the size of a star of the eighth magni-
tude. It seems to be surrounded with a large dense atmo-
sphere, and plainly exhibits a disc. When examined with a mag-
nifying power of about 200. From a great number of observa-
tions, Schroeter found the atmosphere of Ceres to be 675 Eng-
lish miles high, and he perceived that it was subject to num-
erous changes. The visible hemisphere was sometimes over-
shadowed, and at other times it cleared up; so that he thinks
there is little chance of discovering the period of its diurnal ro-

tation. The atmosphere of Ceres, like that of the Earth, is
very dense near the planet, and becomes rarer at a greater dis-
tance, which produces a very singular effect in the variations of
its apparent diameter. When Ceres is approaching to the
Earth, its diameter increases much more rapidly than it ought
to do from the diminution of the distance. This arises, as
Schroeter has observed, from the finer exterior strata of its at-
mosphere becoming visible while it approaches the Earth. A
similar phenomenon was observed in the comet of 1799, where
the finer and less solid strata of its coma came into view as its
proximity to the Earth increased. In moonlight, the rarer
strata of Ceres's atmosphere became invisible.

Ceres performs her revolution round the Sun in four years
seven months and ten days; and her mean distance from that
luminous body is nearly 260,000,000 of English miles. The eccen-
tricity of her orbit is a little greater than that of Mercury,
while its inclination to the ecliptic exceeds that of all the old
planets. The observations which have been hitherto made
upon this celestial body do not seem sufficiently correct to
enable us to determine its magnitude with any degree of accu-

According to the measurements of Herschel, the diameter
of Ceres does not exceed one hundred and sixty miles, while the
observations of the German astronomer Schroeter make it 1624
miles. Schroeter accounts for this remarkable difference be-
tween his measurements and those of Dr. Herschel, by maintaining, that the projection-micrometer used by the English astronomer was placed at too great a distance from the eye, and that he measured only the middle clear part of the nucleus of the planet. Schroeter made a number of experiments on this interesting subject, from which he has concluded, that, for long-sighted eyes, an illuminated projection-disc must not be removed above eight feet from the eye of the observer; and that, when the distance is greater, the diameter of the planet is found too small, by a quantity depending on the increase of distance, on the degree of illumination, and on the state of the observer’s eye. When the projection-discs were placed at the distance of 3 feet 9.9 inches, and 4 feet 3.9 inches from the eye, the diameter of Juno was found to be 2.526 seconds; but when a disc, 3.5 inches in diameter, was removed to the distance of 143 feet 4 inches from the observer, the diameter of Juno was found to be only 0.50 seconds,—about five times smaller than it ought to have been.

The following Table presents, at one view, the various particulars which are known respecting the planet Ceres.

<table>
<thead>
<tr>
<th>Years.</th>
<th>Months.</th>
<th>Days.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tropical revolution, from Lande,</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>From Maskelyne’s table</td>
<td>1631d</td>
<td>12h</td>
</tr>
<tr>
<td>Annual motion</td>
<td>2° 18’ 14”</td>
<td></td>
</tr>
<tr>
<td>Mean longitude, January 1, 1818</td>
<td>10° 26’ 51” 7”</td>
<td></td>
</tr>
<tr>
<td>Place of ascending node in 1818</td>
<td>2° 20’ 45” 1”</td>
<td></td>
</tr>
<tr>
<td>Place of perihelion in 1818</td>
<td>4° 27’ 18” 21”</td>
<td></td>
</tr>
<tr>
<td>Eccentricity in 1806, the mean distance being 1, according to Westphal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual diminution</td>
<td>0.00000563</td>
<td></td>
</tr>
<tr>
<td>Inclination of orbit in 1818</td>
<td>10° 37’ 55”</td>
<td></td>
</tr>
<tr>
<td>Annual diminution</td>
<td>0°.11</td>
<td></td>
</tr>
<tr>
<td>Annual motion</td>
<td>1°.18</td>
<td></td>
</tr>
<tr>
<td>Mean distance from the Sun, that of the Sun from the Earth being 1,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diameter in English miles, Herschel</td>
<td>260,000,000</td>
<td></td>
</tr>
<tr>
<td>Do. do. including the atmosphere, Schroeter</td>
<td>163</td>
<td></td>
</tr>
<tr>
<td>Height of Ceres’ atmosphere</td>
<td>677</td>
<td></td>
</tr>
<tr>
<td>Apparent mean diameter, as seen from the Earth, according to Harding</td>
<td>2°.5</td>
<td></td>
</tr>
<tr>
<td>Do. according to Schroeter, comprehending the atmosphere at the mean distance of the Earth</td>
<td>6°.302</td>
<td></td>
</tr>
<tr>
<td>Mean annual tropical motion, according to Westphal</td>
<td>77°.7783</td>
<td></td>
</tr>
<tr>
<td>Log. of 1 greater axis</td>
<td>0.1421029</td>
<td></td>
</tr>
</tbody>
</table>
On Pallas.

The planet Pallas was discovered at Bremen, in Lower Saxony, on the 28th March 1802, by Dr. Olbers, the same active astronomer who rediscovered Ceres. It is situated between the orbits of Mars and Jupiter, and is nearly of the same magnitude with Ceres, but of a less ruddy colour. It is surrounded with a nebulosity of less extent, and performs its annual revolution in nearly the same period. The planet Pallas, however, is distinguished in a very remarkable manner from Ceres and all the other primary planets, by the immense inclination of its orbit. While these bodies are revolving round the Sun in almost circular paths, rising only a few degrees above the plane of the ecliptic, Pallas ascends above this plane at an angle of about 25 degrees, which is nearly four times greater than the inclination of Mercury. From the eccentricity of Pallas being greater than that of Ceres, or from a difference of position in the line of their apsides, while their mean distances are nearly equal, the orbits of these two planets mutually intersect each other—a phenomenon which is altogether anomalous in the solar system.

The atmosphere of Pallas, according to the observations of Schroeter, is to that of Ceres as 101 to 146, or nearly as 2 to 3. It undergoes similar changes, but the light of the planet exhibits greater variations. On the 1st of April, the atmosphere of Pallas suddenly cleared up, and the solid nucleus or disc of the planet was alone visible. About 24 hours afterwards she appeared pale and surrounded with fog, and this appearance continued during the 3d and 4th of April. Schroeter has shown, that this phenomenon does not arise from the diurnal rotation of the planet.

The diameter of Pallas has not yet been determined with sufficient accuracy. Dr. Herschel makes it only 80 miles, which is but one-half the diameter of Ceres, while Schroeter makes it no less than 2099 miles, which is considerably larger than the magnitude that he assigned to Ceres. The elements of the
orbit of Pallas, and the other particulars which are known respecting this planet are given in the following Table:—

<table>
<thead>
<tr>
<th>Description</th>
<th>Years</th>
<th>Months</th>
<th>Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tropical revolution,</td>
<td>4</td>
<td>7</td>
<td>11</td>
</tr>
<tr>
<td>Siderereal revolution, from Maskelyne’s table</td>
<td>1703</td>
<td>6</td>
<td>11.5</td>
</tr>
<tr>
<td>Annual motion, from Maskelyne’s table</td>
<td>2</td>
<td>18</td>
<td>17</td>
</tr>
<tr>
<td>Mean longitude, January 1, 1803</td>
<td>221</td>
<td>34</td>
<td>55.64</td>
</tr>
<tr>
<td>Place of ascending node in 1803</td>
<td>172</td>
<td>28</td>
<td>12</td>
</tr>
<tr>
<td>Place of perihelion</td>
<td>121</td>
<td>8</td>
<td>8.54</td>
</tr>
<tr>
<td>Eccentricity, the mean distance being 1</td>
<td>0.2447424</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inclination of orbit in 1803</td>
<td>24.37</td>
<td>20.35</td>
<td></td>
</tr>
<tr>
<td>Mean distance from the Sun, that of the Earth being 1</td>
<td>2.768</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean distance in English miles</td>
<td>266,000,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diameter in English miles, according to Herschel</td>
<td>80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ditto ditto according to Schroeter</td>
<td>2099</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ditto ditto, comprehending the atmosphere</td>
<td>3036</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height of Pallas’ atmosphere</td>
<td>468</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apparent mean diameter, as seen from the Earth, according to Herschel</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ditto according to Schroeter, comprehending the atmosphere at the mean distance of the planet from the Earth</td>
<td>6.514</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

On Juno.

The planet Juno, situated between the orbits of Mars and Jupiter, was discovered by Mr. Harding, at the observatory of Lilienthal, near Bremen, on the evening of the 1st September 1804. While this astronomer was forming an atlas of all the stars, so far as the eighth magnitude, which are near the orbits of Ceres and Pallas, he observed, in the constellation Pisces, a small star of the eighth magnitude, which was not mentioned in the Histoire Céleste of La Lande; and being ignorant of its longitude and latitude, he put it down in his chart as nearly as he could estimate with his eye. Two days afterwards, the star disappeared; but he perceived another which he had not seen before, resembling the first in size and colour, and situated a little to the south-west of its place. He observed it again on the 5th of September, and finding that it had moved a little farther to the south-west, he concluded that this star belonged to the planetary system.
The planet Juno is of a reddish colour, and is free from that nebulousity which surrounds Pallas. Its diameter and its mean distance are less than those of the other new planets. It is distinguished from all the other planets by the great eccentricity of its orbit; and the effect of this is so extremely sensible, that it passes over that half of its orbit which is bisected by its perihelion, in half the time that it employs in describing the other half, which is farther from the Sun. From the same cause, its greatest distance from the Sun is double the least distance, the difference between the two distances being about 127 millions of miles.

Though there is no nebulous appearance around the planet Juno, yet it appears from the observations of Schroeter, that it must have an atmosphere more dense than that of any of the old planets of the system. A very remarkable variation in the brilliancy of this planet has been observed by this astronomer. He attributes it chiefly to changes that are going on in its atmosphere, though he thinks it not improbable that these changes may arise from a diurnal rotation performed in 27 hours. The following elements were calculated by Nicolai.

<table>
<thead>
<tr>
<th>Years</th>
<th>Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual revolution</td>
<td>4</td>
</tr>
<tr>
<td>Mean longitude, 1819, at Mainz,</td>
<td>117° 45'</td>
</tr>
<tr>
<td>Place of ascending node,</td>
<td>171° 6'</td>
</tr>
<tr>
<td>Place of perihelion in 1819,</td>
<td>53° 32'</td>
</tr>
<tr>
<td>Excentricity, Gauss,</td>
<td>0.2543634</td>
</tr>
<tr>
<td>Inclination of orbit,</td>
<td>13° 3'</td>
</tr>
<tr>
<td>Mean distance from the Sun in English miles,</td>
<td>280,000,000</td>
</tr>
<tr>
<td>Mean distance,</td>
<td>2.069</td>
</tr>
<tr>
<td>Daily tropical motion,</td>
<td>813°.86981</td>
</tr>
<tr>
<td>Diameter in English miles, according to Schroeter,</td>
<td>1425</td>
</tr>
<tr>
<td>Apparent mean diameter, as seen from the Earth, according to Schroeter,</td>
<td>3°.057</td>
</tr>
</tbody>
</table>

On Vesta.

From the regularity observed in the distances of the old planets from the Sun, some astronomers supposed that a planet existed between the orbits of Jupiter and Mars. This idea was entertained by M.M. Lambert, Bode, and Wurm. By assuming 10 as the mean distance of the Earth from the Sun, they found the follow-
On the five new planets.

The discovery of Ceres confirmed this happy conjecture; but the opinion which it seemed to establish respecting the harmony of the solar system, appeared to be completely overthrown by the discovery of Pallas and Juno. Dr. Olbers, however, imagined that these small celestial bodies were merely the fragments of a larger planet, which had been burst asunder by some internal convulsion, and that several more might yet be discovered between the orbits of Mars and Jupiter. He therefore concluded, that though the orbits of all these fragments might be differently inclined to the ecliptic, yet, as they must have all diverged from the same point, they ought to have two common points of reunion, or two nodes in opposite regions of the heavens, through which all the planetary fragments must sooner or later pass. One of these nodes Dr. Olbers found to be in Virgo, and the other in the Whale, and it was actually in the latter of these regions that Mr. Harding discovered the planet Juno.

With the intention, therefore, of detecting other fragments of the supposed planet, Dr. Olbers examined thrice every year all the little stars in the opposite constellations of the Virgin and the Whale, till his labours were crowned with success on the 29th March 1807, by the discovery of a new planet in the constellation Virgo, to which he gave the name of Vesta.

As soon as this discovery was made known in England, the planet was observed at Blackheath, on the 20th April 1807, by

<table>
<thead>
<tr>
<th>Distances.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury,</td>
</tr>
<tr>
<td>Venus,</td>
</tr>
<tr>
<td>Earth,</td>
</tr>
<tr>
<td>Mars,</td>
</tr>
<tr>
<td>Ceres,</td>
</tr>
<tr>
<td>Jupiter,</td>
</tr>
<tr>
<td>Saturn,</td>
</tr>
<tr>
<td>Uranus,</td>
</tr>
</tbody>
</table>

The distances of more remote Planets, if they exist, |
| 3076 = 4 + 3.2° |
| 1540 = 4 + 3.2° |
| 772 = 4 + 3.2° |

If we begin to reckon from Venus, and call a the rank of the planet, its distance will be 4 + 3.2° a. This table may be prolonged by doubling the distance, beginning from the Earth, and subtracting 4. Thus for Uranus, we have 2 × 100 − 4 = 196. This law, which is quite empirical, is not rigorously accurate, and [no conjecture has yet been formed respecting the foundation of it. See De Lamber's Astronomie, tom. ii, p. 549, 550.
S. Groombridge, Esq., an ingenious and active astronomer, who has successfully devoted his leisure and his fortune to the advancement of astronomy. He continued to observe it with his excellent astronomical circle till the 20th May, when, from its having ceased to become visible on the meridian, he had recourse to equatorial instruments. On the 11th of August, Mr. Groombridge resumed his meridional observation, from which he has computed part of the elements of its orbit; and he had the good fortune to observe the ecliptic opposition of the planet on the 8th of September 1808, at 7h 30', in longitude 11° 15' 54' 26''. His observations were continued till the beginning of November 1808, and he expected to have found the planet again at its opposition in February 1810; but, from a continuance of cloudy weather, and probably from errors in the elements, he did not succeed.

The planet Vesta is of the 5th or 6th magnitude, and may be seen in a clear evening by the naked eye. Its light is more intense, pure, and white than any of the other three; and it is very similar in its appearance to the Georgium Sidus. It is not surrounded with any nebulous; and even with a power of 636, Dr. Herschel could not perceive its real disc. The orbit of Vesta cuts the orbit of Pallas, but not in the same place where it is cut by that of Ceres. According to the observations of Schröter, the apparent diameter of Vesta is only 0.488 of a second, one half of what he found to be the apparent diameter of the 4th satellite of Saturn; and yet it is very remarkable, that its light is so intense, that Schröter saw it several times with his naked eye.

M. Burekhardts is of opinion, that Le Monnier had observed this planet as a fixed star, since a small star, situated in the same place, and noticed by that astronomer, has since disappeared.

The following are the elements of the orbit of Vesta, computed by Mr. Groombridge, from his own observations.

<table>
<thead>
<tr>
<th>Years</th>
<th>Days</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>66</td>
<td>4</td>
</tr>
<tr>
<td>Place of perihelion</td>
<td>8° 13' 0&quot; 0' 0&quot;</td>
<td></td>
</tr>
<tr>
<td>Place of ascending node</td>
<td>3° 14' 38' 0&quot;</td>
<td></td>
</tr>
<tr>
<td>Inclination of orbit</td>
<td>7° 8' 20&quot;</td>
<td></td>
</tr>
<tr>
<td>Mean distance</td>
<td>2.163</td>
<td></td>
</tr>
<tr>
<td>Eccentricity in parts of the Earth's radius</td>
<td>0.0955</td>
<td></td>
</tr>
</tbody>
</table>
The following elements are given by M. Gauss:

Mean longitude at Gottingen, 204° 46' 45"
Place of ascending node, 103° 10' 41"
Place of perihelion, 250° 19' 36"
Inclination of orbit, 7° 7' 51"
Mean distance, 2.383198
Eccentricity, 0.188826

The orbits of the four new planets projected from the places of their perihelion, and their eccentricities, as given in the preceding elements, are represented in the view of the solar system given in Plate I, and in Plate IV, Fig. 1. The mean distances employed are,

<table>
<thead>
<tr>
<th>Planet</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceres</td>
<td>2.765</td>
</tr>
<tr>
<td>Pallas</td>
<td>2.791</td>
</tr>
<tr>
<td>Juno</td>
<td>2.657</td>
</tr>
<tr>
<td>Vesta</td>
<td>2.373</td>
</tr>
</tbody>
</table>

The orbits appear to intersect each other in various places; and it is obvious, that the points of intersection must be perpetually shifting, according to the changes in the aphelia of the planets.


CHAP. II.

ON THE ORIGIN OF THE FOUR NEW PLANETS, AND ON METEORIC STONES.

The existence of four planets between the orbits of Mars and Jupiter, revolving round the Sun at nearly the same distances, and differing from all the other planets in their diminutive size, and in the form and position of their orbits, is one of the most singular phenomena in the history of astronomy. The incompatibility of these phenomena with the regularity of the planetary distances, and with the general harmony of the system, naturally suggests the opi-
nion that the irregularities in this part of the system were produced by some great convulsion, and that the four planets are the fragments of a large celestial body which once existed between Mars and Jupiter. If we suppose these bodies to be independent planets, as they must be if they did not originally form one, their diminutive size, the great eccentricity and inclination of their orbits, and their numerous intersections when projected on the plane of the ecliptic, are phenomena absolutely inexplicable on every principle of science, and completely subversive of that harmony and order which before the discovery of these bodies pervaded the planetary system. But if we admit the hypothesis, that these planets are the remains of a larger body, which circulated round the Sun nearly in the orbit of the greatest fragment, the system resumes its order, and we discover a regular progression in the distances of the planets, and a general harmony in the form and position of their orbits. To a mind capable of feeling the force of analogy, this argument must have no small degree of weight, and might be reckoned a sufficient foundation for a philosophical theory. We are fortunately, however, not left to the guidance merely of analogical reasoning. The elements of the new planets furnish us with several direct arguments drawn from the eccentricity and inclination of their orbits, and from the position of their perihelion and nodes, and all concurring to shew that the four new planets have diverged from one point of space, and have therefore been originally combined in a larger body.

To those who are acquainted with physical astronomy, it is needless to state the difficulty of ascertaining the paths of four bodies whose masses are known, and which have diverged from one common node, with velocities given in quantity and direction. This problem is much more perplexing than the celebrated problem of three bodies, and is therefore beyond the grasp of the most refined analysis. It is not difficult, however, to ascertain, in general, the consequences that would arise from the bursting of a planet, and to determine within certain limits the form and position of the orbits, in which the larger fragments would revolve round the Sun.

When the planet is burst in pieces by some internal force capable of overcoming the mutual attraction of the fragments, it is obvious that the larger fragment will receive the least impetus from the explosive force, and will therefore circulate in an orbit
deviating less than any other of the fragments from the original path of the large planet; while the lesser fragments being thrown off with greater velocity, will revolve in orbits more eccentric, and more inclined to the ecliptic. Now the eccentricity of Ceres and Vesta is nearly \( \frac{1}{3} \) of their mean distance, that of Ceres being rather the greatest; and the eccentricity of Pallas and Juno is \( \frac{1}{2} \) of their mean distance, the eccentricity of Pallas being a little greater than that of Juno. We should therefore expect from the theory, that Pallas and Juno would be considerably smaller than Ceres and Vesta, and that Ceres should be the larger fragment, and should have an orbit more analogous in eccentricity and inclination than that of any of the smaller fragments to the other planets of the system. In so far as the diameters of the new planets have been measured, the theory is most strikingly confirmed by observation. According to Dr. Hérschel, the diameter of Ceres is 168 miles, while that of Pallas is only 80. The observations of Schroeter make Juno considerably less than Ceres: and though the diameter of Vesta has not been accurately ascertained, yet the intensity of its light, and the circumstance of its being distinctly visible to the naked eye, are strong proofs that it exceeds in magnitude both Pallas and Juno. The striking resemblance between the two lesser fragments Pallas and Juno in their magnitudes, and in the extreme eccentricity of their orbits, would lead us to anticipate similar resemblances in the position of their nodes, in the place of their aphelia, and in the inclination of their orbits; while the elements of Ceres and Vesta should exhibit similar coincidences. Now the inclination of Ceres is 10°, and that of Vesta 7°; while the inclination of Juno is 21°, and that of Pallas 24\( \frac{1}{2} \)°; the two greater fragments having nearly the same inclination, and keeping near the ecliptic, while the lesser fragments diverge from the original path, and rise to a great height above the ecliptic, and far above the orbits of all the other planets in the system. The inclination of the orbits of all the new planets is represented in Plate V, Fig. 24, where the greatest angle of divergency is 17\( \frac{1}{2} \)°. If it shall be found, from observation, that Vesta is one of the smaller fragments, we may then account for its position with regard to Ceres, and for the small inclination and eccentricity of its orbit, by supposing the planets Ceres, Pallas, and Juno, to have diverged in the same plane, and nearly at right angles to the ecliptic, while Vesta diverged
from the direction of the original planet in a plane parallel with
the ecliptic. This will be understood from Fig. 25, where $OC$

is the path of the greater fragment Ceres; $OJ$, $OP$, the direc-
tion in which the fragments Juno and Pallas were projected,
lying in different planes $OCJ$, $OCP$; and $OV$, the direction
in which Vesta was projected in a plane $OCV$, nearly perpen-
dicular to the plane $OPC$. This opinion is strongly confirmed
by the fact, that the orbit of Vesta is nearer to the Sun than
any of the orbits of the other three fragments.

In the position of the nodes, we perceive the same coincidence.
The orbits of Pallas and Juno cut the ecliptic in the same point,
and the nodes of Ceres and Vesta are not far distant. This will
be distinctly seen in Fig. 26, where the two smaller fragments
still keep together, and the two larger ones are not very remote.

If all the fragments of the original planet had, after the ex-
plosion, been attracted to the larger fragment, it is obvious that
they would all move in the same orbit, and consequently have
the same perihelion. If the fragments received a slight degree
of divergency from the explosive force, and moved in separate
orbits, the points of their perihelion would not coincide, and
their separation would increase with the divergency of the
fragments. But since all the fragments partook of the motion
of the primitive planet, the angle of divergency could never be
very great, and therefore we should expect that all the peri-
helia of the new planets would be in the same quarter of the
heavens. This theoretical deduction is most wonderfully con-
firmed by observation. It will appear from Fig. 27, where we
have projected the perihelia of the four new planets, that all the
perihelia are in the same semicircle, and all the aphelia in the
opposite semicircle; the perihelia of the two larger fragments,
Ceres and Vesta, being near each other, as might have been ex-
pected, while there is the same proximity between the perihelia
of the lesser fragments Pallas and Juno.

These singular resemblances in the motions of the greater
fragments, and in those of the lesser fragments, and the strik-
ing coincidence between theory and observation in the eccentri-
city of their orbits, in their inclination to the ecliptic, in the po-
sition of their nodes, and in the places of their perihelia, are
phenomena which could not possibly result from chance, and
which concur to prove, with an evidence amounting almost to
demonstration, that the four new planets have diverged from one common mode, and have therefore composed a single planet.

Let us now proceed to consider the other phenomena which might be supposed to accompany this great convulsion. When the cohesion of the planet was overcome by the action of the explosive force, a number of little fragments, detached along with the greater masses, would, on account of their smallness, be projected with very great velocity; and being thrown beyond the attraction of the larger fragments, might fall towards the Earth when Mars happened to be in the remote part of his orbit. The central parts of the original planet being kept in a state of high compression by the superincumbent weight, and this compressing force being removed by the destruction of the body, a number of less fragments might be detached from the larger masses by a force similar to the first. These fragments will evidently be thrown off with the greatest velocity, and will always be separated from those parts which formed the central portions of the primitive planets. The detached fragments, therefore, which are projected beyond the attraction of the larger masses, must always have been torn from the central parts of the original body; and it is capable of demonstration, that the superficial or stratified parts of the planet could never be projected from the fragments which they accompany.

When the portions which are thus detached arrive within the sphere of the Earth's attraction, they may revolve round that body at different distances, and may fall upon its surface in consequence of a diminution of their centrifugal force; or, being struck by the electric fluid, they may be precipitated on the Earth, and exhibit all those phenomena which usually accompany the descent of meteoric stones. Hence we perceive the reason why the fall of these bodies is sometimes attended with explosions, and sometimes not; and why they generally fall obliquely, and sometimes horizontally, a direction which they never could assume if they descended from a state of rest in the atmosphere, or had been projected from volcanoes on the surface of the Earth.

If we compare the specific gravity of meteoric stones with the density of the new planets, we shall obtain another argument in support of the theory. It appears from the observations of Dr.
Maskelyne on the attraction of Shehallien, and particularly from the experiments of Mr. Cavendish on the attraction of leaden balls, that the density of the Earth increases towards its centre; and therefore the density of the central parts must exceed the average density of the whole globe. This gradation of density no doubt arises from the weight of the superincumbent mass; and hence we are fully entitled to conclude, that the density of the central parts of every other planet is greater than the average density of the body. As it is demonstrable, therefore, that the fragments of the large planet, which are supposed to be meteoric stones, must have been detached from the central parts of the primitive planet, the specific gravity of meteoric stones ought to exceed the average density of the planet. According to the observations of Mr. Playfair, the density of Shehallien is only 2.7, while that of the Earth is 4.8; so that the density of the central parts of our globe cannot be less than 7 or 8, in order to make up the mean density. Now, the density of the new planets, estimated from their position in the system by the method of Lagrange, is nearly 2; and reasoning from analogy, and following the proportion already stated in the case of the Earth, we should expect that the average density of meteoric stones should be about 3.2, which happens to be the exact specific gravity of the greatest number of these bodies. This coincidence is truly surprising, and when taken in connection with the evidence arising from the form and position of the orbits of the new planets, gives a probability to the theory which no other hypothesis can claim. Those who maintain that meteoric stones have fallen from the Moon, or have been produced in our own atmosphere, have adopted these hypotheses because they had no other to choose. To suppose that dense bodies, containing a great proportion of iron, are generated in the air, is an assumption repugnant to every principle of science; and to maintain that they are projected by lunar volcanoes, when such volcanoes are only conjectured to exist, and when a force of projection would be requisite, which has never been exhibited in any volcanic eruption on our earth, is one of those hypotheses which is neither suggested by facts, nor founded on analogy. Astronomers have indeed perceived some faint gleams of light in the obscure part of the lunar disc, but this is no proof that these radiations are the flames of a volcano. The aeronaut, who is hovering above our own globe, might, with equal
justice, imagine, that he was soaring above burning mountains, when he saw merely an accidental fire, or was contemplating tracts of heath that were occasionally blazing upon its surface.

We shall now conclude this section, by endeavouring to answer a very plausible objection which may be urged against the preceding theory. If meteoric stones are the fragments of a planet, why are they all of the same kind? If our own Earth were to be burst in pieces, we should find among its fragments stones of every description. This objection is founded on the supposition that the Earth is everywhere stratified, and that there exists at its centre the same diversity of minerals which occur at its surface. This opinion is purely hypothetical. We have scarcely penetrated beyond the surface of the globe, and we have every reason to believe that the stratification is completely superficial. The density of the internal mass is known to be extremely great, and the magnetism of the Earth demonstrates that this mass must be either iron-stone or melted metals which have the magnetic virtue. Now, if we suppose the Earth to be burst in pieces by some internal force, the smaller fragments that would be projected beyond its sphere of attraction must come from the central parts, and none of the superficial or stratified parts would be detached from the fragment to which they belong. The only way in which we can conceive the superficial parts of the planet to be affected, is by the shock given to the fragment on which they rest. But this shock cannot possibly produce a velocity greater than the velocity of the fragment itself; and since the fragment is supposed by the hypothesis to continue in an orbit not far from the orbit of the original planet, its superficial parts must also remain in the same region of the heavens. The portions of our globe, therefore, that would be thrown beyond the reach of its attraction, would be the dense parts towards its centre, which in all probability would be either iron-stone, or melted metals that had the magnetic virtue. Reasoning from analogy, therefore, we should draw the same conclusion respecting the imaginary planet between Mars and Jupiter; and it is a very singular circumstance, that meteoric stones contain a great proportion of iron, that they are endowed with the magnetic virtue, and that the large meteoric stones which have been found in Siberia and in South America are masses of melted iron.

It would not be difficult to anticipate a number of objections
which might be urged against the preceding theory; but however formidable these may be, we ought to remember, that such difficulties do not belong to the hypothesis itself, but arise from our ignorance of the changes induced upon the fragments during their passage through the Earth's atmosphere; and that they belong equally to every hypothesis that has yet been suggested. It is not fair, therefore, to demand from one theory an explanation of difficulties which belong to all. It is sufficient to give a plausible explanation of the phenomena; and to combine, under a general principle, the scattered facts that cannot otherwise be generalised consistently with the established laws and analogies of nature.

Since the preceding views were laid before the public, the celebrated M. De Lagrange has published a memoir on planetary explosion, in the Connaissance des Tems for 1814, p. 211. He supposes the bursting of a planet to be a very probable event, and he has investigated formulae for computing the velocity with which the fragments of a burst planet must be projected, in order to move in elliptical, parabolic, or hyperbolic orbits. He determines also the explosive force necessary to burst a planet, so that one of its fragments may become a comet, and he shews that a fragment detached from the Earth would become a direct comet if the velocity of its projection were 121 times that of a cannon-ball, and a retrograde comet, if its velocity were 196 times that of a cannon-ball. For planets situated beyond the orbit of the Georgium Sidus, a velocity 12 or 15 times greater than that of a cannon-ball would make the fragments move in an elliptical or parabolic orbit, whatever be the dimensions of the direction in which they are projected. In the case of other planets than the Earth, the number of times the velocity of a cannon-ball that the fragment should have to become a comet will be found by dividing 121 or 156, according as it is to be direct or retrograde, by the square root of the mean distance of the planet. As a less velocity is requisite to make the fragments move in an ellipse, the velocity necessary for the four small planets will be less than 20 times that of a cannon-ball.
CHAP. III.

ON THE NEW DISCOVERIES, &c. IN MERCURY, VENUS, MARS, JUPITER, AND SATURN.

However brilliant have been the discoveries in astronomy, by which the present century has been distinguished, yet those which were made on the old planets of the system by Dr. Herschel and Mr. Schroeter, with the assistance of powerful telescopes, are not less interesting and important. The discovery of mountains in Mercury and Venus, of the double ring and interior satellites of Saturn, and the determination of its diurnal revolution, are a few of the important facts which have been added to astronomy, by the improvement of the telescope.

On Mercury.

The planet Mercury is about 3224 English miles in diameter, and revolves round the Sun at the distance of 37 millions of miles. He emits a brilliant white light, and twinkles like the fixed stars. The dazzling splendour of his rays, the shortness of the interval during which observations can be made upon his disc, and his proximity to the vapours of the horizon when he is observed, have prevented astronomers from making any interesting discoveries respecting this planet. When Mercury is viewed with a telescope of high magnifying power, he exhibits to all the other planets nearly the same phases, as the Moon does to the Earth, being sometimes horned, and sometimes nearly full. Dr. Herschel has frequently examined Mercury with telescopes magnifying 200 and 300 times; but he always appeared equally luminous in every part of his disc, without any dark spot or ragged edge. Mr. Schroeter, however, would appear to have been more successful. He maintains that he has seen not only spots, but even mountains, in Mercury; and that he succeeded in measuring the altitude of two of them. One of these mountains was little more than 1000 toises in height, but the other measured 8900 toises, or ten miles and three quarters, which is nearly thrice as high as
Chimboraco, the highest mountain upon our own Earth. The highest mountains are situated in the southern hemisphere of Mercury. By examining the variation in the daily appearance of Mercury's horns, Schrøter found the period of his diurnal rotation about his axis to be 24 days 5 hours and 28 minutes. Wallot imagined that Mercury had a horizontal refraction of 276°; but Bugge, when observing the transit of this planet in 1802, could perceive no traces of an atmosphere.

Venus

We have already given some account of the observations by which Cassini and Bianchini endeavoured to ascertain the diurnal revolution of Venus. Figures 1st and 2d of Plate II, Sup. represent the spots observed by Bianchini. Fig. 1. and 2.

The powerful telescopes of Dr. Herschel and Mr. Schröter have been recently employed in examining the various appearances of this planet. On the 19th June, 1780, spots of Venus were observed upon the surface of this planet, as represented in Figure 3d, where a d c is a bluish darkish spot, and c e b a brighter spot. Fig. 3, Sup. They met in an angle at a point c, about one-third of the diameter of Venus from the cusp a. This astronomer also observed, that Venus was much brighter round her limb, than in that part which separates the enlightened from the obscure part of her disc. As this brightness round her limb diminishes pretty suddenly, it resembles a narrow luminous border, and therefore does not seem to be the result of any optical deception. The light seemed to decrease gradually between this border and the boundary between the illuminated and obscure parts of her disc. Mr. Schröter had observed before Dr. Herschel, "that the light appears strongest at the outward limb, from whence it decreases gradually, and in a regular progression towards the interior edge;" but he differs from the doctor with regard to the sudden diminution of this marginal light. "With regard to the cause of this appearance," says Dr. Herschel, "I may venture to ascribe it to the atmosphere of Venus, which, like our own, is probably replete with matter that reflects and refracts light copiously in all directions. Therefore, on the border where we have an ob-
lique view of it, there will, of consequence, be an increase of this luminous appearance." Dr. Herschel considers the real surface of Venus to be less luminous than her atmosphere, and this accounts for the small number of spots which appear upon her disc. "For this planet," says he, "having a dense atmosphere, its real surface will commonly be enveloped by it, so as not to present us with any variety of appearances. This also points out the reason why the spots, when any such there are, appear generally of a darker colour than the rest of the body." The observations of this astronomer did not enable him to ascertain the diurnal rotation of Venus, or the position of her axis; but he is of opinion, that it can hardly be so slow as 24 days, the period assigned by Bianchini.

The atmosphere of Venus appears to be very dense, not merely from the changes which take place in her dark spots, but as Schroeter inferred, from the illumination of her cusps when she is near her inferior conjunction, where the enlighted ends of the horns reach far beyond a semicircle.

Mr. Schroeter seems to have been very successful in his observations upon Venus; but the results which he has obtained are more different than could have been wished from the observations of Dr. Herschel. He discovered several mountains in this planet, and found, that like those of the Moon, they were always highest in the southern hemisphere, their perpendicular heights being nearly as the diameters of their respective planets. From the 11th December 1789, to the 11th of January 1790, the southern horn b of Venus appeared much blunted, with an enlighted mountain m, in the dark hemisphere, about 18800 toises, or nearly 22 miles high.

Mr. Schroeter measured the altitude of four mountains in Venus, and obtained the following results:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest</td>
<td>18900</td>
<td>22.05</td>
<td>3d Highest</td>
<td>9500</td>
</tr>
<tr>
<td>2d Highest</td>
<td>18750</td>
<td>18.97</td>
<td>4th Highest</td>
<td>9000</td>
</tr>
</tbody>
</table>

In order to determine the daily period of the planet, Mr. Schroeter observed the different shapes of the two horns of Venus. Their appearance generally varied in a few hours, and
became nearly the same at the corresponding time of the subsequent day, or rather about half an hour sooner every day. Hence he concluded, that the period of Venus's daily motion about its axis, must be about 23½ hours; that her equator is considerably inclined to the ecliptic, and the pole at a considerable distance from the point of the horn. On the 30th of December 1790, at 8 o'clock in the morning, the southern horn appeared with the same bluntness, and with the same enlightened mountain in the dark hemisphere, that it had done on the 28th December 1789, at 5 o'clock in the morning. Hence he found, that the period of Venus's daily motion about her axis, must be 23² 20' 59", only about one minute less than that which is given by Cassini. This alternate bluntness and sharpness in the horns of Venus, Schroeter supposes to arise from the shadow of a high mountain. The appearance of Venus, with her rugged edge and blunt horn, is represented in Fig. 4, 5.

The luminous margin which we have already mentioned, induced Mr. Schroeter to believe, that this planet had an atmosphere of a considerable extent. At the interior edge the light becomes dim, till it loses itself in a faint bluish grey, forming a ragged margin (as in Fig. 4, 5), which it is difficult to perceive even with the best telescopes. This diminution of light is much more sensible about the middle d, than at the cusps a, b.

On the 9th of September 1790, he observed, that the southern cusp of Venus disappeared, and was bent like a hook, about 8" beyond the luminous semicircle, into the dark hemisphere. The northern cusp had the same tapering termination, but did not encroach upon the dark part of the disc. A streak, however, of the glimmering bluish light proceeded about 8" along the dark limb, from the point of the cusp from b to c (Fig. 4, 5), b being the extremity of the diameter ab, and consequently the natural termination of the cusp. The streak bc, verging to a pale grey, was faint when compared with the light of the cusp at b. This phenomenon Mr. Schroeter considers as the twilight, or crepuscular light of Venus. "That it is a real twilight," says he, "will appear from the relative appearances of the cusps. On the 9th and 12th March 1790, when the southern cusp extended in a hooked direction, into the dark hemisphere, the pale blue light
appeared only at the point of the northern cusp, and proceeded in a spherical curve into the dark part. On the 10th of March, when the southern cusp did not proceed so far, the pale streak was perceived at both points, but more sensibly at the northern. The bright prolongation of the southern cusp on the 10th and 12th of March, must be ascribed to the solar light on a ridge of mountains, whence it could not be strictly spherical. When the bright prolongation was not considerable, twilight had its due effect, and the true spherical arc of the dark limb appeared faintly illuminated.” From these observations, Mr. Schroeter has calculated that the densest part of Venus’s atmosphere is about 16,020 feet high; and he concludes, that it must rise far above the highest mountains, that it is more opaque than that of the Moon, and that its density is a sufficient reason why we do not discover, in the surface of Venus, those superficial shades, and varieties of appearance, which are to be seen on the other planets.

The planet Venus has generally been considered as about 220 miles less in diameter than the Earth, but it appears from the measurements of Dr Herschel, that when reduced to the mean distance of the Earth, her apparent mean diameter is 18°.79, that of the Earth being 17°.2, that is, 8648 English miles, that of the Earth being 7912. This result is rather surprising, but the observations have the appearance of accuracy.

The explanation of the different phases of Venus has been already given in Vol. I. We shall therefore conclude this section with pointing out the method of finding the proportion between the illuminated and obscure part of her disc at any given time. The following table, calculated for this purpose by Mr. Bode of Berlin (See Tables de Berlin, vol. iii, p. 257), answers for finding the phases of the Moon, as well as those of Venus.
### Table

To find the enlightened Part of the Diameter of the Moon or Venus, supposing the Diameter to be divided into 12 equal Parts.

<table>
<thead>
<tr>
<th>Degrees</th>
<th>0°</th>
<th>30°</th>
<th>60°</th>
<th>90°</th>
<th>120°</th>
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</thead>
<tbody>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parts</td>
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<td>0.804</td>
<td>3.000</td>
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<tr>
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<td>6.101</td>
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<tr>
<td>Parts</td>
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<td>3.277</td>
<td>6.311</td>
<td>9.267</td>
<td>11.346</td>
</tr>
<tr>
<td>Parts</td>
<td>5.023</td>
<td>5.985</td>
<td>3.465</td>
<td>6.523</td>
<td>9.441</td>
<td>11.437</td>
</tr>
</tbody>
</table>

For Venus—Argument. Angle formed at the centre of Venus, by two lines drawn from Venus to the Sun and Earth.

<table>
<thead>
<tr>
<th>Degrees</th>
<th>0°</th>
<th>30°</th>
<th>60°</th>
<th>90°</th>
<th>120°</th>
<th>150°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parts</td>
<td>0.103</td>
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<td>3.560</td>
<td>6.927</td>
<td>9.526</td>
<td>11.481</td>
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<td>3.656</td>
<td>6.731</td>
<td>9.611</td>
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</tr>
<tr>
<td>Parts</td>
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<td>3.753</td>
<td>6.834</td>
<td>9.694</td>
<td>11.563</td>
</tr>
<tr>
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<td>3.850</td>
<td>6.938</td>
<td>9.776</td>
<td>11.601</td>
</tr>
<tr>
<td>Parts</td>
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<td>1.401</td>
<td>3.918</td>
<td>7.041</td>
<td>9.856</td>
<td>11.638</td>
</tr>
<tr>
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<td>4.047</td>
<td>7.145</td>
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<tr>
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<td>7.247</td>
<td>10.014</td>
<td>11.706</td>
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<tr>
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<td>1.612</td>
<td>4.247</td>
<td>7.349</td>
<td>10.091</td>
<td>11.737</td>
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<td>1.684</td>
<td>4.317</td>
<td>7.451</td>
<td>10.167</td>
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<td>5.477</td>
<td>8.535</td>
<td>10.915</td>
<td>11.977</td>
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For Venus—Argument. Angle formed at the centre of Venus, by two lines drawn from Venus to the Sun and Earth.

<table>
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<tr>
<th>Signs</th>
<th>Signs</th>
<th>Signs</th>
<th>Signs</th>
<th>Signs</th>
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</thead>
<tbody>
<tr>
<td>XI.</td>
<td>IX.</td>
<td>VIII.</td>
<td>VII.</td>
<td>VI.</td>
<td></td>
<td></td>
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</tbody>
</table>

For the Moon—Argument. Distance of the Moon from the Sun.
The argument of the preceding table, when applied to Venus, is the angle formed at her centre, by two lines drawn from Venus to the Sun and to the Earth. In order to find this angle, suppose that another line is drawn joining the Earth and Sun. Then add the angle formed at the Sun, or the anomaly of commutation, to the difference between the geocentric longitudes of the Sun and Venus, and this sum being subtracted from six signs, or 180 degrees, will leave the angle formed at Venus.

Example. Let it be required, for example, to find the proportion between the enlightened and the dark portion of Venus’s disc, on the 2d of August 1809. The Sun’s longitude being then, 4° 9° 41'; the heliocentric longitude of Venus 11° 23° 49'; and her geocentric longitude 2° 24° 2', as found from the nautical almanack. Then, as the anomaly of commutation is equal to the difference between the heliocentric longitude of the planet and the longitude of the Earth, as seen from the Sun, we have

- Helioc. long. of Venus, 11° 23° 49'
- Long. of Earth, subtract 10° 9° 41'
- Angle at the Sun, or anomaly of commutation, 1° 14° 8'
- Long. of Sun, 4° 9° 41'
- Geoc. long. of Venus, subtract 2° 24° 2'
- Difference between geoc. long. of the Sun and Venus, 1° 15° 39'
- Angle at the Sun, add 1° 14° 8'
- Sum subtract, 2° 29° 47'
- From six signs, 6° 0° 0'
- Argument, 3° 0° 13'

With this argument enter the table, and you will find 6,000 answering to 90, and the proportional parts for 18', found by the rule of proportion, will be .028, which, subtracted from 6,000, as the numbers in the table are decreasing, leaves 5,977 for the diameter of the enlightened part of Venus. Her whole diameter being 12,000, the diameter of the dark part of her disc will be 6,028; so that she is nearly a half Moon, and not far from her greatest elongation from the Sun.

The planet Venus may be often seen in the day-time with the naked eye; and by means of a telescope, furnished with a screen
for intercepting the direct rays of the Sun, she may be observed when she is very near the Sun, both at the superior and inferior conjunctions.

Mr. Dick of Perth has been particularly successful in seeing Venus under these circumstances. He observed her on the 16th October 1819, when she was only 6 days and 19 hours past her superior conjunction. At that time her distance from the Sun's eastern limb was only 1° 28' 42''. Hence Mr. Dick concludes, 1st, That Venus may be distinctly seen at the moment of her superior conjunction with the Sun, with a moderate magnifying power, when her geocentric latitude exceeds 1° 44' 47''; and, 2dly, That during the space of 583 days, in all 19 months, the time of her revolving from one conjunction of the Sun to a like conjunction again, when the latitude, at the time of her superior conjunction exceeds 1° 44' 47'', she may be seen by means of an equatorial telescope every clear day without interruption, except at the moment of her inferior conjunction, and four days before and after it. See the Edinburgh Philosophical Journal, vol. iii, p. 191.

**Mars.**

The planet Mars is remarkable for the redness of its light, the brightness of its polar regions, and the variety of spots which appear upon its surface. The atmosphere of this planet, which astronomers have long considered as of an extraordinary size and density, is the cause of the remarkable redness of its light. When a beam of white light passes through any medium, its colour inclines to red, in proportion to the density of the medium, and the space through which it has travelled. The momentum of the red, or least refrangible rays, being greater than that of the violet or most refrangible rays, the former will make their way through the resisting medium, while the latter are either reflected or absorbed. The colour of the beam, therefore, when it reaches the eye, must partake of the colour of the least refrangible rays, and this colour must increase with the number of the violet rays that have been obstructed. Hence we see that the morning and evening clouds are beautifully tinged with red; that the Sun, Moon, and stars, appear of the same colour when near
the horizon; and that very luminous object seen through a dry mist is of a ruddy hue. Now, the planet Mars is allowed to have an atmosphere of great density and extent, as is manifest from the dim appearance of the fixed stars, that are placed even at a distance from his disc.¹ The dim light, therefore, by which Mars is illuminated, having to pass twice through his atmosphere before it reaches the Earth, must be deprived of a great proportion of its violet rays, and consequently the colour of the resulting light by which Mars is visible must be red. As there is a considerable difference of colour among the other planets, and likewise among the fixed stars, are we not entitled to conclude, that those in which the red colour predominates, are surrounded with the greatest, or densest atmospheres? According to this principle, the atmosphere of Saturn must be the next to that of Mars in density or extent.

After Galileo had discovered the phases of Mars, which are mentioned in Chap. II, p. 22, 23, Vol. I, Dr. Hook and Cassini discovered upon the disc of this planet a number of dark spots. Dr. Hook perceived some trifling changes in their position, but Cassini had the merit of determining from these changes, that the diurnal revolution of the planet was performed in 24 hours 40 minutes.

The luminous zone at the southern pole of Mars, which had been often noticed by astronomers, was particularly observed by Maraldi. During six months’ observations, he found it subject to many changes. Sometimes it appeared bright, at other times faint, and after completely disappearing, it returned with its original brightness. When this spot was most luminous, the disc of Mars did not appear exactly round, but the bright part of its southern limb that terminated this spot appeared to project like a bright cap, whose exterior arch was a portion of a larger extent than the rest of the planet’s limb. This appearance resembled exactly the new Moon, when the dark part of her disc is enlightened by the Earth, and is evidently an optical deception, arising from the same cause. See Chap V.

¹ Cassini observed, that a star in Aquarius, at the distance of six minutes from the disc of Mars, became so faint before its occultation, that it could not be seen by a telescope with a three-foot telescope. The same phenomenon was observed by Roemer at Paris. Dr. Herschel considers the atmosphere of Mars as less than has been generally imagined, but he still regards it as dense and extensive.
In 1719, a favourable opportunity occurred for observing the spots upon Mars. When he was within two degrees of his peri helion, he was in opposition to the Sun, and appeared superior to Jupiter in brightness and magnitude. Maraldi observed him at that time through a refracting telescope 84 feet long, and saw the appearance which is represented in Figs. 1 and 2. A long belt extending half way round his disc, was joined by a shorter belt, forming with it an obtuse angle. By the motion of this angular point, Maraldi found its daily period to be $24^h\, 40'$, the very same with that of Cassini.

These luminous spots were observed from 1777 to 1783 by Dr. Herschel, who, by ascertaining the changes in their position, has determined the inclination of the axis, and the place of the nodes of Mars. The polar spots are represented at $a$ in Figures 3, 4, 5, 6, 7, 8, 9, 10, 11, where $a$ is the south polar spot, and $b$ the north polar one. In Fig. 4, the south polar spot has a very singular appearance, similar to what was observed by Maraldi. In consequence of its great splendour, it seems to project beyond the disc of Mars, producing a break at $c$, increased by the gibbous appearance of the planet. The south polar spot is represented in Figures 5, 6, 7, 8, 9, 10, 11, which complete the whole equatorial circle of appearances in Mars, as they are observed in immediate succession. These Figures are all connected together in one projection, in Fig. 12. "The centre of the circle marked 17," says Dr. Herschel, "is placed on the circumference of the inner circle, by making its distance from the centre of the circle marked 15, answer to the interval of time between the two observations, properly calculated and reduced to sydereal measure. The same has been done with regard to the circles marked 18, 19, 20, &c. And it will be found by placing any of these connected circles, so as to have its contents in a similar situation with the figures in the single representation which bear the same number, that there is a sufficient resemblance between them; but some allowance must undoubtedly be made for the unavoidable distortions occasioned by this kind of projection. (Phil. Trans. 1784, p. 241.)

From the similarity between Mars and the Earth, in their diurnal motion, and in the position of their equator, Dr. Herschel imagines that the bright spots at the poles of this pla-
net are produced by the reflection of the Sun's light from its frozen regions, and that the melting of masses of polar ice is the cause of the variation in the magnitude of the spots. Hence, in 1781, when the Antarctic glaciers had not felt for twelve months the thawing influence of the Sun, the south polar spot was extremely large, and in 1783, it had suffered a considerable diminution from an exposure of 8 months to the solar rays.

As the diurnal rotation of Mars has been accurately established by the motion of its spots, it was natural to expect, that in conformity to the laws of gravity, it should exhibit a spheroidal form. Owing to the gibbous appearance of this planet, there is some difficulty in taking accurate measures of his equatorial and polar diameters. Dr. Herschel, however, has succeeded in the attempt, and found that the figure of Mars was an oblate spheroid, whose equatorial diameter is to the polar as 1355 to 1272, or nearly as 16 to 15. Dr. Herschel also found, that the inclination of Mars' axis to the ecliptic is 59° 42'; that the node of the axis is in 17° 47' of Pisces; that the obliquity of the ecliptic on the globe of Mars, is 28° 42'; that the point Asc on the ecliptic of Mars, answers to our 19° 23' of Sagittarius; that the equatorial diameter of Mars reduced to the mean distance of the Earth, is 9° 8'', and that the time of his diurnal rotation is 24h 39'. The remarkable flattening at the poles of Mars probably arises from a considerable variation in the density of his different parts. La Place has computed the density of this planet to be about 1/4 of that of the Earth.

From the circumstance of Mars's having no satellite, and appearing to require light in the Sun's absence, M. Fontenelle has imagined that this planet is phosphorescent, and gives out, during night, the light which it has imbibed in the day.

Jupiter.

The planet Jupiter revolves round his axis in 9 hours 55 minutes and 37 seconds. His form, like that of the Earth and Mars, is an oblate spheroid, the equatorial being to the polar diameter as 14 to 13. This result was obtained from the accurate observations of Dr. Herschel, and it is a remarkable coincidence between theory and observation, that from the influence of the equatorial parts of Jupiter upon
the motion of the nodes of his satellites, Laplace has found the proportion between his equatorial and polar diameters to be as 10000000 to 9286992, a result which differs only a very little from the ratio of 14 to 13.

When we look at Jupiter through a good telescope, Jupiter's disc, in lines parallel to his equator. These appearances were first observed by two Jesuits, Zappi and Bartoli. They were afterwards examined in 1633, by Fontana, Rheita, Riccioli, Grimaldi, and Campani, the last of whom, on the 1st of July 1664, perceived four dark belts, and two white ones. These belts are variable both in number, distance, and position. Sometimes 7 or 8 belts have been observed, and on the 28th May 1780, Dr. Herschel perceived the whole disc of Jupiter covered with small curved belts, or rather lines, that were not continuous across his disc. This appearance of the planet is represented in Plate III, Fig. 13, 14. The parallel belts, however, are most common, and in clear weather may be seen by a good achromatic telescope, with a magnifying power of 40. The appearance which they exhibit in Dr. Herschel's telescopes, is represented in Figures 15 and 16. Sometimes they are interrupted in their length, as in Fig. 15. At other times they seem to increase and diminish alternately, to run into one another, or to separate into others of a smaller size. Bright and dark spots frequently appear in the belts, as represented in Fig. 16. Some of these revolve with greater rapidity than others, from which it appears, that they are not permanent spots upon the planet itself.

When Jupiter was in his perihelion in 1785 and 1786, M. Schröter observed his belts with a four-foot Newtonian telescope, magnifying 150 times. He perceived upon his disc, several new spots, which were black and round. In 1787, he saw two dark belts in the middle of Jupiter's disc, and near to them, two white and luminous belts, resembling those which were observed by Campani. The equatorial zone, which was comprehended between the two dark belts, had assumed a dark grey colour, bordering upon yellow. The northern dark belt then received a sudden increase of size, while the southern one became partly extinguished, and afterwards increased into an uninterrupted belt. The luminous belts also suffered several
changes, growing sometimes narrower, and sometimes one half larger than their original size.

The appearance of Jupiter, as seen by Schroeter at the time of its occultation by the Moon, on the 7th April 1792, is represented in Plate V, Fig. 5. The equatorial belt from a to d was very distinct, consisting of two zones a b, c d, of a brownish grey colour, separated by a more luminous interval b c. Two well defined stripes, which Schroeter had noticed for two years, appeared at e and f; and now crossed the whole disc. The polar regions at g and h appeared more dun and grey than the bright part of the planet. The most remarkable phenomena, however, were two nebulous undefined spots i and k, perceptibly darker than the principal belt d d; and a still more remarkable spot l, circular and imperfectly defined, and somewhat brighter than the luminous space b c e b. A similar spot was observed in 1786 and 1787 in the same part of the planet. At 10h 40' 50", the spot i was about the middle of its parallel. Fig. 5, No. 2, shews the spots and belts when Jupiter was emerging from behind the Moon, o p being the outward limb of the Moon, and m n the boundary between light and darkness.

Different opinions have been entertained by astronomers respecting the cause of the belts and spots of Jupiter. By some they have been regarded as clouds, or as openings in the atmosphere of the planet, while others imagine that they are of a more permanent nature, and are the marks of great physical revolutions, which are perpetually agitating and changing the surface of the planet. The first of these opinions sufficiently explains the variations in the form and magnitude of the belts, but it by no means accounts for the permanence of some of the spots, and the parallelism of the belts of Jupiter. The first observed by Cassini, which appeared eight times between the years 1665 and 1708, could not possibly be occasioned by any atmospheric variations; and its disappearance for five years, between 1708 and 1713, is a presumptive, though not a decisive argument, that it arose from some changes in the body of the planet. We are, however, rather disposed to think, that from the frequent appearance of this spot, it is permanent upon the body of Jupiter, and that its disappearance is owing to the interposition of clouds in the atmosphere of the planet.
were the effect of an earthquake or inundation, and if it were
the mark of a new island or continent, as has been conjectured.

upon what principle can we account for its reappearance in
1713, in precisely the same form and position? May we not
then suppose, that the clouds of Jupiter, partaking of the great
velocity of his diurnal motion, are formed into strata parallel
with the equator; that the body of Jupiter reflects less light
than the clouds, and that the belts are nothing more than the
body of the planet seen through the parallel interstices which lie
between the different strata of clouds. The permanent spot
seen by Cassini will of course only be seen when it is immedi-
ately below one of these interstices, and will therefore always
appear as if it accompanied one of the belts.2

The four satellites of Jupiter, of which a short
account has been already given in Vol. I, may in gen-
eral be seen with a telescope which magnifies 30 ter-
times. The third and fourth, indeed, have been sometimes
seen with the naked eye (Phil. Mag. xxv, p. 175), but it is
only when the air is uncommonly pure that we can expect to
be indulged with such a sight. These small bodies have been
observed by astronomers with great assiduity during the last
century, and the tables of their motions have been brought to
degree of perfection which the most sanguine expectations of
astronomers could never have anticipated. The tables of War-
gentin for finding the eclipses of these bodies, and the more
recent and accurate ones of De Lamare, founded on La Place's
theory of their mutual attractions, have been of essential use
to geographers, in enabling them to determine with accuracy
the longitude of places upon the surface of the Earth. To
astronomers the system of Jupiter and his satellites is equally
interesting. Though a century and a half has scarcely elapsed
since their discovery, yet, from the extreme shortness of their
revolutions, they present to us great and interesting changes,
which are not effected in the course of many centuries in the
planetary system.

The following table contains a full view of the elements of
the satellites of Jupiter, as deduced from the theory of La
Place, and from the most recent observations of modern astro-

1 This spot has always been seen in connexion with the great southern belt of
Jupiter. The belt indeed has been observed without the spot, but this was pro-
bably owing to a variation in the distance of the belt from the equator of Jupiter.
## Table of the Elements of the Satellites of Jupiter

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<th>Periodical revolution,</th>
<th>14th 18° 27' 33&quot;</th>
<th>14th 13° 13' 42&quot;</th>
<th>7th 3° 42' 33&quot;</th>
<th>16th 10° 39' 8&quot;</th>
<th>According to Wargentin. Used by La Place. Delambre.</th>
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<td>Synodical revolution.</td>
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<td></td>
<td>Delambre.</td>
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<tr>
<td>Motion in 100 Julian years.</td>
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<td>20655 7° 25' 29' 11&quot;</td>
<td>20655 7° 25' 29' 11&quot;</td>
<td>20655 7° 25' 29' 11&quot;</td>
<td>Delambre.</td>
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<tr>
<td>Epoch for the midnight,</td>
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<tr>
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<td>Daily motion.</td>
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<td></td>
<td>Delambre.</td>
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<tr>
<td>Distance of each satellite,</td>
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<td></td>
<td></td>
<td>Delambre.</td>
</tr>
<tr>
<td>the radius of Jupiter being unity.</td>
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<td></td>
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<td>Apparent mean distance,</td>
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<td>Mean inclination,</td>
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<td>Diameter of the satellites, as seen from the centre of Jupiter at their mean dist.</td>
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<tr>
<td>Radius of the shadow in degrees of the orbits of the satellites,</td>
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<td>Semiduration of eclipses,</td>
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<td></td>
<td>Delambre.</td>
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<tr>
<td>Time which each satellite takes to enter the shadow,</td>
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<td>Delambre.</td>
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<tr>
<td>Masses of the satellites, that of Jupiter being 1</td>
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<td></td>
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<td>Delambre.</td>
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<tr>
<td></td>
<td></td>
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<tr>
<td>II. Satellite.</td>
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<td></td>
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<tr>
<td>III. Satellite.</td>
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<tr>
<td>IV. Satellite.</td>
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<td>0° 11 11 26 49</td>
<td>0° 10 16 20</td>
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<tr>
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<td>3° 20° 19&quot; 3&quot; 27&quot;</td>
<td>0° 21° 34&quot; 10&quot; 0&quot;</td>
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<td>23.3</td>
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<td>2° 27&quot;</td>
<td>4° 42&quot;</td>
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<td>2° 36° 0&quot;</td>
<td>According to Wargentin. Used by La Place. Delambre.</td>
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<tr>
<td>6° 20°</td>
<td>20° 43° 30°</td>
<td>20° 8° 2&quot;</td>
<td>2° 12° 26&quot;</td>
<td>According to Wargentin. Used by La Place. Delambre.</td>
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<td>3° 43° 30&quot;</td>
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<td>According to Wargentin. Used by La Place. Delambre.</td>
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<td>10° 3° 30&quot;</td>
<td>6° 1° 3&quot; 2&quot;</td>
<td>3° 43° 30&quot;</td>
<td>2° 12° 26&quot;</td>
<td>According to Wargentin. Used by La Place. Delambre.</td>
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<td>1° 7° 33° 2</td>
<td>1° 25° 42° 4&quot;</td>
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<td></td>
</tr>
<tr>
<td>1° 10° 53° 45</td>
<td>1° 28° 54° 1&quot;</td>
<td>1° 50° 9° 1</td>
<td>2° 27° 13° 1</td>
<td>According to Wargentin. Used by La Place. Delambre.</td>
<td></td>
</tr>
<tr>
<td>22° 0.01038</td>
<td>306°.20730</td>
<td>604°.50604</td>
<td>630°.60762</td>
<td>According to Wargentin. Used by La Place. Delambre.</td>
<td></td>
</tr>
<tr>
<td>10° 14° 30°</td>
<td>10° 13° 45&quot;</td>
<td>10° 14° 24&quot;</td>
<td>10° 16° 39°</td>
<td>According to Wargentin. Used by La Place. Delambre.</td>
<td></td>
</tr>
<tr>
<td>2 3&quot;</td>
<td></td>
<td></td>
<td></td>
<td>Calculated by La Place. Delambre.</td>
<td></td>
</tr>
<tr>
<td>0.00000173 81</td>
<td>0.0000232355</td>
<td>0.0000484972</td>
<td>0.0000426591</td>
<td>Calculated by La Place. Delambre.</td>
<td></td>
</tr>
</tbody>
</table>

- Calculated by La Place.
In looking at the satellites of Jupiter through a common telescope, they appear to be of different magnitudes, but their diameters are so extremely small, that it is difficult to obtain an accurate measure of them by the application of the micrometer. The eclipses of these bodies, however, furnish us with a method of estimating their magnitude; for it is evident that the largest satellite will take longer time than the smaller ones to enter into his shadow. In this way M. Bailly determined the diameters which are given in the preceding table (See *Mém. Acad.* 1771, p. 590, 619, 623). The other measures which follow them in the same table were deduced by La Place from the masses of the satellites, and may be considered as very accurate (See *Mécanique Céleste*, tom. iv, p. 171, 172). By comparing the shadows of the satellites when seen upon the disc of Jupiter, Wargentin found that the third and fourth were five or six times larger than the first, and the first twice as great as the second. According to Dr. Herschel, the third satellite of Jupiter is considerably larger than the rest; the first is a little larger than the second, and nearly the size of the fourth; and the second is a little smaller than the first and fourth, or the smallest of the four. Hence the doctor expresses their relative magnitudes thus, $3 \cdot \frac{1}{4} \cdot 2$. (*Philosophical Transactions*, 1797, Part II. p. 351).

When the brilliancy of the satellites of Jupiter is examined at different times, it appears to undergo a considerable change. By comparing the mutual positions of the satellites with the times when they acquire their maximum of light, Dr. Herschel concluded that, like our Moon, they all turned round their axis in the same time that they performed their revolution round Jupiter. Maraldi had formerly deduced the same result for the fourth satellite, by observing the period of its variations.

From the theory of the reciprocal attractions of the three first satellites, La Place has discovered two very remarkable theorems concerning their motions. He found, that the mean motion of the first satellite added to twice the mean motion of the third satellite, is numerically equal to thrice the mean motion of the second satellite; that is, making $m$ the mean motion of the first, $m'$ that
of the second, and \( m'' \) that of the third, we have by the theorem,
\[
  m + 2m'' = 3m',
\]
or
\[
  m + 2m'' - 3m' = 0.
\]
By taking the mean motion of the satellites for 100 Julian years, as determined by De Lambre, La Place found that
\[ m + 2m'' - 3m' = \text{only 9 seconds}. \]
a coincidence between theory and observation which is truly astonishing.

The second theorem deduced by La Place is equally curious, though, from particular causes, it does not accord so well with observation. He found, that the epoch of the first satellite, minus three times that of the second, plus two times that of the third, is exactly equal to a semicircle, or 180 degrees; that is, making \( l, l', l'' \) the mean longitudes or epochs of the satellites, we have
\[
l - 3l + 2l'' = 180, \text{ by theory.}
\]
By taking the real epochs of the three satellites for the midnight, beginning the 1st January 1750, as determined by De Lambre, we obtain
\[
l - 3l + 2l'' = 180^\circ 1^\prime 30^\prime 6.
\]
This result differs only 63 seconds from the theory; but the cause of this difference is very satisfactorily explained by La Place in the *Mécanique Céleste*, tom. ii., p. 135, 136.

From the last of these theorems it follows, that the three first satellites of Jupiter can never be eclipsed at the same time. For if this were possible, the longitude of three satellites would be equal at the time of their eclipse, that is, \( l = l' = l'' \), consequently,
\[
l - 3l + 2l'' = 0,
\]
which is impossible. When the second and third satellites are eclipsed at the same time, their longitudes will be equal; that is, \( l = l' \); consequently, in this case, the theorem becomes
\[
l - l' = 180;
\]
that is, the difference of the longitudes of the first and second is \( 180^\circ \); but the second being in opposition to Jupiter at the time of its eclipse, the first satellite must be distant from it \( 180^\circ \); consequently, when the second and third satellites of Jupiter are simultaneously eclipsed, the first is always in conjunction with Jupiter. On the contrary, it is obvious, that
when the Sun is simultaneously eclipsed by the second and third satellites, that is, when they pass at the same time across his disc, the first satellite is in opposition to the planet.

By following out this principle, we shall find, that when the first and third satellites are simultaneously eclipsed, the difference between either of their longitudes and that of the second is 60°, for in this case \( t = t' \), and the equation becomes
\[-3l' + 3l'' = 180°, \]
\[-l' + l'' = 60°.\]

In like manner, we shall find, that when the first and second are simultaneously eclipsed, the difference between either of their longitudes and that of the third is 90°, or the third is in quadrature with Jupiter. For in this case \( l = l'' \), and hence
\[-2l' + 2l'' = 180°, \]
\[-l' + l'' = 90°.\]

It is obvious from these interesting results, that a wonderful provision is made in the system of Jupiter, to secure to that planet the benefit of his satellites. When Jupiter is deprived, at the same instant, of the light of the first and second satellites, or of the first and third, the remaining one of the three first cannot possibly be eclipsed at the same time, but is in such a point of its orbit as to give considerable light to the planet. The simultaneous eclipse of the second and third satellites forms an exception to this remark; for, at the same instant, the first satellite has its dark side turned to the planet. Even in this case, however, the first satellite, when emerging from the Sun's beams, is gradually turning more and more of its luminous hemisphere to Jupiter, to supply the loss of light arising from the want of the other two satellites.

We shall now conclude this account of Jupiter's satellites, with giving the results obtained by La Place, from a comparison of his formulæ with observation.

He found that the orbit of the first satellite moves upon a fixed plane, which passes constantly between the equator and the orbit of Jupiter, by the mutual intersection of these two last planes, whose respective inclination is 3° 5' 30", according to observation. The inclination of this fixed plane upon the equator of Jupiter is only 6½ seconds by the theory. The inclination of the orbit of the satellite to its fixed plane is equally small; so that we may conceive the first satellite as in motion upon a plane passing through the equator of Jupiter.
into the melting vessel. I could give sufficient reason for the whole of this process; but it will be enough to state, the metal will always prove good when so malleable.

"The tin will mostly be found in too small a quantity in the above proportions; but as different sorts of copper require different proportions of tin, the proper quantity can only be known by making a trial, which is most conveniently done in the second melting, by taking a small quantity out of the melting vessel with an iron ladle, having an upright handle: half an ounce will be quite sufficient; when cold, grind it upon a plate of metal with a little fine emery, to discover whether it breaks up too much to bear grinding; afterwards break it, to judge of its strength and colour, which may be done in a few minutes: more tin may be added, if required, a little at a time, until it is brought to a proper state for working. By working, I mean grinding and polishing.

"Nothing that I have yet mentioned deserves the name of difficult, compared to the last operation of grinding and polishing; particularly in the working of flat metals, such as the little metals for a Newtonian telescope.

"I have known one of the most experienced workmen bestow the labour of three weeks upon one of these; and, after all, he owned to me it was not flat; this metal was not more than two inches in its transverse diameter. But to obtain any thing perfectly
flat, or straight, or square, or round, or spherical, or any other figure, is not within the reach of Human Industry."

The late indefatigable and ingenious Earl of Stanhope had a plan for constructing a still more stupendous Optical Instrument than even the 40 feet Telescope of Sir Wm. Herschel. Mr. Varley informs us, in page 36 of No. 1, January 1820, of the London Journal of Arts and Sciences, that "his Lordship's vast design was no less than the construction of a Telescope of 384 feet in Length, with Reflectors 6 feet in Diameter.

"The observer may sit or stand in a warm room, and, without ever changing his position, observe more than one half of the horizon, the object appearing directly before him, however elevated it may be in the heavens; thus continuing in the easiest posture and without ever being exposed to the open air. No other telescope affords these very desirable advantages.

"In other telescopes, the smallness of the eyeglasses is very objectionable where highly magnifying powers are wanted; in compound eyepieces particularly, (which are by far the best,) it is next to impossible to obtain them small enough. In the Stanhope telescope, the greatest powers can be obtained with glasses of not less than two inches focus; which are of a size much more manageable in every
pears to be more luminous than Saturn himself. Hence Dr. Herschel has concluded, that it is not any shining fluid, or aurora borealis, as some have concluded, but a solid body, equal in density to the planet. The Doctor is also of opinion, that the edge of the ring is not flat, but of a spherical, or rather spheroidal, form.

In examining the plane of the ring with a powerful telescope, he perceived near the extremity of its arms or ansae, several lucid or protuberant points, which seemed to adhere to the ring. At first he imagined them to be satellites; but he afterwards found, upon careful examination, that none of the satellites could exhibit such an appearance; and he therefore concluded, that these lucid points adhered to the ring, and that the variation in their position arose from a rotation of the ring round its axis, which he found to be performed in 10h 32m 15s. This result is very remarkable; for if we conceive a satellite moving round Saturn, and having for its orbit the mean circumference of the ring, and if we calculate, according to the second law of Kepler, its sydereal revolution, we shall find that the duration of its revolution is nearly equal to the revolution of the ring. According to Dr. Robison, the inner edge of Saturn's ring should revolve in 11h 16', and the outer edge in 17h 10'. Schroeter seems to doubt of the rotation of the ring.

The surface of the ring of Saturn does not seem to be exactly plane. One of the ansae sometimes disappears, and presents its dark edge, while the other ansa continued to appear, and exhibited a part of its plane surface. On the 9th October 1714, the ansae appeared twice as short as usual, and the eastern one much longer than the western; and on the 12th October, Saturn was seen with only its western ansa. On the 11th of January 1774, M. Messier observed both the ansae completely detached from the planet, and the eastern one larger than the other. In 1774, Dr. Herschel likewise observed Saturn with a single ansa. From these observations, it is natural to conclude, that there are irregularities on the surface of the ring, and that the disappearance of the ansae arises from a curvature in its surface.

* When the ring of Saturn was extremely oblique to the eye, M. Messier observed upon it several luminous points, which were greater than the delicate line of light that formed the ansae of the ring.
These inequalities in the surface of the ring are considered by La Place as absolutely necessary for maintaining the ring in equilibrium round Saturn; and he has shewn, that if the ring were a regular body, similar in all its parts, its equilibrium would be disturbed by the slightest force, such as the attraction of a comet or a satellite; and that it would finally be precipitated upon the surface of the planet. Hence this celebrated philosopher has concluded, that the different rings, with which Saturn is encircled, are irregular solids, of unequal breadth in different parts of their circumference, so that the centres of gravity do not coincide with their centres of figure; and that these centres of gravity may be considered as so many satellites circulating round Saturn, at distances depending on the inequality of the parts of each ring, and with periods of rotation equal to those of their respective rings. Hence the ring will turn round its centre of gravity in the same time that it revolves round Saturn. It is obvious, that the action of the Sun and the satellites of Saturn upon these rings, ought to produce motions of precession analogous to those of the Earth's equator; and that as these motions ought to be different for each ring, they ought finally to move in different planes. This result, however, is contrary to observation; and, accordingly, La Place has discovered, that the action of the equator is the cause which retains all the rings in one plane. It was from this phenomenon, of which the cause is now apparent, that he ascertained the rotation of the planet, before Dr. Herschel had determined it by direct observation. See Mécanique Céleste, tom. ii, p. 165, 373, and Mem. Acad. Par. 1787.

Not content with explaining the various phenomena presented by the ring of Saturn, astronomers have travelled beyond the precincts of their science to explain the manner in which the ring was formed. Maupertuis, in his Discours sur la Figure des Astres, has maintained, that this luminous girdle was the tail of a comet, which the attraction of Saturn had compelled to circulate around him. Mairan asserted that the diameter of the planet was originally equal to the diameter of its outer ring; and, that by

* Mr. Short assures us, that with an excellent telescope, he observed the surface of the ring divided by several dark concentric lines, which seemed to indicate a number of rings proportional to the number of dark lines which he perceived.
some unknown cause, the exterior shell of Saturn was broken to pieces which were attracted by his body: But the equatorial parts of the exterior shell remained entire, and thus formed a ring about the planet. Buffon imagines that the ring is a part of the equator which has been detached by the excess of centrifugal force. Without spending time in the discussion of these hypotheses, it may be sufficient to observe, that we may as well attempt to account for the formation of the satellites as of the ring of Saturn; that none of them seem to have been the effect of any accidental cause; and that the most rational solution of the difficulty is to suppose, that when Saturn was created and launched into the heavens, he was at the same instant encircled with a luminous ring, to answer some important purpose, which astronomers have not yet had the sagacity to discover.

The disappearance and reappearance of Saturn’s ring having been already explained in Vol. I, § 201, we shall conclude this interesting subject, by pointing out the method of determining the phases of Saturn’s ring for any given time. The Table which is employed for this purpose, serves also to find the form of the orbits of the four first satellites of Saturn, as seen from the Earth. (See Tables de Berlin, tom. iv, p. 157.)

Table for finding the apparent Figure of the Ring and the Orbits of the four first Satellites of Saturn.

<table>
<thead>
<tr>
<th>Argument.</th>
<th>Long. of Saturn + 13° 43' 30&quot;.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.000</td>
</tr>
<tr>
<td>3</td>
<td>0.027</td>
</tr>
<tr>
<td>6</td>
<td>0.051</td>
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<td>9</td>
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<td>12</td>
<td>0.108</td>
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<tr>
<td>15</td>
<td>0.135</td>
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<td>18</td>
<td>0.161</td>
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<tr>
<td>21</td>
<td>0.187</td>
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<tr>
<td>24</td>
<td>0.212</td>
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<tr>
<td>27</td>
<td>0.236</td>
</tr>
<tr>
<td>30</td>
<td>0.260</td>
</tr>
<tr>
<td>XI. V.</td>
<td>+</td>
</tr>
<tr>
<td>X. IV.</td>
<td>-</td>
</tr>
<tr>
<td>IX. III.</td>
<td>+</td>
</tr>
</tbody>
</table>
In order to find the figure of Saturn's ring, add \( \frac{13^\circ 43' 30''}{13^\circ 43' 30''} \) to the geocentric longitude of Saturn, \( \frac{8^\circ 9' 28''}{13^\circ 43' 30''} \), and with this as an argument, enter the table with the signs at the head or foot, and the degrees at the side; and the corresponding numbers in the table will express the smaller axis of the ring, the greater axis being 1000. This result, however, requires a correction, which depends upon the latitude of Saturn. Reduce his latitude, therefore, to minutes, and the fourth part of his latitude, thus reduced, being applied to the preceding result with the sign \( + \) if his latitude be north, but with the sign \( - \) if his latitude be south, will give the true apparent size of the lesser axis of the ring.

Let it be required, for example, to find the form of Saturn's ring on the 25th December 1809, when the geocentric longitude of Saturn is \( 8^\circ 9' 28'' \), and his geocentric latitude \( 1^\circ 37' \) or \( 97^\circ \) north.

\[
\begin{array}{l}
\text{To the geocentric longitude of Saturn,} & \frac{8^\circ 9' 28''}{13^\circ 43' 30''} \\
\text{Add the constant quantity,} & \frac{13^\circ 43' 30''}{13^\circ 43' 30''} \\
\text{Argument,} & \frac{5^\circ 23' 11'' 30''}{-0.0417} \\
\text{which corresponds in the table with} & \frac{+0.517}{-0.024} \\
\text{Apply one fourth of the latitude, or \( \frac{1}{4} \)} & \frac{-0.024}{-0.024} \\
\text{The smaller axis of the ring,} & \frac{+0.517}{+0.517} \\
\end{array}
\]

Hence the smaller axis of Saturn's ring is to its greater axis, at the given time, as \( 541 \) is to 1000, so that the ring will be very open on the 25th December, and may be easily seen with a telescope. When the sign \( + \) is before the result, it indicates, that the most distant half of the ring is farther north than the centre of Saturn, and consequently, that we see the upper or northern surface of the ring. The opposite sign \( - \) indicates, that the most distant half of the ring is more south than the centre of Saturn, and the southern side of the ring is then visible. The result which is thus obtained, marks also the figure of the orbit of the four first satellites of Saturn.

When we look with a good telescope at the body \( \text{Figure of} \) of Saturn, he appears, like most of the other planets, \( \text{Saturn} \), to be of a spheroidal form, arising from a rapid rotation about his axis. On the 14th September 1789, Dr. Herschel measured his diameter, and found that the equatorial diameter was \( 22^\circ 8' \), and the polar diameter \( 20^\circ 6' \), which gives the proportion
of nearly 10 to 11. It appears, however, from more recent observations made by the same astronomer, that the polar is to the equatorial diameter as 32 to 35, or as 11 to 12 nearly. Till the year 1805 Dr. Herschel had always regarded Saturn as an accurate spheroid; but on the 12th April of that year, he was struck with a very singular appearance exhibited by the planet. The flattening at the poles did not seem to begin till a very high latitude; so that the real figure of the planet resembled a square, or rather a parallelogram, with the four corners rounded off deeply, but not so much as to bring it to a spheroid. After examining Saturn with his telescopes, and comparing it with the form of Jupiter, Dr. Herschel concluded that this was the real form of the ring (See Phil. Trans. 1805.) This form of
Plate II. the planet is represented in Plate II, Figure 7. Sup. Fig. 7. The following are the proportional dimensions of Saturn's disc:—

| Diameter of the greatest curvature | 36 |
| Equatorial diameter | 35 |
| Polar diameter | 32 |
| Latitude of the longest diameter | 43° 20' |

The surface of Saturn is diversified, like that of some of the other planets, with dark spots and belts. Huygens observed five belts, which were nearly parallel to the equator. Dr. Herschel has likewise observed several belts, which in general are parallel with the ring. On the 11th November 1793, immediately south of the shadow of the ring upon Saturn, he perceived a bright, uniform, and broad belt, and close to it a broad and darker belt, divided by two narrow white streaks; so that he saw five belts, three of which were dark, and two bright. The dark belt had a yellowish tinge. (Phil. Trans. 1794, p. 28.) These belts generally cover a larger zone of the disc of Saturn than the belts of Jupiter occupy upon his surface.

Dr. Herschel has likewise perceived dark spots upon Saturn's disc; and, by the changes in their position, has determined the daily rotation of the planet to be performed in 10° 10' 0" 44', round an axis perpendicular to the plane of the ring. La Place had formerly found from theory, that the interior ring ought to perform its revolution in 10 hours. (Mem. Acad. 1787) The ring of Saturn,
therefore, revolves in the same time nearly as the planet, and round the same axis.

It is well known, that the flattening at the poles of the Earth, Jupiter, Mars, and Saturn, arises from the centrifugal force of their equatorial parts. On account of the great diameter of Jupiter, and the rapidity of his daily motion, his equatorial parts move with immense velocity; and, therefore, in consequence of their great centrifugal force, this planet is more flattened at his poles than either the Earth or Mars. It is remarkable, however, that Saturn should be more flattened at his poles than Jupiter, though the velocity of the equatorial parts of the former is much less than that of the latter. When we consider, however, that the ring of Saturn lies in the plane of his equator, and that it is equally, if not more dense than the planet, we shall find no difficulty in accounting for the great accumulation of matter at the equator of Saturn. The ring acts more powerfully upon the equatorial regions of Saturn than upon any part of his disc; and by diminishing the gravity of these parts, it aids the centrifugal force in flattening the poles of the planet. Had Saturn, indeed, never revolved upon its axis, the action of the ring would, of itself, have been sufficient to give him the form of an oblate spheroid.

The planet Saturn is surrounded with no fewer than seven satellites, which supply him with light during the absence of the Sun. The fourth of these satellites was first discovered by Huygens, on the 25th March 1655. Cassini discovered the fifth in October 1671, the third on 23d December 1672, and the first and second in the month of March 1684. The sixth and seventh satellites, which were discovered by Dr. Herschel in 1789, are nearer to Saturn than any of the rest; though, to avoid confusion, they are named in the order of their discovery. These satellites are all so small, and placed at such a distance from the Earth, that they cannot be seen unless with excellent telescopes. Wolfgang saw the five old satellites with an achromatic telescope of ten feet; and, on the 19th December 1793, Dr. Herschel saw them distinctly with a power of 60 applied to his ten feet reflector. The sixth and seventh are the smallest of the whole; the first and second are the next
smallest; the third is greater than the first and second; and the fourth is the largest of them all. The fifth satellite surpasses all of them but the fourth in brightness, when it is at its western elongation from Saturn; but at other times it is extremely small, and entirely disappears at its eastern elongation. This phenomenon, which was at first observed by Cassini, appears to arise from one part of the satellite being less luminous than the rest. In consequence of the rotation of this satellite about its axis, this obscure part of its disc is turned towards the Earth when it is in the part of its orbit east of Saturn; and the luminous part of its surface becomes visible while it enters into the western part of its orbit. Dr. Herschel observed this satellite through all the variations of its light; and concluded that, like our Moon, and the satellites of Jupiter, it turned round its axis in the same time that it performed its revolution round the primary planet. When he used his twenty feet telescope, he never lost sight of the satellite, even when its light was most faint.

The first satellite of Saturn revolves at the distance of 4,893 semidiameters of the planet, in $1^d \ 21^h \ 18^m \ 26^s$; the second at 6,268 semidiameters of Saturn, in $2^d \ 17^h \ 44^m \ 51^s$; the third at 8,754 semidiameters of Saturn, in $4^d \ 12^h \ 25^m \ 11^s$; the fourth at 20,297 semidiameters of Saturn, in $15^d \ 22^h \ 41^m \ 13^s$; the fifth at 59,154 semidiameters of Saturn, in $79^d \ 7^h \ 53^m \ 43^s$; the sixth at 3,080, in $23^h \ 37^m \ 23^s$; and the seventh at 3,952 semidiameters of Saturn, in $1^d \ 8^h \ 53^m \ 9^s$.

The following Table shews, at one view, the various particulars which are known respecting these satellites.
<table>
<thead>
<tr>
<th>New Name, First Satellite</th>
<th>Old Names, Saturnian Satellite, Periodical revolution, in days and decimals,</th>
<th>Place of nodes, accord- ing to Cassini,</th>
<th>Distance in inches from the mean equator of Saturn.</th>
<th>Inclination of orbit.</th>
</tr>
</thead>
<tbody>
<tr>
<td>According to Hevelius,</td>
<td>13,7024</td>
<td>5° 17' 0&quot; 6'</td>
<td>39° 19&quot; 49'</td>
<td>30° 0&quot; 9' 6&quot;</td>
</tr>
<tr>
<td>New Name, Second Satellite</td>
<td></td>
<td>5° 20' 20&quot;</td>
<td>5° 17' 0&quot; 6'</td>
<td>30° 0&quot; 9' 6&quot;</td>
</tr>
<tr>
<td>New Name, Third Satellite</td>
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<td>5° 20' 20&quot;</td>
<td>5° 17' 0&quot; 6'</td>
<td>30° 0&quot; 9' 6&quot;</td>
</tr>
<tr>
<td>New Name, Fourth Satellite</td>
<td></td>
<td>5° 20' 20&quot;</td>
<td>5° 17' 0&quot; 6'</td>
<td>30° 0&quot; 9' 6&quot;</td>
</tr>
<tr>
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<td>30° 0&quot; 9' 6&quot;</td>
</tr>
<tr>
<td>New Name, Sixth Satellite</td>
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<td>5° 20' 20&quot;</td>
<td>5° 17' 0&quot; 6'</td>
<td>30° 0&quot; 9' 6&quot;</td>
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</table>

<table>
<thead>
<tr>
<th>Table, containing the Longitudes, Distances, &amp;c. of the Satellites of Saturn.</th>
<th>Periodical revolution, in days and decimals,</th>
<th>Place of nodes, accord- ing to Cassini,</th>
<th>Distance in inches from the mean equator of Saturn.</th>
<th>Inclination of orbit.</th>
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<tbody>
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<td>5° 17' 0&quot; 6'</td>
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<td>5° 17' 0&quot; 6'</td>
<td>30° 0&quot; 9' 6&quot;</td>
</tr>
<tr>
<td>New Name, Second Satellite</td>
<td></td>
<td>5° 20' 20&quot;</td>
<td>5° 17' 0&quot; 6'</td>
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<td></td>
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<td>5° 20' 20&quot;</td>
<td>5° 17' 0&quot; 6'</td>
<td>30° 0&quot; 9' 6&quot;</td>
</tr>
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<table>
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<tr>
<th>New Name, Seventh Satellite</th>
<th>Old Names, Saturnian Satellite, Periodical revolution, in days and decimals,</th>
<th>Place of nodes, accord- ing to Cassini,</th>
<th>Distance in inches from the mean equator of Saturn.</th>
<th>Inclination of orbit.</th>
</tr>
</thead>
<tbody>
<tr>
<td>According to Hevelius,</td>
<td>13,7024</td>
<td>5° 17' 0&quot; 6'</td>
<td>39° 19&quot; 49'</td>
<td>30° 0&quot; 9' 6&quot;</td>
</tr>
<tr>
<td>New Name, First Satellite</td>
<td></td>
<td>5° 20' 20&quot;</td>
<td>5° 17' 0&quot; 6'</td>
<td>30° 0&quot; 9' 6&quot;</td>
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<tr>
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<td></td>
<td>5° 20' 20&quot;</td>
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<td>30° 0&quot; 9' 6&quot;</td>
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<tr>
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<td></td>
<td>5° 20' 20&quot;</td>
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<td>30° 0&quot; 9' 6&quot;</td>
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<tr>
<td>New Name, Fourth Satellite</td>
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<td>5° 20' 20&quot;</td>
<td>5° 17' 0&quot; 6'</td>
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<tr>
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<tr>
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<td>5° 20' 20&quot;</td>
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<tr>
<td>New Name, Seventh Satellite</td>
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<td>5° 17' 0&quot; 6'</td>
<td>30° 0&quot; 9' 6&quot;</td>
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The position of the satellites of Saturn, and the figure of their orbits, may be easily found for any particular time, by tables of their motions, calculated by Cassini, and given in the *Tables de Berlin*; and from tables calculated by Dr. Herschel, and published in the *Phil. Trans. of Transactions* for 1780. Their configurations may also be found by a very simple instrument called a Saturni-labe, which is described in La Lande's *Astronomy*, vol. iii. p. 203.

La Place's theory of the satellites of Saturn.

The theory of the satellites of this planet is less perfect than that of the satellites of Jupiter. The difficulty of observing their eclipses, and of measuring their elongations from Saturn, have prevented astronomers from determining with their usual precision the mean distances and the revolutions of these secondary planets. In the position of their orbits, however, there is something very remarkable. While the orbits of the six inner satellites, that is, the first, second, third, fourth, sixth, and seventh, all lie in the plane of Saturn's ring, the orbit of the fifth deviates considerably from this plane. La Place imagines that the accumulation of matter at Saturn's equatorial parts retains the orbits of the six first satellites in the plane of the equator, in the same manner as it maintains the ring in that plane. The action of the Sun, indeed, tends to draw them from the plane; but the effect of this action becomes sensible only on the orbit of the fifth or inner satellite, which sufficiently accounts for the deviation of its path from the general plane in which Saturn constrains the other satellites to move. The orbits of the satellites of Saturn move, like those of the Moon, and the satellites of Jupiter, upon fixed planes, which pass constantly by the nodes of the equator and the orbit of Saturn, between these two last planes. Their orbits preserve their inclination almost invariable, and their nodes have a retrograde motion nearly uniform. See *Mécanique Céleste*, tom. iv, p. 173, 185.
CHAP. IV.

ACCOUNT OF NEW DISCOVERIES, &c. RESPECTING THE BODY OF THE SUN, AND ITS MOTION IN FREE SPACE.

When we look at the Sun with a telescope of moderate magnifying power, furnished with a piece of black glass, to intercept a portion of the solar rays, we occasionally perceive a number of dark spots upon its surface, of various forms and magnitudes. Though these spots have sometimes been sufficiently large to be distinguished by the naked eye, yet they were not discovered till after the invention of the telescope. They seem to have been first seen either by our countryman Harriot, to whom the science of astron, as we were under great obligations, or by John Fabricious, who published an account of his observations in 1611, at Wittenberg. The dedication of this work is dated 13th June 1611; but the observations of Harriot upon the solar spots began on the 8th of December 1610. It is obvious, indeed, from the work of Fabricius, that he had seen the Sun’s spots during the year 1610, but it is not certain that he saw them before Harriot. It is a remarkable circumstance, that Fabricius was acquainted with no method of intercepting a portion of the solar rays, in order to save the eye. He observed the Sun when he was in the horizon, and when his brilliancy was impaired by thin clouds, and floating vapours; and he advises those who repeat his observations to receive at first a small portion of the Sun, and gradually to accustom the eye to a greater portion, till it is able to bear the full blaze of its light. When the altitude of the Sun became considerable, Fabricius was compelled to abandon his observations; and he informs us, that his eye was so much affected by the impression of the solar light, that, during the two following days, he could not see objects with the same distinctness as formerly.

1 This work is entitled Joh. Fabricii Phrysis de Maculis in Sole observatio, et apparente causum cum Sole conversione narratio. Wittenberg, 1611, 4to, 43 pag.
2 See Ephemerides de Berlin, 1788, p. 154.
At the beginning of the year 1611, Scheiner and Galileo seem to have observed, about the same time, the spots of the Sun. Scheiner was professor of mathematics at Ingolstadt; and having accidentally turned his telescope to the Sun, when thin clouds were flying across his disc, he perceived a number of black spots, and shewed them to several of his pupils. The report of this discovery was widely propagated; and, though Scheiner was solicited by many of his friends to publish an account of the solar spots, yet he was prevented from yielding to their wishes by a dread of the ecclesiastical power. His friend Mark Velser, however, who was one of the magistrates of Augsburg, and to whom Scheiner had transmitted a detail of his observations, published an account of the discovery, on the 5th January 1612, in three letters, under the signature of Apelles post Tabulam. Scheiner imagined that the spots which appeared on the Sun did not belong to that luminary, but were planets, like Mercury and Venus, which revolved in orbits not very distant from the Sun. Galileo, who had already made many observations on the solar spots, and to whom Velser transmitted a copy of Scheiner’s letters, with the request that he would favour him with his opinion of the new phenomena, was at first averse to hazard his sentiments on a subject which might again provoke the hostility of the church; but, on the 4th of May 1612, he at length ventured to express his opinions to Velser, and to combat the notion entertained by Scheiner, of the cause of the solar spots. Galileo observed, that these spots were not of a permanent form, as they ought to have been if they were satellites; but that they often united, separated, increased, and dispersed like vapours or clouds. He maintains, that these spots are upon the surface of the Sun; that they describe circles parallel to each other; that the motion of the Sun round its axis every month again presents the spots to our view; that some of the spots continue one or two days, and others thirty or forty; that they contract in their breadth, when they approach the Sun’s limb, without suffering any diminution of their length; and that they are seldom seen at a greater distance than 30° from the Sun’s

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Scheiner, many years afterwards, published a large work on this subject, entitled, Rosa Ursina, sive Sol ex admirando facularum et macularum variorum phemoneno varius, a Chrisophero Scheiner, Germano Suevo, a societate Jesu. 1630. Folio, 774 pag.
equator. Galileo likewise perceived on the disc of the Sun
faculae or luculi, which are spots brighter than the rest of his
disc, and which move in the same manner as the dark spots.4

The spots of the Sun have been distinctly ob-
served by astronomers since the time of Galileo, and
many new and curious facts have been brought to
light respecting these interesting phenomena. The spots are
very various, both in magnitude and shape. Most of them
have a very dark nucleus, surrounded by an umbra or a fainter
shade. The boundary between the umbra and the nucleus is
distinct and well defined, and the part of the umbra nearest the
dark nucleus is generally brighter than the more distant portion.
However irregular be the outline of the dark nucleus,
the outer circumference of the umbra is always curvilinear,
without any angles or sharp projections. When any spot be-
gins to increase or diminish, the nucleus and umbra expand
and contract at the same time. During the process of diminu-
tion, the umbra encroaches gradually upon the nucleus; so that
the figure of the nucleus, and the boundary between it and the
umbra, are in a state of perpetual change; and it often happens
that, during these variations, the encroachment of the umbra
divides the nucleus into two or more nuclei. When the spots
disappear, the umbra continues for a short time visible after the
nucleus has vanished, and unless the umbra is succeeded by a
facula, or luminous spot, the place where it disappears resembles
the other portions of the solar surface. Large umbræ are sel-
dom seen without a nucleus in their centre, but small umbræ
frequently appear by themselves. When Dr. Long was examin-
ing the Sun’s image, received upon a sheet of white paper, he
observed a large round spot divide itself into two spots, which
receded from each other with immense rapidity. The Reverend
Dr. Wollaston perceived a phenomenon of a similar kind, with a
twelve inch reflector. A spot burst in pieces when he was ob-
serving it, like a piece of ice, which, thrown upon a frozen pond,
breaks in pieces, and slides in various directions.

Besides these changes in the spots, which are owing to some
cause with which we are yet unacquainted, they undergo variations

4 An account of Galileo’s observations, will be found in his book, entitled, Istoria
Dimostazioni, intorno a li macchie solari, Roma 1613. In the preface to this work,
he observes that he shewed the spots in the Sun to several persons in the quirinal
garden of Cardinal Pandini, in April 1611.
of an optical kind, from their change of position on the disc of the Sun. The nature of this variation will be easily understood, by placing a black spot upon a common globe, and observing the different shapes which it assumes, while the globe is made to revolve about its axis. When the spot is near the middle of the Sun's disc, its breadth is then greater, but it diminishes gradually as it advances towards the edge of his disc. This variation in the figure of the spots, and some of the other variations already mentioned, are represented in Plate III, Fig. 17, where A B is a portion of the Sun's disc, and a, a, a, the appearances of a spot on seven successive days, as observed by Hevelius. Hence it is obvious, that these spots are upon the surface of the Sun, and that their motion across his disc, from east to west, is produced by the revolution of the Sun about his axis. The time in which any spot returns to its former position upon the Sun's disc, is about 27 days 7 hours and 37 minutes; but as the Earth has, during this time, advanced in its orbit from east to west, and in some measure followed the motion of the spot, the real time in which the spots perform their revolutions will be found to be 25 days 10 hours. This will be understood by supposing that a spot has just vanished behind the western limb of the Sun; in the course of 27 days 7 hours and 37 minutes it again vanishes behind the same limb; but, during this interval of time, the Earth has advanced in its orbit, and in the same direction with the spot; and therefore, when the spot reaches the Sun's western limb, after one complete revolution the western limb of the Sun, behind which it vanishes, has shifted in absolute space to the westward, so that the spot has performed a complete revolution, and part of a revolution round the centre of the Sun. We have therefore 365. 5th 48 + 27, 7th 37', or 392. 15h 25' is to 365. 5th 48'' as 27, 7th 37', the apparent revolution of the spots is to 25. 9h 56', the real revolution of the spot, or the time in which the Sun performs his rotation about its axis. The axis of the Sun, round which this revolution is performed, is inclined 7° 20' to the ecliptic, and the node of the solar equator is in the 18th degree of Gemini. The solar spots are never seen towards the poles of that luminary. They are generally confined within a zone, stretching about 30° 5' on both sides of his equator, though sometimes they have been seen in the latitude of 39° 5'.
M. Silberschlag of Magdeburgh made several observations on the solar spots in the year 1768, from which he draws the strange conclusions that they have a motion of rotation, and that they change their place on the surface of the Sun, independent of his monthly revolution. He also concluded that the spots had not merely the dimensions of length and breadth, but that they consisted of thick masses of opaque matter. (Bernouilli’s *Leit. Astron.*, p. 6.)

Galileo, Hevelius, (Silengraphia, p. 83), and the Theory of Maupertuis, (Œuvres, vol. i. p. 61,) seem to have considered the spots as scoria floating in the in-flammable liquid matter, of which they conceive the Sun to be composed. This opinion, however, will appear highly improbable, when we consider the regularity with which the spots frequently reappear on the eastern limb of the Sun, and the effect that the centrifugal force of the Sun would have in carrying all these floating exuaria to the equatorial regions.

M. de La Hire and La Lande consider the solar spots as arising in the opaque body of the Sun, the eminences of which are sometimes uncovered, in consequence of the alternate flux and reflux of the liquid igneous matter in which that opaque mass is generally enveloped. The part of the opaque mass which thus rises above the general surface gives the appearance of the nucleus, while those parts of the opaque mass which lie only a little beneath the igneous matter, produce the appearance of the surrounding umbra.

This theory has been very ably opposed by our learned countryman, the late Dr. Wilson, professor of practical astronomy in the university of Glasgow, who maintains, with great appearance of truth, that the solar spots are depressions rather than elevations; and that the black nucleus of every spot is the opaque body of the Sun, seen through an opening in the luminous atmosphere with which he is en-circle. This explanation was suggested to Dr. Wilson by the phenomena of the great solar spot which appeared in November 1769, and is founded on the following facts: When any spot is about to disappear behind the Sun’s western limb, the eastern portion of the umbra first contracts in its breadth, and then vanishes. The nucleus then gradually contracts and vanishes, while the western portion of the umbra still remains visible.
When a spot comes into view on the Sun's eastern limb, the eastern portion of the umbra first becomes visible, then the dark nucleus, and then the western part of the umbra makes its appearance. When two spots are near each other, the umbra of the one spot is deficient on the side next the other; and when one of the spots is much larger than the other, the umbra of the largest will be completely wanting on the side next the small one. If the large spot have little ones on each side of it, its umbra does not totally vanish, but seems flattened and pressed in towards the nucleus; but the umbra again expands from this compressed state as soon as the little spots disappear. From this cause, Dr. Wilson concludes, that the western portion of the umbra may disappear before the nucleus, when a small spot happens to appear on the western side of the nucleus. All these appearances strongly confirm the opinion of Dr. Wilson, that the black part of the spots is the dark body of the Sun, seen through an opening in the luminous matter.

The reverend Dr. Wollaston, and M. de La Lande, however, have maintained, that though the umbra generally varies according to the manner now described, yet the phenomenon is not universal, and cannot, therefore, be employed as the foundation of a system. La Lande mentions three observations of his own, and four observations by Cassini and De la Hire, in which the umbra did not vanish, as Dr. Wilson describes it. This anomaly, however, may have arisen from some small spots in the neighbourhood of the large one, and cannot possibly be considered as an argument, that the spots are not excavations in the Sun's surface. At all events, it may be shewn, that in some spots the umbra may not change as it approaches the limb, in consequence of the shallowness and gradual shelving of the opening in the luminous atmosphere.

Dr. Wilson's In order to confirm experimentally his theory of solar globe, the solar spots, Dr. Wilson constructed a globe, consisting of two strong hollow hemispheres, formed by pasting slips of paper upon a wooden ball, and afterwards fastened together upon an iron axis. A thick paste, made of glue and Spanish white, were laid, in successive coats, upon this outward shell, till it became of considerable thickness. The globe was then made smooth and spherical; and as soon as it was dried, and the crust white, the spots or excavations were made in its surface, by boring instruments of steel, constructed, in all their
cutting edges, from a scale of parts of the diameter of the ball. The bottom of the hollows were then painted black with Indian ink, and the slope, or shelving sides of the excavations, were distinguished from the brightness of the external surface by a shade of the pencil, which increased towards the external border. When this artificial Sun was fixed in a suitable frame, and examined, at a great distance, with a telescope, the umbra and the nucleus exhibited the same phenomena which have been observed in the real Sun.

La Lande has objected to Dr. Wilson's theory, that the great spots seen by De la Hire on the 3d June 1703, and by Cassini in 1719, made an indentation, or notch, in the solar disc, which he conceives to be incompatible with the opinion that this spot was an excavation. Dr. Wilson, however, has shewn, that excavations may cause something like an indentation in the Sun's limb; and maintains, that the notches do not always accompany large spots; and that the unfrequency of their occurrence, and the want of accurate observations, should preclude astronomers from bringing them forward in support of any class of opinions.

We conceive that the most irrefragable objection to the opinion, that the spots are eminences, which rise above the general level of the luminous matter, arises from the uniform diminution of the spots, as they advance from the central part of the Sun to his western limb. If these dark solar mountains are deserted by the luminous matter, why do they appear largest when they reach the centre of the Sun's disc? Whenevcr the height of the mountains greatly exceeds the diameter of their base, instead of contracting in the dimension of breadth, they ought to increase as they approach the limb; and, at all events, should exhibit phenomena very different from what should take place upon the supposition that the spots are depressions in the luminous matter. It may be said, indeed, that the height of these eminences bears no proportion to the diameter of their base; but this is an assumption of which no theorist is entitled to avail himself.

The faculae, or parts of the surface of the Sun which are brighter than the rest of his disc, require to be examined with good telescopes. They are generally seen in the places where spots have appeared; and sometimes the facula which envelopes an assemblage of spots, is
NEW DISCOVERIES RESPECTING THE SUN. CH. IV.

distinguished by a very great degree of brilliancy. These faculae, according to the reverend Dr. Wollaston, are often converted into dark ones. He observed a bright facula appear on the east limb of the Sun, which next day became a spot. (See Phil. Trans. 1774, vol. 64, 337, and Anciens Memoires, p. 663.) He also observed a mottled appearance over the face of the Sun, which, though most visible near the limb, was also perceptible in the centre, but never appeared towards the poles. The celebrated astronomer M. Messier has made a number of curious observations upon the solar faculae. He often saw them enter upon the disc of the Sun, disappear as they approached the centre, and afterwards re-appear on his other limb. In general, they continued visible for about three days after they appeared, and were seen, for the same space of time, before they quitted the Sun's western limb. In these faculae, spots generally arise, of a magnitude proportional to the brightness of the facula. When this did not happen, M. Messier found that the faculae were the precursors of spots, which ordinarily appeared near the same place on the following day; and hence he was always able to predict the appearance of spots about 24 hours before they entered the Sun's disc, and to anticipate from the situation and brightness of the faculae, the brilliancy and position of the spots themselves. See Mem. Acad. Par. 1784. M. Schroeter has seen these faculae in every part of the Sun's limb, but particularly in a zone between 20° of north and 20° of south solar latitude. They generally subtended an angle of about two or three minutes, and always appeared most brilliant when they were near the limb. (Beobachtungen, 1789.)

Observations of Dr. Herschel of the solar spots before they were examined by the powerful telescopes of Dr. Herschel. This astronomer continued his observations from 1779 to 1794, and has disclosed a number of curious phenomena, which throw much light upon the nature and construction of the Sun. Before we direct the attention of the reader to the several conclusions which the Doctor has deduced, we shall give an account of the different phenomena which he observed on the surface of that luminary. It will be necessary, however, to premise, that he regards the luminous surface of the Sun as neither a liquid substance, nor an elastic fluid, but as luminous clouds, floating in
the solar atmosphere; and that he considers the dark nucleus of the spots as the opaque body of the Sun, appearing through the openings in his atmosphere. Rejecting the old terms, of Spots, Nuclei, Umbra, Faculae, &c. Dr. Herschel has framed a new nomenclature, and comprehends all the solar appearances under the names of Openings, Shallows, Ridges, Nodules, Corrugations, Indents, and Pores. (See Phil. Trans. 1791; and 1801, Part II. p. 15.)

Openings are the appearances, in which the opaque body of the Sun is visible, in consequence of the removal of part of the luminous clouds. One of these openings, with a shallow about it, which was seen on the 4th January 1801, a good way past the Sun's centre, is represented in Plate III., Fig. 18. On the western side of the shallow, its thickness was visible from its surface down and; but, on the eastern side, the thickness could not be seen, the edge of the shallow only being visible. A section of this opening is shewn in Fig. 19, where the lines a b c d; corresponding with those in Fig. 18, are supposed to be drawn from the eye of the observer. The line d passes through the opening to the opaque body of the Sun. It is obvious, from Fig. 19, that the thickness of the shallow is visible only on one side, from the position of the observer's eye. Large openings are generally surrounded with shallows, though many openings, and particularly small ones, have no shallows. Openings have a tendency to unite to each other; and new ones often break out near others. Ridges and nodules generally accompany openings. Dr. Herschel imagines that the openings are produced by an elastic gas, which issues through the incipient openings, or pores, and forcing its way through them, spreads itself on the luminous clouds. The direction of the gaseous stream is often oblique; so that the luminous clouds are thrown laterally, and form a larger shallow on one side. Openings sometimes have a difference of colour. They divide when divided, and sometimes they increase again; but, in general, when they are divided, they diminish, and disappear, leaving the surface more than usually disturbed. They are sometimes converted into large indentations, and not unfrequently into pores. Fig. 20 represents an opening, with a branch from its shallow: In the course of an hour it assumed
the appearance shewn in Fig. 21. Fig. 22 is another opening, with a long shallow. In three hours it assumed the appearance in Fig. 23; and an hour after this, an opening appeared in the shallow, as in Fig. 24. The openings are generally at their greatest extent, as in Fig. 25, when the shallows begin to vanish, and the lips, or projections, to disappear. The division of the decaying opening is shewn in Fig. 26, where the luminous passage across the opening resembles a bridge thrown over a hollow.

Shallows are places from which the luminous solar clouds of the upper regions are removed, and are therefore depressed below the general level of the surface of the Sun. The thickness of the shallows is visible: they sometimes exist without openings. They generally begin from the openings, or branch out from shallows already formed, and go forwards. Fig. 27 shews the two branches, A, B, of a shallow, proceeding from an opening, C. In the course of half an hour, Fig. 28, the shallow B is nearly united to the narrow part of the shallow surrounding the opening D, while the shallow A seems to advance in a direction towards the opening E. In the space of another half hour, the shallow B has completely run into the shallow about D, while the shallow A has increased in breadth towards F. The shallow A became afterwards pointed, as in Fig. 29; and in the course of an hour, it became broad at the point, and a new branch broke out at G. From these changes, Dr. Herschel concludes, that the shallows are occasioned by something issuing from the openings, which drives away the luminous clouds, from the parts where it finds the least resistance, or which dissolves these clouds as soon as it reaches them. The new branch afterwards began to increase, and another branch, marked H, Fig. 28, began to break out from the shallow around E. These changes Dr. Herschel attributes to the gas, or substance, which at first forced open the passages, and is now widening them. Three small branches, a, b, c, were seen to project from the shallow of the large opening in Fig. 31. The vacancies between these branches were afterwards filled up, by the same cause that occasioned them, so as to increase the breadth of the shallow on that side of the opening. The shallows have no corrugations, but are tufted, like masses of dense clouds. The decay of the shallows is supposed to arise from
the encroachment of the luminous clouds, in consequence of
the enfeebled energy of the gas or substance that produced
them.

Ridges are elevations of the luminous clouds above the
ir, general level, or above the general surface of
the Sun. These elevations generally surround openings, though
they have sometimes been perceived where openings do not
exist. Ridges soon disperse. One of them occupied a space
which subtended an angle of 2° 46'', corresponding to 75,000
English miles. Dr. Herschel ascribes the formation of the ridges
to the disturbance of the luminous clouds, by the elastic gas
which issues from the opening; or he conceives that this gas
may act below the luminous clouds, so as to elevate them above
their ordinary level.

Nodules, formerly called faculae, or luculi, are small, but brilliant, and highly elevated parts of the
luminous clouds. Dr. Herschel imagines that they may be
ridges, seen obliquely, or foreshortened.

Corrugations are elevations and depressions of the luminous matter, having a mottled appearance, and
consisting of light and dark places. The dark places appear
to be lower than the bright places; and, in a favourable atmo-
sphere, the corrugations may be as distinctly perceived as the
rough surface of the Moon. They extend over every part of
the Sun's surface. Their shape and position is perpetually
changing, and they increase, diminish, divide, and vanish
quickly.

Indentations are the dark parts of corrugations; and from the circumstance of their being visible very
near the limb of the Sun, it would appear that they are not
much depressed below the level of the luminous clouds. The
sides of the indentations are like circular arches, (See Fig. 32),
with their bottoms occasionally flat. Indentations are of the
same nature with shallows, varying in size, and sometimes
containing small openings, and at other times changing into
openings. They extend over the whole surface of the Sun, and,
with small magnifying powers, they have the appearance
of points.

Pores are small holes or openings in the low places
of indentations. Sometimes they increase and be-
come openings, and frequently vanish in a short time.
From these interesting facts, Dr. Herschel has deduced a theory of the solar phenomena; which, however ingenious it may be, is founded on assumptions too arbitrary and gratuitous to be recognised in a science which admits of no evidence but demonstration. To suppose that the numerous irregularities on the surface of the Sun are occasioned by an elastic enpyreal gas which rises through the openings, and disturbs the equilibrium of the luminous mass, is to shew how these irregularities may be produced by the action of a hypothetical agent; but it never can be considered as an explanation of the processes which nature is carrying on in that immense depository of fire. But though we cannot admit the hypothesis proposed by this learned and ingenious astronomer, we are disposed to acquiesce in some of the important conclusions which he has drawn from his observations. From the numerous elevations and depressions of the luminous matter, and from the length of time during which they are visible, the Doctor justly infers that the shining matter of the Sun is not a fluid, but a mass of luminous or phosphoric clouds. He conceives, from the uniformity of colour in the shallows, that below these self-luminous clouds there is another stratum of clouds of inferior brightness, which is intended as a curtain to protect the solid and opaque body of the Sun from the intense brilliancy and heat of the luminous clouds. By means of his photometer, Dr. Herschel found that the light reflected by the inferior clouds is 469 out of 1000; and that the light reflected by the opaque body of the Sun is only 7. Hence it appears that the Sun consists of a dark solid nucleus, surrounded by two strata of clouds. The outermost of these is the region of that light and heat which is diffused from the centre to the remotest parts of the system, while the interior stratum is supposed to protect the inhabitants of the Sun from the fiery blaze of the stupendous furnace by which they are inclosed.  

5 It is a curious fact, that the opinions of Dr. Herschel, respecting the nature of the Sun, were maintained about 22 years ago by a Dr. Elliot, who was tried at the Old Bailey for shooting Miss Boydell. The friends of the Doctor maintained that he was insane, and called several witnesses to establish this point. Among these was Dr. Simons, who declared that Dr. Elliot had, for some months before, shown a fondness for the most extravagant opinions; and that, in particular, he had sent to him a letter, on the light of the celestial bodies, to be communicated to the Royal
That the Sun may, at the same time, be the
source of light and heat, and yet capable of support-
ing animal life, is one of those conclusions which we
are apt to admit without hesitation, and to cherish
with peculiar complacency. The mind is filled with admira-
tion of the wisdom of God, and swells with the most sublime
emotions, when it conceives that apparently the most inaccessible
regions of creation are peopled with animated beings; and
that, while the Sun is the fountain of the most destructive of
the elements, it is, at the same time, the abode of life and felici-
ty. In impressions of this kind, however, delightful though
they be, we must not rashly indulge, lest we should afterwards
find that we have been admiring an order of things which does
not exist in nature, and have thus been indirectly reflecting on
the infinite wisdom that sanctioned an opposite arrangement.
Whenever we allow our feelings to interfere with our reasonings,
we are apt to yield ourselves to the guidance of loose analogies
and imperfect views, and become the defenders of opinions,
which every subsequent observation and discovery will only
tend to overthrow. We conceive that the opinion of the Sun’s
being a habitable globe rests on reasonings of this nature; and
as the subject is curious and worth examination, we shall en-
deavour to place it in its proper light.

When the invention of the telescope enabled astro-
nomers to detect the striking resemblances between the
different planets of the system, it was natural to
conclude, that as they were composed of similar materials, as
they revolved round the same centre, and were enlightened by
similar moons, they were all intended by their wise Creator to
be the region in which he chose to dispense the blessings of
existence and intelligence to various orders of animated beings.

Society. This letter confirmed Dr. Simmons in the belief that this unhappy man was
under the influence of this mental derangement; and, as a proof of the correctness of
this opinion, he directed the attention of the court to a passage of the letter, in which
Dr. Lhomat states, “that the light of the Sun proceeds from a dense and universal
aurora, which may afford ample light to the inhabitants of the surface (of the Sun)
beneath, and yet be at such a distance aloft as not to annoy them. No objection,
says he, ariseth to that great luminary being inhabited; vegetation may obtain there,
as well as with us. There may be water and dry land, hills and dales, rain and
fair weather; and as the light, so the season, must be eternal; consequently it may
easily be conceived to be by far the most blissful habitation of the whole system.”
(See the Gentleman’s Magazine for 1787, p. 636.)
The human mind cheerfully embraced this sublime view of creation, and, guided by the principle that nothing was made in vain, man extended his views to the remotest corners of space, and perceived in every star that sparkles in the sky the centre of a new system of bodies, teeming with life and happiness, and displaying fresh instances of the power and beneficence of their Maker. Having thus traversed the illimitable regions of space, and, considering every world which rolls in the immense void as the scene on which the Almighty has exhibited his perfections, the mind, unable to command a wider range, rests in satisfaction on the faithful analogies which it has pursued. While the planets were thus regarded as habitable worlds, astronomers considered the Sun and the stars as the reservoirs from which light and heat were dispensed to man, and as the great central magnets which bound together, and guided in their course the various planets which surround them. These offices were reckoned sufficient for the great luminary; and astronomers were led by no analogy, and by no consideration of final causes, to view it as the seat of animal existence: they left it to the poets to people, with a colony of salamanders, these regions of eternal fire.

The solar observations of Dr. Wilson first suggested the opinion that the Sun was an opaque and solid body, surrounded with a luminous atmosphere; and the telescopes of Dr. Herschel have tended still farther to establish this opinion. The latter of these astronomers, therefore, imagined that the functions of the Sun, as the source of light and heat, might be performed by the agency of its external atmosphere; while the solid nucleus was reserved and fitted for the reception of inhabitants. This conjecture, however, is consonant with nothing which we find in nature. It is inconceivable, indeed, that luminous clouds, yielding to every impulse, and in a state of perpetual change, could be the depository of that devouring flame, and that insupportable blaze of light which are emitted by the Sun; and it is still more inconceivable that the feeble barrier of planetary clouds could shield the subjacent mass from the destructive elements that raged above. The opacity of the interior globe of the Sun is no reason why it may
CH. IV. NEW DISCOVERIES RESPECTING THE SUN.

not act a part in the production or preservation of the solar heat. On the contrary, it appears highly probable and consistent with other discoveries that the dark solid nucleus of the Sun is the magazine from which its heat is discharged, while the luminous or phosphorescent mantle, which that heat freely pervades, is the region where its light is generated. Dr. Herschel's own experiments assure us, that invisible rays, which have the power of heating, and which are totally distinct from those which produce light, are actually emitted from the Sun: and that luminous rays, incapable of producing heat, are discharged from the same source. These facts, therefore, not only confirm the theory which we have stated, but receive, in return from that theory, the most satisfactory explanation. The invisible rays which pervade every part of the solar spectrum, formed by a prism, and which extend beyond its red extremity, are emitted from the opaque nucleus, and therefore excite no sensation of light on the human retina; while the coloured rays which form the spectrum itself are discharged from the luminous matter that encircles the solid nucleus, and are therefore endowed with the property of illumination. Hence it is easy to assign the reason why the light and heat of the Sun are apparently always in a state of combination, and why the one emanation cannot be obtained without the other. The heat projected from the dark body, and the light emitted from the luminous atmosphere, are thrown off in lines diverging in every possible direction; so that the two radiations must be uniformly intermingled, and, as in a stream flowing from two contiguous sources, the heat must always accompany its kindred element. That light and heat are two different substances, distinguished by different properties, is a proposition which seems to flow from the most recent experiments. We find the invisible heat

convinced that no clouds, however dense, could impede its rapid transmission, even to the parts below. Besides, the diameter of the Sun is 111 times as great as that of the Earth; and, at its surface, a heavy body would fall through no less than 450 feet in a single second; so that, if every circumstance permitted human beings to reside in it, their own weight would present an insuperable difficulty, since it would become nearly 30 times as great as upon the surface of the Earth, and a man of moderate size would weigh above two tons." Dr. Thomas Young's Nat. Phil. vol. 1, p. 50, 1, 2.

The quantity of heat which is transmitted to the habitable regions of the Sun for the purposes of vegetation must necessarily accumulate, till it becomes insupportable, as there is no possibility of its escaping back to the luminous atmosphere.
of the Sun existing separately from its light, and possessing a
degree of refrangibility less than the least refrangible rays of
the prismatic spectrum. Light has likewise been found separate
from heat; and though it may be imagined that this arises
from the extreme attenuation of the light, yet when the light of
the Moon is concentrated by powerful burning mirrors, we
ought certainly to have expected that the heat, if any did exist,
would be appreciable by delicate thermometers. Every attempt,
however, to detect heat in the rays of the Moon has completely
failed; and we are therefore entitled to presume that a greater
proportion of heat than of light has been absorbed by that lu-
minary. If light and heat, then, be two different substances,
edowed with different chemical and physical properties, is it
not unphilosophical to suppose, that they are emitted from the
same source, when we have actually two different regions in
the Sun, to which we can with more propriety refer their or-
gin?

This opinion, which we propose only as a conjecture, founded
on the most probable analogies, will receive considerable confir-
mation, if we can adduce any strong analogical arguments against
the supposition that the Sun is a habitable world; for if the
nucleus is not fitted for the reception of living beings, it is the
more probable, that it acts a capital part in the production or
preservation of the solar heat. Some arguments have already
been suggested relative to this point. We shall endeavour to
illustrate two other considerations, which, we trust, will have some
weight in favour of our opinion. Since those who consider the
Sun as a habitable world, found this opinion upon analogical
arguments, we are entitled to avail ourselves of all the assist-
ance which can be drawn from the same source. If the Sun,
then, be a great habitable planet, we may expect to find in it
those points of resemblance to the other planets which are re-
garded as distinctive marks of a habitable world; and if we shall
find, that any analogy which subsists with respect to all the
other planets fails, when applied to the Sun, we are entitled to
consider this difference as a proof that the Sun is not inhabited.

In proceeding from the remotest of the planets to the centre
of the system, we find, that a general law prevails respecting
the densities of the planets. These densities appear to increase,
as the planet is nearer the Sun. Thus, we have for the density
of the
With a single exception in the case of the Georgium Sidus, whose density is not yet accurately ascertained, the densities uniformly increase according as the habitable world approaches to the centre of light and heat. We should, therefore, have expected, from analogy, that the habitable part of the Sun would have exceeded Mercury in density; because it is nearer than that planet to the source of light and heat. This, however, is far from being the case; the density of the Sun is only $1\frac{7}{9}$, a little greater than the density of water. Here, then, we have a complete breach in the analogy which we anticipated; and it is no objection to this argument, to say, that the situation of the Sun, in the centre of the system, may exempt it from the general law of density; because this is a virtual admission, that analogical reasoning, on which Dr. Herschel’s opinion is founded, cannot be fairly applied in such a case.

If the Sun is a habitable globe, we can scarcely avoid drawing the conclusion with Dr. Elliot, that “it must be by far the most blissful habitation in the whole system.” We should expect, at least, that the solar inhabitants would be rational beings, endowed with intelligence equal to that of man, and availing themselves of their central position, to study the interesting phenomena of the various planets which revolve around them, and of the numerous suns which their own globe would seem to resemble. If there is one place in the system more than another where astronomy could be studied with the greatest facility, and carried to the highest perfection, that place would be in the Sun, where, excepting the phenomena arising from its monthly rotation, the real and apparent motions of the heavenly bodies must be exactly the same. But these results of analogy are mere illusions of the mind: Nature has drawn an impenetrable curtain between the inhabitants of the Sun and the worlds which circulate around them; she has doomed them to the most solitary dwelling in the whole circle of creation, and has marked them as either unfit or unworthy to enjoy the noblest privileges of intelligent beings. The planets and the stars are equally invisible from the surface of this luminary, unless when a tran-
NEW DISCOVERIES RESPECTING THE SUN.  CH. IV.

A single glimpse of the heavens is obtained through an accidental opening in the solar atmosphere. From the year 1676, to the year 1684, there was not a single spot in the Sun's atmosphere; so that, during eight successive years, the inhabitants of that globe, if they do exist, never once obtained a glance of that starry firmament, from the contemplation of which a Supreme Being could scarcely have excluded any of his rational creation.

To maintain, therefore, that the Sun is peopled by intelligent beings, is to reason in defiance of the strongest analogies, and support opinions which posterity will rank among the aberrations of the human mind. Might we not as well suppose, that the central caverns of our own planet, which cosmogonists have filled with fire or with water, are the abode of a rational population, who, like the inhabitants of the Sun, are occasionally permitted to obtain a transient view of the heavens, through the craters of volcanoes, or the chunks and fissures which may accompany the convulsions of the globe?

On the connexion of the solar phenomena with the productiveness of the seasons.

Before concluding our remarks upon the construction of the Sun, we must take notice of another opinion of Dr. Herschel's respecting the solar spots, which has been less generally received than that which we have been combating. Imagining that the luminous atmosphere of the Sun is the region of light and heat, he concluded, that when the ridges, corrugations, and openings in this atmosphere are numerous, the heat emitted by the Sun must be proportionally increased, and that this augmentation must be perceptible by its effects upon vegetation. He expected, therefore, that in those years when the solar spots were most numerous, vegetation would be most luxuriant; and that this effect might be ascertained from the price of wheat, as marking the productiveness of the season. By comparing the solar appearances, as given by Landc. with the table of the price of wheat in Smith's Wealth of Nations, he obtained results which, on the whole, appear favourable to his hypothesis. We do not readily see upon what principle Dr. Herschel concludes that the existence of spots indicates an abundance of luminous matter. We should rather have been disposed to think, that in proportion to the number and magnitude of the openings, the light and heat of the Sun would have been diminished, as so much of the Sun's surface is then disqualified for the discharge of its usual functions. If there is
really an increased luxuriance of vegetation in those years when the solar openings, &c. are most numerous, an opinion which we are much disposed to call in question, we conceive that the theory which we have already explained affords a very satisfactory explanation of the fact. The heat being supposed to be emitted from the dark body of the Sun, it is obvious, that when there is any opening in his luminous atmosphere, the heat emanating from the internal nucleus must be more copiously discharged, in consequence of receiving no obstruction from the luminous clouds; or, if we regard the variations in the Sun's surface as produced by variations in the heat which rises from the nucleus, we may naturally suppose, that when the heat of the Sun is most intense, it will produce the greatest changes in the luminous atmosphere.

Dr. Herschel has invented a very ingenious contrivance for moderating the heat and light of the Sun, when it is examined by means of powerful telescopes. (Phil. Trans. 1801, p. 302.) He abandoned the common method of using dark-coloured glasses, and had recourse to fluids. For this purpose, he employed a small square trough, having, in two of its opposite sides, well polished plates of glass. A small handle on one side of the trough, and a spout in the other, were made, for the purpose of pouring out any portion of the liquid when the rest was to be diluted. The trough was then placed in an excavation in the eye-piece of the telescope, so that the rays of the Sun might pass through the fluid before they reached the eye of the observer. By colouring the fluid, the light may be softened at pleasure, and the heat is completely removed by the water. Dr. Herschel found that ink, diluted with water, and filtered through paper, gave a distinct image of the Sun, as white as snow. By this mixture, he could observe the Sun in the meridian, without the smallest injury to his eye, or to the glasses, even when he used a mirror nine inches in diameter, and when the eye-pieces were open, as in night observations.

As the phenomenon called the Zodiacal Light has been generally supposed to arise from the Sun's atmosphere, we consider this as the proper place for giving an account of the appearance. Though this light seems to have been observed by Descartes (Principia, § 136, 137;) and by Childrey, about 1659 (Britannia Baconica, 1661;) yet it did
NEW DISCOVERIES RESPECTING THE SUN.  CH. IV.

...not attract general notice till the year 1693, when it was observed by Cassini, and received its present name. The zodiacal light, which is less bright than the milky way, is seen at certain seasons of the year, before the rising, and after the setting of the Sun. It resembles a triangular beam of light, rounded a little at the vertex. Its base is turned towards the Sun, and its axis is inclined to the horizon, and lies in the direction of the zodiac. The vertical angle of this luminous cone is sometimes 26°, and sometimes 10°; its length, reckoning from the Sun, which is its base, is sometimes 45°, and at other times 150°. M. Pingre saw one in the torrid zone, which was 120° long, and whose horizontal breadth was from 8° to 30°. (See Traité Physique et Historique de L’Aurore Boreale, par M. de Mauran, 1731, 1754.) The best time for seeing the zodiacal light is about the 1st of March, at seven o’clock in the evening, when the twilight is ending, and the equinoctial point in the horizon. The luminous triangle will then appear to be directed towards Aldebaran, as in Plate III, Fig. 33, its axis forming an angle of 64° with the horizon; but if it is viewed in the morning, before sunrise, the angle which it makes with the horizon will be only 26°. In the year 1781, M. Flauzeres observed it in the month of January. On the 21st of March, at half-past seven o’clock, it ended beyond the Pleiades, and was 61° long, 10½° broad, and 8° high. According to M. Foulquier, the zodiacal light is always seen at Gaudaloupe, unless when the weather is bad. M. Humboldt observed the zodiacal light at Caraccas on 18th January, after 7th a.m. The point of the pyramid was at the height of 53°. The light totally disappeared at 9h 35’ apparent time, about 3h 50’ after sunset, without any diminution in the serenity of the sky. On the 15th February it disappeared 2h 50’ after sunset, and the altitude of the pyramid was 50° on both those occasions; the intensity of the zodiacal light varied in a very sensible manner, at intervals of two or three minutes. These changes took place in the whole pyramid, especially towards the interior, far from the edges; sometimes the light was very faint, and sometimes it exceeded that of the milky way in Sagittarius.—(Humboldt’s Personal Narrative, Vol. IV, p. 95.)

As this phenomenon uniformly accompanies the Sun, it has been naturally ascribed to an atmosphere round this luminary, extending beyond the orbit of Mercury, and sometimes even
beyond that of Venus. The zodiacal light is supposed to be a section of this atmosphere, which, being extremely flat at its poles, cannot be supposed to partake of the Sun's monthly motion. M. Laplace has shewn that the Sun's atmosphere cannot reach even the orbit of Mercury, and that it could not in any case display this particular form. Dr. Thomas Young (Lect. on Nat. Phil. vol. i, p. 502) remarks, that the only probable manner in which it can be supposed to retain its figure, is by means of a revolution much more rapid than the Sun's rotation. Some philosophers have ascribed the phenomenon, without any reason, to the refraction of the Earth's atmosphere.

Besides the revolution of the Sun round his axis in 25 days, and his irregular motion about the centre of gravity of the Solar system, he appears to have a progressive motion in absolute space. As all the bodies of the system necessarily partake of this motion, it can only be perceptible from a change in the position of the fixed stars, to which the system is advancing, or from which it recedes. This change of place, or proper motion in the fixed stars, as it has been called, was first observed by Halley, and afterwards by Le Monnier. Tobias Mayer, however, advanced a step farther than these astronomers. He compared the places of about 80 stars, as determined by Roemer, with his own observations, and he found that the greater number of them had a proper motion. He was aware that this change of place might be explained by a progressive motion of the Sun towards one quarter of the heavens; but as the result of his observations does not accord with this hypothesis, he remarks, that many

7 Tandem, quum et quæri possit, quae hujus motus causa sit, hoc unum monere visum, illum explicari non posse per motum totius nostri systematis solarias, etiam impossibile sit Solem, ut ejusdem cum fixis natura, in nostro mundano promoveri. Nam si Sol et cum ipsa planetæ omnes nostrunques domicilium terræ, recta tenderent versus plagam aliquam universæ fixæ, quæ in ea plaga adparentem, paulatim a se invicem discedere, et quæ sunt in opposita parte coli coire viderentur; non secus ac per silvam ambulantibus arborese quæ ante viam sunt, disjungi videntur, quæ a tergo, congræ. Hujusmodi communi legi cum arietici non sint hi fixarum motus, ut proprius inspecto abscons petes: Palam est eos non esse mere adpARENTes, at ub hab similitive communi causa oriundos, sed fixis propriis. Ipsa autem vera atque genuina horum causa fortæ per plurà adhuc secula ignorabitur. (Mayeri Opera Inedita, vol. i, p. 79.)
centuries must elapse before the true cause of this motion is explained.

The late Dr. Wilson of Glasgow suggested, upon theoretical principles, the possibility of a solar motion; and La Lande deduced the same opinion from the rotatory motion of the Sun: but these conjectures have been almost completely confirmed by another species of argument.

If the Sun has a motion in absolute space, directed towards any quarter of the heavens, it is obvious that the stars in that quarter must appear to recede from each other, while those in the opposite region seem gradually approaching. The proper motion of the stars, therefore, in those opposite regions, as ascertained by a comparison of ancient with modern observations, ought to correspond with this hypothesis.

Dr. Herschel has examined this subject with his usual success, and he has certainly discovered the direction in which our system is gradually advancing. He found that the apparent proper motion of about 46 stars out of 56 are very nearly in the direction which should result from a motion of the Sun towards the constellation Hercules, or, more accurately, to a point in the heavens whose right ascension is 250° 52' 30'', and whose north polar distance is 40° 22'. (See Phil. Trans. 1788, p. 203; and Phil. Trans. 1805.)

By considering the motion of the satellites round their primary planets, and of the primary planets round the Sun, Dr. Herschel supposes that the proper motion of the Sun is not rectilinear, but that it is performed round some distant and unknown centre. Just, however, as the conception appears to him, we can scarcely allow ourselves to think that there is an immense central body of sufficient magnitude to carry around it all the systems with which astronomers have filled the regions of space; but we may suppose, with La Lande, that there is a kind of equilibrium among all the systems of the world, and that they all have a periodical circulation round their common centre of gravity. (Astronomie, par La Lande, tom. iii, p. 307, § 3283.)

We shall have occasion to resume this subject when we come to treat of the proper motion of the fixed stars.
ON THE NEW DISCOVERIES AND PHENOMENA IN THE MOON.

The motions and the phases of the Moon have been already described in the first volume of this work. The proportion between the enlightened and obscure part of her disc may be found, for any given time, from the table, which has been already explained, when treating of the planet Venus. By subtracting the longitude of the Sun from that of the Moon, we obtain the argument of the table, or the Moon's distance from the Sun, with which we enter the table, and take out, in the way already explained, the proportion between the dark and illuminated parts of her disc. See page 109 of this volume.

If we observe the Moon, in serene weather, when she is about three or four days old, the part of her disc which is not enlightened by the Sun is faintly illuminated by the light that is reflected from the Earth, and the horns of the enlightened part appear to project beyond the old Moon, as if they were part of a sphere considerably larger in diameter than the unenlightened part.¹ It was long deemed a sufficient explanation of this appearance to say, that bright objects affected the retina, to a greater distance than those which were less luminous; and that, therefore, as ink sinks upon soft paper, the image of the bright part of the Moon expands on the retina, and gives it the appearance of projecting beyond the darker portion of her disc. The explanation of this phenomenon, as given by Dr. Jurin,² is much more satisfactory. He supposes that the eye cannot accommodate itself, with sufficient distinctness, to view objects at such a distance as the Moon. The pencils of rays, therefore, unite before they reach the retina, and will form an indistinct and enlarged image of the Moon. It is perfectly demonstrable, and may be proved by the simple experiment of looking at the figure of the Moon, cut out of white paper, and

¹ This phenomenon is vulgarly, though expressively called "The Old Moon in the New Moon's arms."
placed upon a dark ground, that when this luminous body is viewed, either at a distance too remote, or too near, for perfect vision, its image upon the retina will be enlarged, and the illuminated part will encroach upon the obscure portion, and appear to embrace it, in the very same way as it is seen in the heavens. Dr. Jurin, however, has taken it for granted, that the eye cannot see the Moon with perfect distinctness; a position which, however probable it may be, does not rest upon the evidence of experiment.

The illuminated portion of the Moon’s disc, when she is three or four days old, obviously receives its light from the Earth, which, to the lunar inhabitants, will then appear to be nearly like a full Moon. As the age of the Moon increases, this secondary light is gradually enfeebled, both in consequence of the diminution of the luminous part of the Earth, and of the increase of the enlightened part of the Moon. On one occasion, however, the weather being uncommonly favourable, we observed the secondary light when the Moon was nine days and fourteen hours old.

This secondary light of the Moon has been explained by Riccioli and Leslie, upon the supposition that the Moon is phosphorescent. They conceive, that it is impossible to account in any other way for the extreme brilliancy of her disc; and the latter of these philosophers has explained, upon this hypothesis, the thread of light, or the lucid bow which seems to connect the two horns of the Moon. As we shall give a very different explanation of this curious phenomenon, it may be proper to state Mr Leslie’s theory in his own words. “After emerging from conjunction with the Sun, her sharp horns are seen connected by a silver thread, or lucid bow, which completes the circle; and a very faint light seems to be suffused over the included space. This bright arch, however, becomes always less vivid; and before the Moon is five or six days old, it has almost totally vanished. The pale outline of the old Moon is commonly ascribed to the reflection, or secondary illumination from the Earth. But if it were derived from that source, it would appear densest near the centre, and gradually more dilute towards the edge. I rather should refer it to the spontaneous light which the Moon may continue to emit for some time after the phosphorescent substance has been excited by the action of the solar beams.
The lunar disc is visible, although completely covered by the shadow of the Earth; nor can this fact be explained by the reflection of the Sun's rays in passing through our atmosphere; for why does the rim appear so brilliant? Any such reflection could only produce a diffuse light, obscurely tinged the boundaries of the lunar orb; and, in this case, the Earth, presenting its dark side to the Moon, would have no power to heighten the effect by reflection. But even when this reflection is greatest about the time of conjunction, its influence seems extremely feeble. The lucid bounding arc is occasioned by the narrow lunula, which, having recently felt the solar impression, still continues to shine, and, from its extreme obliquity, glows with concentrated effect."

The phenomenon described in the preceding passage is represented in Plate II, Supr. Fig. 9, where a diluted light appears to be shed over the obscure portion of the Moon's disc, while a lucid bow, more bright than the rest of the obscure part, seems to join the lunar horns. When we examine this luminous horn in the heavens, the lower part of it at a, is always much broader than the upper part at b; and when the Moon has considerable libration, so as to withdraw from the Earth a portion of the eastern limb, the bow ceases to be continuous, and the part at b is no longer visible. These two appearances, which I have often observed, are sufficient to overthrow the explanation which has been already given; for, upon that hypothesis, the lucid bow ought to have been broadest in the centre, diminishing towards the horns, exactly like the enlightened part of the Moon's disc. We are fortunately, however, not confined to arguments of this kind, satisfactory though they be. The true explanation of the phenomenon is so simple and convincing, that it is scarcely possible not to give it an implicit reception. If we look at the large map of the Moon, given in this work, or any other map which exhibits even a tolerable representation of the lunar surface, we shall find that the eastern limb of the Moon is separated from the central parts of her disc by darker regions, and that the luminous portion comprehended between these darker regions, and the circular line which bounds her eastern limb, has actually the form of a bow, which is broadest towards her southern

limb, and gradually diminishes in breadth towards her northern horn. The immediate cause, therefore, of the lucid bow, is to be sought for in the accidental circumstance of the Moon's eastern limb being more luminous than the adjacent regions towards the centre. The central parts of the Moon, indeed, are equally luminous with her eastern limb; but their brilliancy is impaired by their proximity to the illuminated portion. It is obvious, that this explanation of the phenomenon may be equally just, whether the secondary light of the Moon is caused by phosphorescence, or by reflection from the Earth. Hence we see the reason why the bow is broadest at $a$, and narrowest at $b$, and why the libration of the Moon withdrawing the narrow part $b$ of the bow, destroys its continuity. This will be easily understood, by inspecting Plate II, Sup. Fig. 9, and comparing it with the large map of the Moon.

When we look at the surface of the Moon with a good telescope, we find that its appearance is wonderfully diversified. Besides the large dark spots, which are visible to the naked eye, we perceive extensive valleys, and long ridges of highly elevated mountains, projecting their shadows on the plains below. Single mountains occasionally rise to a great height, while hollows, more than three miles deep, and almost exactly circular, are excavated in the plains. The margin of these circular cavities, is often elevated a little above the general level, and a high eminence rises in the centre of the cavity. When the Moon approaches to her opposition with the Sun, the elevations and depressions upon her surface in a great measure disappear, while her disc is marked with a number of brilliant points, and permanent radiations.

Maps of the Moon. These various appearances have been accurately represented in maps of the Moon's surface. This was first attempted, but in a very rude manner, by Riccioli. Hevelius, in his Selenography, afterwards gave more just delineations of the lunar disc, during the whole of her progress round the Earth. A map of the Moon, as she appears when full, was drawn by Cassini, and has been copied, though extremely incorrect, into most of our modern treatises on astronomy. Excellent drawings of the Moon were made by Mr. Russel; but the most accurate and complete that have yet been published, are those of the celebrated Schroeter, who has given highly
magnified views of most parts of the Moon's surface. The large engraving of the Moon, which accompanies this work, was drawn with great care by the editor, and appears to be a tolerably correct resemblance of the lunar surface.

As the attention of astronomers has been much directed to the nature and construction of this luminary; and as an accurate acquaintance with the spots is necessary in finding the longitude from lunar eclipses, we shall give very extensive tables of the names and positions of the spots of the Moon.

The first table is formed from the observations of Lambert, and contains the longitude and latitude of 207 spots, with the names given them by Riccioli and Hevelius.

The observations in the second table were made by the celebrated Tobias Mayer. The positions of the spots, marked in italics, were ascertained by a great number of observations, and were the leading points from which the rest were obtained. All the spots given in this table are contained in the preceding one; but the observations of Mayer are much more accurate than those used by Lambert; and the reason will be readily seen why we have not struck these spots out of the first table.

The third table contains the names which have been recently given by Schroeter to the spots which were formerly anonymous. The positions of these spots we have determined in a rough manner, by comparing the spots of the Moon, as given by this astronomer, with the map and table constructed by Tobias Mayer.

The notes at the foot of each table contain general remarks on the nature and appearance of the different spots. The letter E, affixed to the longitude of the spots, denotes that they are to be found on the eastern side of the Moon's disc, on the left hand of the meridian which passes through the Moon's centre; while the letter W signifies that they are placed on the western side of that line. The letter N, affixed to the latitudes, signifies that the spots are in the Moon's northern hemisphere; and the letter S, that they are placed on the south of the equator.