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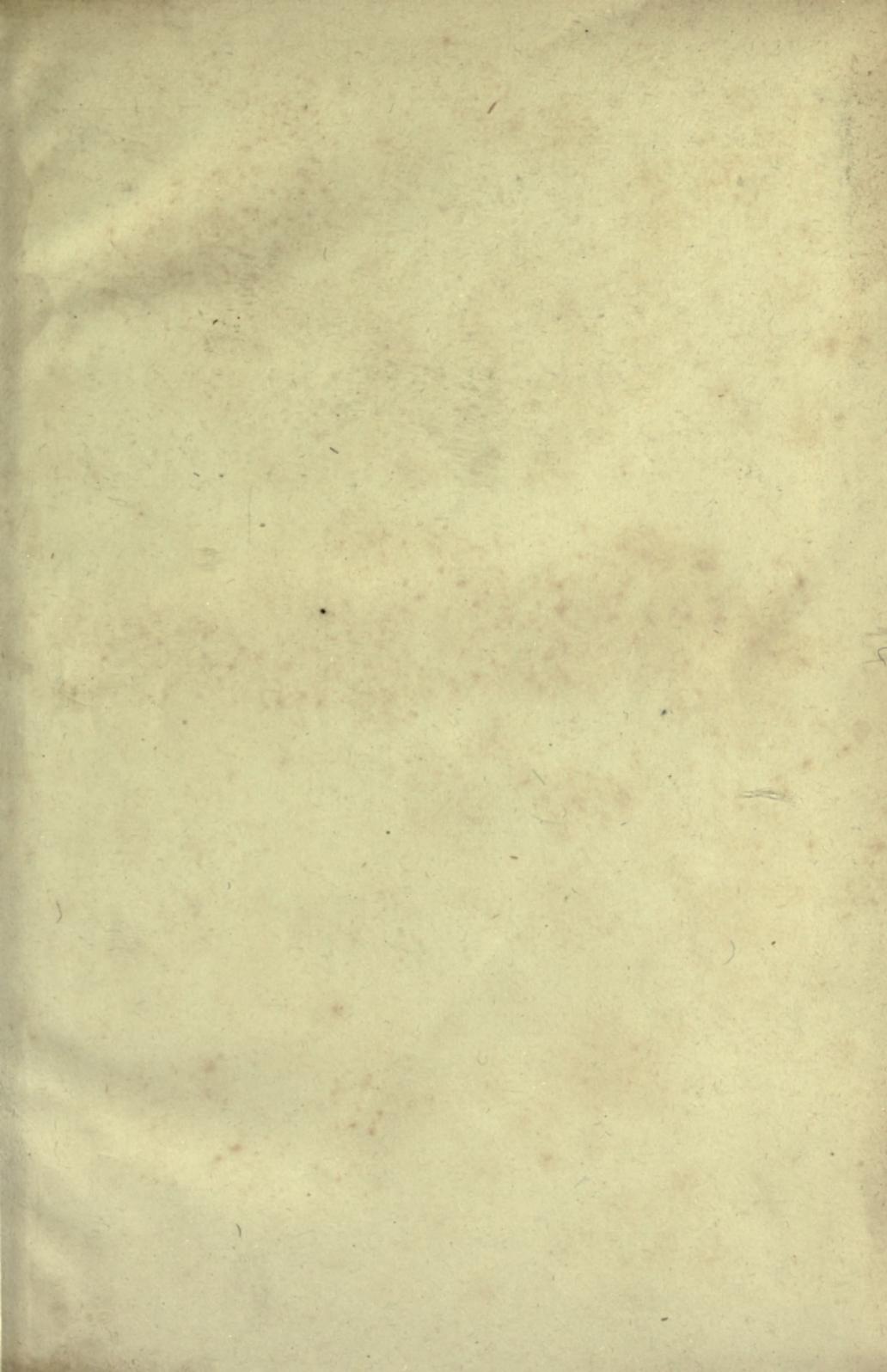
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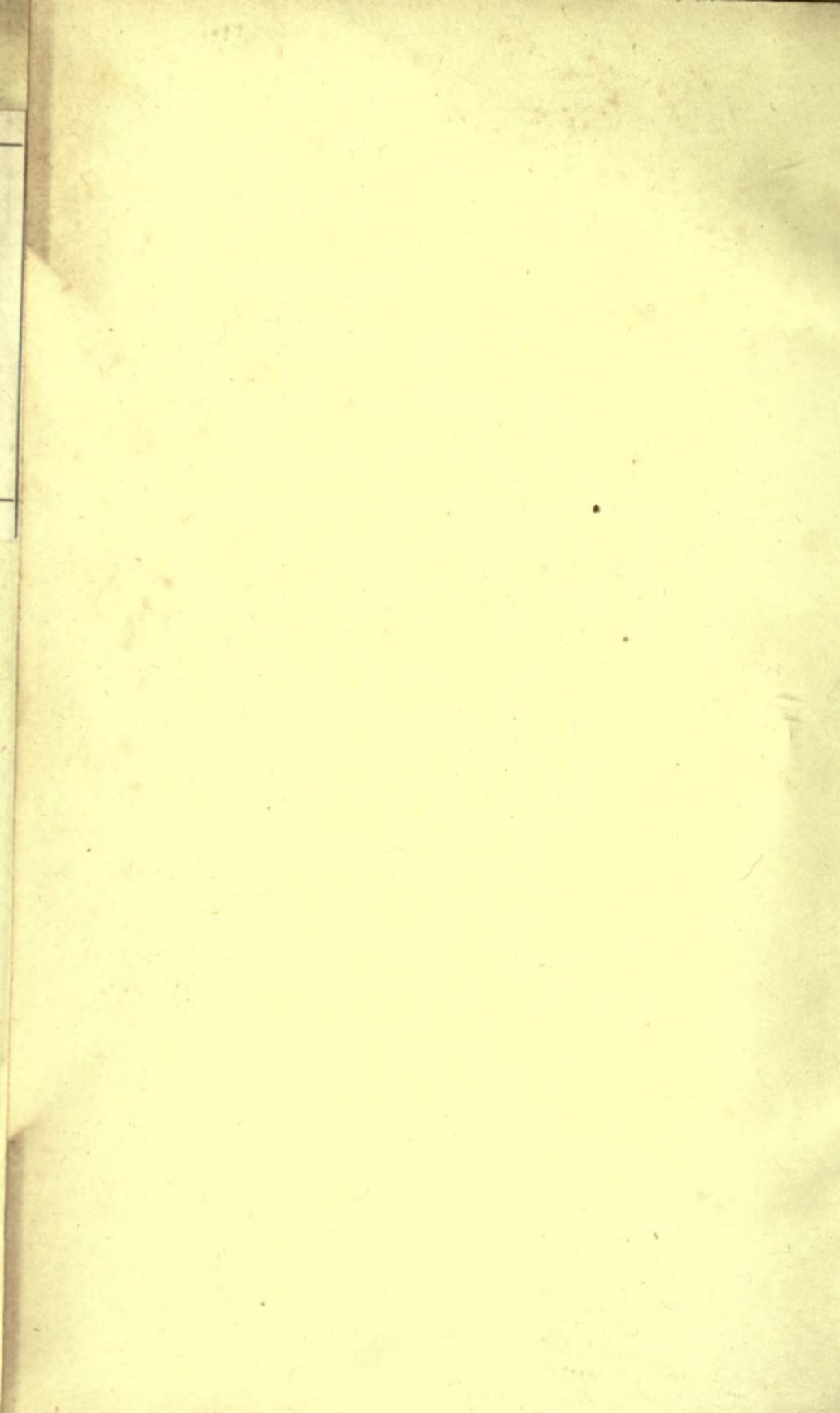
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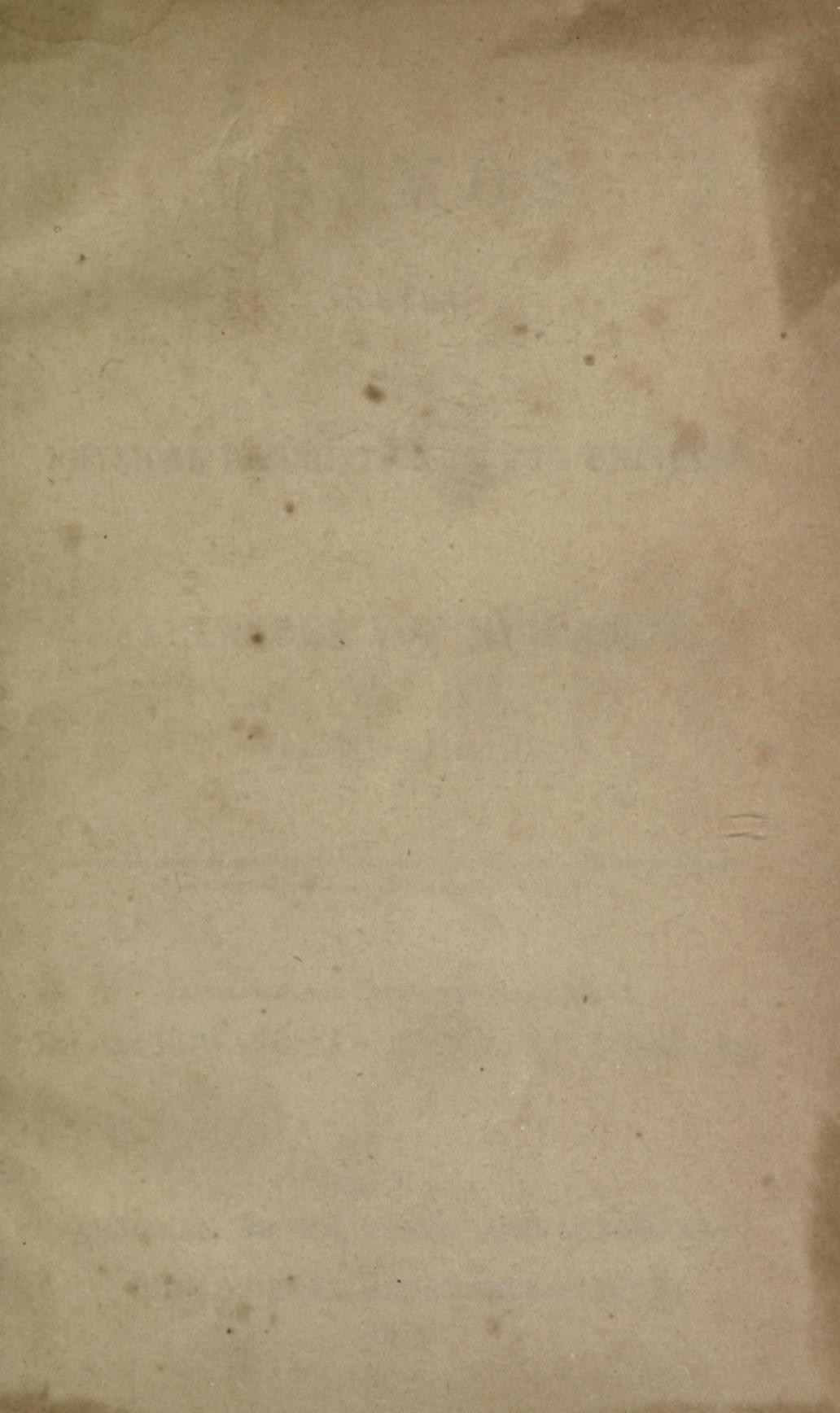
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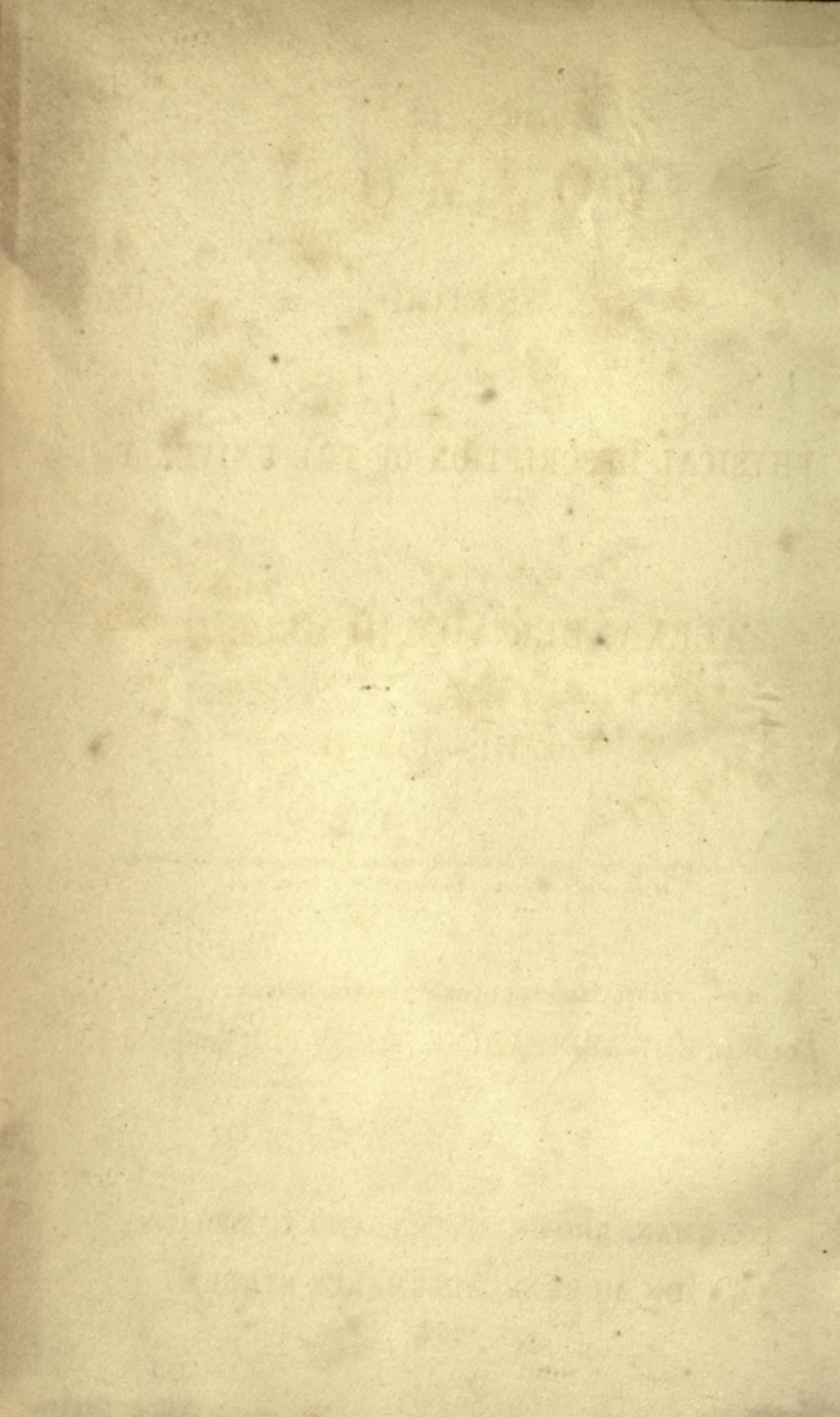
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SKETCH

OF A

PHYSICAL DESCRIPTION OF THE UNIVERSE.

BY

ALEXANDER VON HUMBOLDT.

VOL. III.—PART II.

*Naturæ vero rerum vis atque majestas in omnibus momentis fide caret, si quis modo partes ejus
ac non totam complectatur animo.*—PLIN. H. N. lib. vii. c. 1.

TRANSLATED UNDER THE SUPERINTENDENCE OF

COLONEL EDWARD SABINE, R.A., V.P. & TREAS. R.S.

LONDON:

LONGMAN, BROWN, GREEN, AND LONGMANS;

AND

JOHN MURRAY, ALBEMARLE STREET.

1852.

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NOTICE

ALEXANDER FOX JUMMINGS

LONDON:
WILSON AND OGILVY, 57, SKINNER STREET,
SNOWHILL.

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- | Page | line | |
|-----------|------|--|
| 8 ... | 2, | from bottom, for "third and last volume," read "third and fourth volumes." |
| 44 ... | 12, | from top, for "Aristillus," read "Aristyllus." |
| 72 ... | 5, | from bott. for "at 14' 7"," read "first 14' 7", then 11'." |
| 74 ... | 17, | from top, for "167976," read "167612." |
| 203 ... | 8, | for "ε Lyræ," read "ε 5 Lyræ." |
| 212 ... | 6, | after "earliest calculations," insert "and measurements." |
| 266 ... | 6, | after "1851" close the parenthesis. |
| 348 ... | 3, | after "Laplace," insert ⁽⁵⁵⁶⁾ . |
| 363 ... | 5, | from bottom, after "earth," insert ⁽⁵⁸⁶⁾ . |
| 370 ... | 23, | from top, for " ⁽⁶⁰³⁾ read " ⁽⁶⁰²⁾ ." |
| ii. ... | 10, | from bottom, for "105," read "108." (The reference to the English edition is correct.) |
| xiii. ... | 11, | for "393," read "392." (The reference to the English edition is correct.) |
| lxv. ... | 5, | from top, for "593," read "540." |



VII.

THE NEBULÆ.—WHETHER ALL NEBULÆ ARE MERELY REMOTE AND VERY DENSE CLUSTERS OF STARS? — THE TWO MAGELLANIC CLOUDS IN WHICH NEBULÆ AND NUMEROUS CLUSTERS OF STARS ARE CROWDED TOGETHER.— THE BLACK PATCHES OR “COAL-SACKS” OF THE SOUTHERN CELESTIAL HEMISPHERE.

BESIDES the visible celestial bodies which shine with sidereal light,—either by their own proper light, or by planetary illumination, either isolated, or variously associated forming multiple stars and revolving round a common centre of gravity,—we behold also other forms or masses having a milder, fainter, nebulous, lustre ⁽³⁵⁸⁾. These,—which are seen in some instances as small disk-shaped luminous clouds having a well-defined outline, whilst in other instances their forms vary greatly, their boundaries are ill-defined, and they are spread over much wider spaces in the sky,—appear at the first glance, to the assisted eye which views them through the telescope, to differ altogether from the heavenly bodies which have been treated of in detail in the four preceding sections. As astronomers have been inclined to infer from the observed but hitherto unexplained movements of visible stars ⁽³⁵⁹⁾ the existence of other *unseen* celestial bodies,

so the experience of the resolvability of a considerable number of nebulae has led in the present and most recent times to inferences as to the non-existence of any true nebulae, and even of any cosmical or celestial nebulosity whatsoever. Whether, however, the well-defined nebulae of which I have spoken be indeed composed of self-luminous nebulous matter, or whether they are merely remote, closely crowded, and rounded clusters of stars, they must ever continue to be regarded as highly important features in our knowledge of the arrangement of the structure of the Universe and of the contents of celestial space.

The number of nebulae whose places in Right Ascension and Declination have been determined already exceeds 3600, and some of those of irregular form and indefinite outline extend over a breadth equal to eight diameters of the moon. According to a former estimate of William Herschel (made in 1811), at least $\frac{1}{270}$ of the entire surface of the heavens is occupied by nebulae. Seen through colossal telescopes their contemplation leads us into regions from whence, according to no improbable assumptions, a ray of light requires millions of years ere it can reach our eyes,—to distances for which the dimensions of the nearest sidereal stratum (distances of Sirius, or the calculated distances of the double stars in Cygnus and Centaurus), scarcely afford an adequate unit of measure. Supposing the well-defined nebulae to be elliptical or spherical clusters of stars, then their “conglomeration” itself indicates the existence of some mysterious mode of action in the gravitating forces whose influence they obey. If, on the other hand, they are vaporous masses having one or more nebulous nuclei, then the difference of the degree of condensation exhibited tells us of the possi-

bility of a process of gradual formation of stars from unconsolidated matter. No other class of cosmical forms, no other objects of contemplative rather than of measuring astronomy, are so highly fitted to engage and exercise the power of imagination, not simply as a symbolical image of the infinite in space, but also because the examination of different states or forms of being, and their conjectural connection as stages of existence at successive periods of time, hold out a hope of insight into an antecedent process of formation (360).

The historical development of our present degree of knowledge respecting nebulæ teaches us that in this as in almost all other departments of natural knowledge, the same opposite opinions which are now supported by numerous adherents were long ago similarly defended, although on much feebler grounds. Since the general employment of telescopes, we see Galileo, Dominique Cassini, and the sagacious John Mitchell, regarding all nebulæ as remote groups or clusters of stars; while, on the other hand, Halley, Derham, Lacaille, Kant, and Lambert, maintained the existence of starless nebulous masses. Kepler, (as well as, previous to the application of telescopic vision, Tycho de Brahe), was a zealous supporter of the theory of the formation of stars from cosmical nebulous matter, by the condensation of celestial vapours into spherical bodies. He believed, "*cœli materiam tenuissimam*" (the nebulosity which shines in the Milky Way with a mild sidereal light) "*in unum globum condensatam stellam effingere;*" he based his opinion not on a process of condensation taking place in the well-defined, rounded nebulæ, for these were unknown to him, but on the sudden shining forth of new stars on the margin of the Galaxy.

The history of our knowledge of nebulæ, if we regard principally therein the number of discovered objects, their thorough examination by the telescope, and an extensive generalization of views, may, like that of double stars, be said to begin with William Herschel. Until his time there were in both hemispheres (including Messier's meritorious labours), only 120 unresolved nebulæ whose positions were determined; whilst as early as 1786, the great Astronomer of Slough published his first catalogue containing 1000. I have noticed in detail in the earlier part of this work that what were called by Hipparchus and Geminus in the *Catasterisms* of the *Pseudo-Eratosthenes*, and by Ptolemy in the *Almagest*, "nebulous-stars," (*νεφελοειδέις*), are clusters of telescopic stars, which, seen by the naked eye, have the appearance of patches of nebulous light (³⁶¹). The same appellation, under the Latinised form of "Nebulosæ," passed in the middle of the 13th century into the *Alphonsine Tables*; probably through the predominating influence of the Jewish Astronomer, Isaac Aben Sid Hassan, chief of the wealthy synagogue at Toledo. The *Alphonsine Tables* first appeared in print at Venice in 1483.

We find in an Arabian astronomer of the middle of the tenth century, Abdurrahman Sufi, of Irak in Persia, the first notice of what is now known to be a wonderful assemblage consisting of a countless host of true nebulæ interspersed with star clusters. The "White Ox" which Abdurrahman saw shining with a milky brightness far down below Canopus, was doubtless the larger Magellanic Cloud, which has an apparent breadth of almost twelve diameters of the moon, and covers a space of 42 square degrees in the heavens; and which is first mentioned by European tra-

vellers at the commencement of the 16th century, although Northmen had advanced along the West Coast of Africa as far as Sierra Leone in $8\frac{1}{2}^{\circ}$ N. lat. nearly two hundred years before (³⁶²). It might have been expected that a shining nebulous mass of such great extent, and perfectly visible to the unassisted eye, would have sooner attracted attention (³⁶³).

The first detached nebula which was seen and recognised as such by telescopic observation, and commented upon as being destitute of stars and as being an object of a peculiar kind, was that near the star ν Andromedæ, and which, like the Nubeculæ, is visible to the naked eye. Simon Marius (Mayer of Gunzenhausen in Franconia), who was first a musician and then court mathematician to a Margrave of Culmbach, the same who saw Jupiter's satellites nine days before they were seen by Galileo, (³⁶⁴) has also the merit of having given the first, and, indeed, a very accurate description of a nebula. In the preface to his *Mundus Jovialis*, (³⁶⁵) he relates that, on the 15th of December, 1612, he discovered a fixed star different in appearance from anything which he had ever before seen. It was situated near the third and northernmost star in the girdle of Andromeda: seen with the unassisted eye it appeared only like a small cloud, and viewed through the telescope he could find in it nothing resembling stars; in which respect it differed from the nebulous stars in Cancer, and from other nebulous groups. All that could be distinguished was a white shining appearance, brighter in the centre and fainter towards the margin. The whole, which was about a fourth of a degree in breadth, resembled a light seen from a distance shining through semi-transparent horn (as in a lantern): "similis fere splendor apparet, si a longinquo candela arden

per cornu pellucidum de noctu cernatur." Simon Marius goes on to ask himself whether this singular star may be one which has newly appeared: he declines giving any decided reply to his own question, but is struck by the circumstance that Tycho Brahe, who had enumerated all the stars in the girdle of Andromeda, had not spoken of this "nebulosa." Thus, in the *Mundus Jovialis*, published in 1614, we find, as I have already remarked (³⁶⁶), an enunciation of the difference between an unresolvable nebula (unresolvable, that is to say, by the telescopic powers then available),—and a "cluster of stars" (German, "Sternhaufen," French, "Amas d'étoiles"), in which the crowding together of many small stars, each of which taken separately would be invisible to the naked eye, causes an appearance of nebulous light. Notwithstanding the great improvement in optical instruments, the nebula in Andromeda continued for almost two centuries and a half to be regarded, as at the time of its discovery, as starless, until, two years ago, George Bond, at the Transatlantic Observatory of Cambridge in the United States, recognised 1500 small stars within its limits. Although its nucleus is still unresolved, I have not scrupled to class it among star clusters (³⁶⁷).

We can only attribute to a singular accident the circumstance that Galileo, who before 1610, when the *Sidereus Nuntius* appeared, had already occupied himself repeatedly with the constellation of Orion, mentions subsequently in his *Saggiatore*, when he might have long been acquainted from the *Mundus Jovialis* with the discovery of the starless nebula in Andromeda, no other nebulae in the heavens than those which even his feeble optical instruments resolved into clusters of stars. What he terms the

“Nebulose del Orione e del Presepe” are spoken of by himself as nothing but “accumulations (coacervazioni) of a countless number of minute stars” (368). He forms one after another, under the delusive names of *Nebulosæ Capitis*, *Cinguli*, et *Ensis Orionis*, star clusters, in which he rejoices at having discovered 400 previously unenumerated stars in a space of 1 or 2 degrees; nor does he ever speak of any unresolved nebula:—how can it have happened that the great nebula in Orion’s sword should have escaped his notice, or failed to rivet his attention? But although it seems probable that Galileo never observed either the large amorphous nebula in Orion, or the round disk of a so-called unresolvable nebula, yet his general views (369) respecting the internal nature of nebulæ were very similar to those to which the greater number of astronomers are now inclined. Like Galileo, Hevelius of Dantzic (a distinguished observer, but who was unfavourable (370) to the use of telescopes in the formation of star-catalogues), no where mentions in his writings the great nebula in Orion. His tables, indeed, scarcely contain as many as 16 nebulæ having their positions determined.

At last, in 1656, Huygens (371) discovered the nebula in Orion’s sword, to which, from its extent, its form, and from the number and celebrity of its later investigators, so much importance has attached; and in 1676 Picard was induced to devote to it his diligent attention. Edmund Halley during his visit to St. Helena (1677) first determined the positions of some, though exceedingly few, of the nebulæ of the southern hemisphere, in parts of the heavens not visible in Europe. The strong predilection which the great Cassini (Jean Dominique), entertained for all parts of contemplative astronomy, led him, towards the end of the 17th

century, to undertake a more careful examination of the nebulae of Andromeda and Orion. He thought that he perceived changes in the latter since the time of Huygens; and that he even discerned in the nebula in Andromeda "stars which cannot be seen with less powerful telescopes." We have reason to believe that he was mistaken in regard to the supposed alterations in the nebula in Orion, but since the remarkable observations of George Bond the same cannot altogether be said in regard to the existence of stars in the nebula in Andromeda. Cassini, it should be remarked, was from theoretic grounds disposed to anticipate such a resolution, since (in direct contradiction to Halley and Derham), he considered all nebulae to be very remote clusters of stars (372). It is true that he looked upon the faint milky lustre of the object in Andromeda as analogous to that of the zodiacal light, but this last was also regarded by him as composed of a countless multitude of small planetary bodies thickly congregated (373).

Lacaille, during his sojourn in the southern hemisphere (at the Cape of Good Hope, and the Isles of France and Bourbon, 1750—1752), augmented the number of observed nebulae so considerably that, as has justly been remarked by Struve, "through this traveller's labours more was then known of the nebulae of the southern heavens than of those visible in Europe." Lacaille moreover attempted not unsuccessfully to arrange the nebulae into classes according to their apparent forms; he also first undertook, although with little result, the difficult analysis of the two Magellanic clouds (*Nubecula major et minor*) with their heterogeneous contents.

If we deduct from the other 42 isolated nebulae which

Lacaille observed in the southern heavens, 14 which can be perfectly resolved into true star-clusters even with low magnifying powers, only 28 remain, while with more powerful instruments, and greater practice and skill in observing, Sir John Herschel succeeded in discovering in the same zone 1500 nebulæ, clusters being similarly excluded.

Unaided, and unguided by any personal observation or experience, and at first unknown to each other ⁽³⁷⁴⁾ although tending in very similar directions, Lambert (from 1749) and Kant (from 1755) exercised their imaginations, and speculated with admirable sagacity on nebulosities, detached galaxies, and islands of nebulae and stars sporadically dispersed in celestial space. Both Kant and Lambert were inclined to the nebular hypothesis, and to the belief of a process of formation continually going forward in space; and even to the idea of the production of stars from cosmical vapour. Le Gentil (1760—1769), long before his distant voyages and disappointment in regard to the observation of the transit of Venus, promoted the study of nebulae by his own observations on the constellations of Andromeda, Sagittarius, and Orion. He employed the object-glass of Campani of 34 French feet focal length, in the possession of the observatory of Paris. The sagacious John Mitchell, in complete opposition to the ideas of Halley and Lacaille, Kant, and Lambert, declared (as Galileo and Dominique Cassini had done) all the nebulae to be clusters of stars,—aggregations of very small or very remote telescopic stars, whose existence would assuredly be demonstrated at some future day by the improvement of instruments ⁽³⁷⁵⁾. A rich accession to the knowledge of nebulae,

rich as compared with the slow advances previously made, was next obtained by the persevering diligence of Messier : deducting those previously discovered by Lacaille and Méchain, his catalogue of 1771 contained 66 nebulae which had never been recorded before. In the poorly provided Observatoire de la Marine (Hôtel de Clugny), his efforts succeeded in doubling the known number of nebulae in both hemispheres (³⁷⁶).

These feeble beginnings were followed by the brilliant epoch of the discoveries of William Herschel and of his son. As early as 1779 the elder Herschel began a regular review of the nebulae with a 7-foot reflector; in 1787 his great 40-foot telescope was completed; and in three catalogues (³⁷⁷) which were published in 1786, 1789, and 1802, he gave the positions of 2500 nebulae and star-clusters. Until 1785, and even almost until 1791, this great observer appears to have inclined, with Mitchell, Cassini, and now Lord Rosse, to regard nebulae, to him unresolvable, as exceedingly remote clusters of stars; but between 1799 and 1802, longer occupation with the subject, led him, as formerly Halley and Lacaille, to embrace the nebular hypothesis, and even, with Tycho Brahe and Kepler, that of the formation of stars from the gradual condensation of cosmical vapour. The two views are not, however, necessarily connected with each other (³⁷⁸). The nebulae and clusters observed by Sir William Herschel were subjected by his son, Sir John Herschel, from 1825 to 1833, to a fresh review, in the course of which he added to his father's list 500 new objects, and published in the Philosophical Transactions for 1833 (p. 365 to 481) a complete catalogue of 2307 nebulae and clusters of stars. This great work contained

all that had been observed in the part of the heavens visible from middle Europe, and in the next immediately succeeding five years (1834 to 1838), we find Sir John Herschel at the Cape of Good Hope examining with a 20-foot reflector the whole of the heavens visible from thence, and thereby adding to the above 2307 nebulæ and star clusters, a fresh list of 1708 positions (³⁷⁹)! Of Dunlop's catalogue of southern nebulæ and clusters (629 in number, observed at Paramatta from 1825 to 1827 with a 9-foot reflector (³⁸⁰) having a mirror of 9 inches diameter), only one-third were transferred to Sir John Herschel's work.

A third great epoch in the knowledge of these mysterious celestial objects has been commenced by the construction of the admirable 50-foot telescope (³⁸¹) of the Earl of Rosse at Parsonstown. All the questions which had been agitated in the long course of fluctuating opinions, and in the different stages of development in cosmical contemplation, now became afresh the subjects of animated discussion in the controversy between the nebular hypothesis and the asserted necessity of relinquishing that hypothesis altogether. From the accounts which I have been able to collect on the authority of distinguished astronomers long conversant with the nebulæ, it appears that out of a great number of objects hitherto supposed to be unresolvable, taken as it were by chance from all classes of such objects in the catalogue of 1833, almost all (Dr. Robinson, the Director of the Observatory of Armagh, gives above 40), were completely resolved (³⁸²). Sir John Herschel expresses himself in a similar manner in his opening speech at the Meeting of the British Association at Cambridge in 1845, as well as in the *Outlines of Astronomy* in 1849. He says: "the reflector of Lord

Rosse has resolved, or shown to be resolvable, multitudes of nebulae which had resisted the space-penetrating power of feebler optical instruments. Although there may be nebulae which this powerful telescope of six English feet aperture shows only as nebulae, without any indication of resolvability, yet from inferences founded on analogy we may conjecture that in reality no difference exists between nebulae and clusters of stars" (383).

The constructor of the powerful optical apparatus at Parsonstown, always carefully separating the result of actual observation from inferences for which it might be hopefully considered that a foundation had been laid, expresses himself with great caution on the subject of the nebula in Orion. In a letter to Professor Nichol of Glasgow, dated March 19, 1846, (384) Lord Rosse wrote:—"From our examination of this celebrated nebula, I can certainly say that very little, if any, doubt remains as to its resolvability. From the state of the atmosphere we could only use half the magnifying power which the mirror is capable of bearing; and yet we saw that everything round the trapezium forms a mass of stars. The rest of the nebula is also rich in stars, and has quite the character of resolvability." At a later period, 1848, Lord Rosse still refrained from announcing the actual achievement of a complete resolution of the nebula in Orion, expressing only the near hope and well-grounded probability of the remaining portion of nebulosity being so resolved.

If, in the animated debate recently awakened respecting the non-existence of a self-luminous nebulous matter in the Universe, we separate what belongs to observation and what to inductive conclusions, a very simple consideration

is sufficient to show that by the increasing perfection of telescopic vision the number of unresolved nebulæ may, indeed, be considerably diminished, but that it is very improbable that the diminution should ever proceed to actual exhaustion. By the successive employment of telescopes of increasing power, each in its turn may be expected to resolve nebulæ which its predecessor had left unresolved; but it will at the same time,⁽³⁸⁵⁾ by its increased space-penetrating power, replace, at least in part, the resolved nebulæ by new ones previously inaccessible to our view. Thus, by increasing optical power, resolution of old, and discovery of new, would follow each other in an endless succession. Should this not be so, we must, it appears to me, either imagine occupied space to have a limit, or else suppose that the world-islands, to one of which we belong, are so distant from each other that no telescope which may hereafter be invented can ever suffice to reach the opposite shore, and that our last (extremest, or outermost) nebulæ will be resolved into clusters of stars, projected, like the stars in the Milky Way, upon a black ground wholly without nebulosity⁽³⁸⁶⁾. But it may be fairly asked, whether we can with probability assume both such a state of the Universe, and such a degree of improvement in optical instruments, that in the whole firmament there shall not remain one unresolved nebula?

The hypothetical assumption of a self-luminous fluid presenting itself in well-defined nebulæ, round or oval, must not be confounded with the similarly hypothetical assumption of a non-luminous ether pervading universal space, and producing by its undulations light, radiant heat, and electromagnetism⁽³⁸⁷⁾. The emanations from the nuclei of comets, which as comet-tails often occupy enormous portions of

space, disperse the to us unknown matter of which they consist among the planetary orbits of the solar system which they traverse; but when separated from the head or nucleus of the comet, the matter of which the tails are formed ceases to be sensibly luminous to our eyes. Newton considered it possible that "vapores ex Sole et Stellis fixis et caudis Cometarum" might become mingled with the atmosphere which surrounds the Earth (³⁸⁸). No telescope has yet discovered anything resembling stars in the vaporous flattened revolving ring of the zodiacal light. Whether the particles of which this ring consists,—and which in accordance with dynamic conditions are imagined by some to have rotations independent of the sun, and by others to revolve simply round that body,—shine by reflected light, or whether, like many terrestrial fogs and vapours, (³⁸⁹) they are self-luminous, remains undecided. Dominique Cassini believed them to be small planetary bodies (³⁹⁰). We feel as it were involuntarily impelled to look in all fluids for detached (³⁹¹) molecular parts, like the full or hollow vesicles in clouds; and the gradations of increasing density in our solar system from Mercury to Saturn and Neptune, (from 1.12 to 0.14: the Earth being taken as = 1,) conduct us to comets, through the outermost strata of whose nuclei faint stars are visible: they even conduct us gradually to detached particles so rare that the forms of their aggregation can scarcely be said to possess definite outlines.

It was these very considerations on the constitution of the apparently nebulous zodiacal light, which, long previous to the discovery of the small planets between Mars and Jupiter, and before the formation of conjectures respecting meteoric asteroids, led Cassini to entertain the idea of cos-

mical bodies of all dimensions and of all degrees of density. We touch here almost involuntarily on the ancient dispute in philosophy on primitive fluidity and composition from distinct molecular particles, which is indeed more accessible to mathematical treatment. Let us hasten to return to that which is purely objective in the phenomenon.

Among 3926 (2451 + 1475) recorded positions, [belonging:—*a*, to the portion of the firmament visible at Slough, and which for the sake of brevity we will here call the northern heavens, (according to three catalogues of Sir William Herschel, from 1786 to 1802, and the above-mentioned review published by his son in the *Phil. Trans.* for 1833); *b*, to the part of the southern heavens visible from the Cape of Good Hope, according to the African Catalogue of Sir John Herschel,] there are contained both nebulæ and clusters of stars. However intimately these objects may in truth be related to each other, yet in order to mark the state of our knowledge at a definite epoch I have reckoned each class separately. I find (³⁹²) in the northern catalogue, 2299 nebulæ and 152 clusters of stars; in the southern or Cape catalogue, 1239 nebulæ and 236 star-clusters. This makes for the whole firmament the number of nebulæ registered in these catalogues as not having yet been resolved into stars, 3538. This number would be raised to 4000 by taking into the account three or four hundred objects seen by the elder Herschel (³⁹³) and not redetermined by his son, as well as 629 observed at Paramatta by Dunlop with a 9-inch Newtonian reflector, and of which only 206 were transferred by Sir John Herschel to his catalogue (³⁹⁴). A similar result has also been very recently published by Bond and by Mädler. Accord-

ing to the present state of our knowledge, therefore, the proportion of the number of nebulæ to that of double stars is about as 2 : 3 ; but it should not be forgotten, that under the denomination of double stars are included those which are merely optically double, and that up to the present time changes of position have only been recognised in an eighth, or perhaps even a ninth part of the whole (³⁹⁵).

The numbers found above, viz. 2299 nebulæ with 152 star-clusters in the northern, and only 1239 nebulæ with 236 clusters in the southern catalogues, shew a comparatively smaller number of nebulæ and a preponderance of star-clusters in the southern hemisphere. Even assuming the probability of all nebulæ being truly in their own nature alike resolvable, *i. e.*, of their being either more remote clusters, or groups composed of smaller, less crowded, self-luminous cosmical bodies, yet this apparent contrast, (to the importance of which Sir John Herschel himself called attention, (³⁹⁶) and that the more strongly as he had employed reflecting telescopes of equal power in the two hemispheres), must at least be held to indicate a striking diversity in distribution in space, *i. e.* in respect to the directions in which they present themselves on the northern or southern firmament to the inhabitants of the earth.

We owe to the same great observer the first exact knowledge and general cosmical view of the distribution of nebulæ and star-clusters over the entire surface of the heavens. In order to examine their situation, their relative abundance in different parts, and the probability or improbability of their succession in certain groupings or lines, he entered between three and four thousand objects graphically in squares of which the sides corresponded to 3° of Declination and

15^m of Right Ascension. The greatest local accumulation is found in the northern hemisphere, distributed through the constellations of Leo and Leo minor, the body, tail, and hind-paws of Ursa major, the nose of Camelopardalis, the tail of Draco, the two Canes venatici, Coma Berenices (where the north pole of the Milky Way ⁽³⁹⁷⁾ is situated), the right foot of Böotes, and above all in the head, wings, and shoulders of Virgo. This zone, which has been called the nebula-region of Virgo, contains, as I have already remarked, in a space ⁽³⁹⁸⁾ occupying the eighth part of the entire celestial sphere, one-third of the whole of the nebulæ. It extends but little beyond the equator, excepting where at the southern wing of Virgo it stretches as far as the extremity of Hydra and to the head of Centaurus, but without touching the feet of the Centaur or the Southern Cross. Another and less considerable assemblage of nebulæ in the northern hemisphere, and which Sir John Herschel calls the nebula-region of Pisces, extends further into the southern hemisphere than does that of Virgo. It forms a zone running from the constellation of Andromeda, which it fills almost entirely, to the breast and wings of Pegasus, the band which unites the two Pisces, the southern galactic Pole, and Fomalhaut. A striking contrast to these well-filled regions is presented by the almost desert space, as respects nebulæ, which surrounds Perseus, Aries, Taurus, the head and upper parts of the body of Orion, Auriga, Hercules, Aquila, and the whole constellation of Lyra ⁽³⁹⁹⁾. If, in the general view of the nebulæ and star-clusters belonging to the Northern Catalogue (that of Slough), given in Sir John Herschel's work on the Cape Observations, and where they are distributed into the several hours of Right Ascension, we

combine them into six groups each of four hours, we obtain :—

| | Hours. | Hours. | | | | | |
|-------|--------|--------|---|---|---|---|-----|
| R. A. | 0 to | 4 | . | . | . | . | 311 |
| | 4 „ | 8 | . | . | . | . | 179 |
| | 8 „ | 12 | . | . | . | . | 606 |
| | 12 „ | 16 | . | . | . | . | 850 |
| | 16 „ | 20 | . | . | . | . | 121 |
| | 20 „ | 24 | . | . | . | . | 239 |

By a more careful separation according to North and South Declination, we find that in the six hours of Right Ascension from nine hours to fifteen hours, there are in the northern hemisphere alone, 1111 nebulae and clusters of stars,⁽⁴⁰⁰⁾ viz. :—

| | Hours. | Hours. | | | | | |
|------|--------|--------|---|---|---|---|-----|
| From | 9 to | 10 | . | . | . | . | 90 |
| | 10 „ | 11 | . | . | . | . | 150 |
| | 11 „ | 12 | . | . | . | . | 251 |
| | 12 „ | 13 | . | . | . | . | 309 |
| | 13 „ | 14 | . | . | . | . | 181 |
| | 14 „ | 15 | . | . | . | . | 130 |

The true northern maximum of nebulae is therefore situated between 12h. and 13h., very near the North Galactic Pole. Farther on, between 15h. and 16h., towards the constellation of Hercules, the decrease is so sudden that the number falls from 130 to 40.

In the southern hemisphere we find not only a much smaller number, but also, generally speaking, a much more uniform distribution of nebulae. Spaces devoid of these celestial phenomena alternate with sporadic nebulae; with

the exception of one remarkable local assemblage; which is indeed even more crowded than the nebulous region of Virgo in the northern hemisphere; for of the Magellanic clouds, Nubecula major alone comprehends 300 nebulæ. The region around the pole is poor in nebulæ in both hemispheres, but as far as 15° of polar distance it is poorer round the southern than round the northern pole in the proportion of 4 to 7. The present North Pole has a small nebula only 5 minutes distant from it; a similar one, to which Sir John Herschel very properly gives the name of "Nebula Polarissima Australis," (No. 3176 of his Cape Catalogue; R. A., 9h. $27^m 56^s$, N. P. D., $179^{\circ} 34' 14''$) is still 25 minutes from the South Pole. The comparatively starless desert round the southern pole, and especially the absence of a pole-star visible to the unassisted eye, were the subject of bitter complaint to Amerigo Vespucci and Vicente Yañez Pinzon, when, at the end of the fifteenth century, they advanced far beyond the Equator to Cape St. Augustin, and when Vespucci even supposed that the fine passage of Dante, "Io mi volsi a man destra e posi mente . . .," and the four stars, "Non viste mai fuor ch' alla prima gente" referred to antarctic circumpolar stars (⁴⁰¹).

Hitherto we have been considering the nebulæ in respect to their number and dissemination on what is called the firmament, an apparent distribution which must not be confounded with the actual distribution in space. From this examination we now pass to their wonderful diversity in individual form. This is sometimes regular, (spherical, elliptical in various degrees, annular, planetary, or resembling a photosphere surrounding a star); and sometimes irregular or amorphous and as difficult of classification as

are the aqueous nebulæ of our atmosphere, the clouds. The normal form (⁴⁰²) of the celestial nebulæ is considered to be elliptical or spheroidal. With equal telescopic power, such nebulæ are most easily resolvable into star-clusters when they are most globular; and on the other hand when the compression in one direction and elongation in the other is greatest they are the most difficult of resolution (⁴⁰³). We find in the heavens gradually varying forms from round to elliptic more or less elongated. (Phil. Trans., 1833, p. 494, Pl. ix. figs. 19—21.) The condensation of the milky nebulosity is always progressive towards a centre, or as in some cases even towards several central points or nuclei. It is only in the class of round or oval nebulæ that double-nebulæ are known; and in these, as there is no perceptible relative motion of the individuals in respect to each other, (either because no such motion exists, or that it is exceedingly slow), we are without the criterion which would enable us to demonstrate the reality of a mutual relation, and which in the case of double stars we possess for distinguishing those which are physically from those which are merely optically double. (Drawings of double-nebulæ are to be found in the Philosophical Transactions for 1833, figs. 68—71. Compare also Herschel, *Outlines of Astronomy*, § 878, and *Observations at the Cape of Good Hope*, § 120.)

Annular nebulæ are among the rarest phenomena with which we are acquainted. In the northern hemisphere, according to Lord Rosse, seven are known to us. The most celebrated annular nebula is the one situated between β and γ Lyræ (No. 57, Messier; No. 3023 of Sir John Herschel's Catalogue); it was first observed by Darquier at

Toulouse in 1779, when the comet discovered by Bode came into its vicinity. Its apparent magnitude is nearly equal to that of Jupiter's disk, and it is elliptical,—the proportion of its diameters being as 4 to 5. The interior of the ring is by no means black, but rather somewhat illuminated. Sir William Herschel had recognised some stars in the ring, and Lord Rosse and Mr. Bond have now entirely resolved it (⁴⁰⁴). On the other hand, the fine annular nebulæ of the southern hemisphere, Nos. 3680 and 3686, are perfectly black in the interior of the ring. No. 3686, moreover, is not elliptical but perfectly round (⁴⁰⁵); all are probably annular or ring-shaped clusters of stars. It is to be remarked that with the increase of optical means, both elliptical and annular nebulæ appear generally less defined in their outlines: in Lord Rosse's telescope the ring-nebula in Lyra even appears as a simple ellipse, having singular diverging thread-like nebulous appendages. It is especially striking to observe the transformation of the nebula which, seen through feebler telescopes, appears simply elliptical, into Lord Rosse's Crab-Nebula.

A class of phenomena less rare than annular nebulæ, but of which Sir John Herschel counts only 25, almost three-fourths being in the southern hemisphere, consists of what are called planetary nebulæ, which were first discovered by William Herschel, and are among the most wonderful of celestial phænomena. They have a most striking resemblance to the disks of planets. In the greater number of instances they are either round or somewhat oval; sometimes with sharply defined boundaries, and sometimes with confused and vaporous edges. The disks of several have a very uniform light; others are "mottled or of a peculiar

texture as if curdled." They never show traces of condensation towards the centre. Five planetary nebulae have been recognized by Lord Rosse as annular nebulae with one or two central stars. The largest planetary nebula is situated in the Great Bear, (not far from β Ursae maj.) and was discovered by Méchain in 1781. The diameter of the disk (⁴⁰⁶) is 2' 40". The planetary nebula in the Southern Cross, (No. 3365, Cape Observations, p. 100,) with a disk of scarcely 12" diameter, has the brightness of a star of between the 6th and 7th magnitudes. The colour of its light is an indigo-blue, and (among nebulae) this remarkable hue is found also in three objects of a similar form, in which, however, the blue is less intense (⁴⁰⁷). The blue tint of some planetary nebulae by no means contradicts the possibility of their being composed of small stars, for we are acquainted with blue stars, not only as forming both members of a pair or double-star, but also in clusters consisting either entirely of blue, or of blue mixed with red and yellow small stars (⁴⁰⁸).

The question whether the planetary nebulae are very distant nebulous stars in which the difference between an illuminating central star and a surrounding vaporous envelope escapes our telescopic vision, has been alluded to in an earlier portion of my work (⁴⁰⁹). May Lord Rosse's giant telescope at length afford the means of investigating the nature of these wondrous planetary vaporous disks! Difficult as it is to form a clear conception of the complicated dynamic conditions under which, in a spherical or spheroidically elliptical cluster of stars, the rotating, congregated suns, becoming specifically denser as the centre is approached, form a system in equilibrium (⁴¹⁰), this difficulty becomes

still greater in those circular, well-defined, planetary nebulous disks which show an entirely uniform brightness not increasing towards the centre. Such a state of things seems less compatible with the form of a globe (or with thousands of small stars in a state of aggregation) than with the idea of a gaseous photosphere, which in our sun is supposed to be covered with a thin, untransparent, or at least very faintly illuminated vaporious stratum. May it be that in the planetary nebula the light appears so uniformly distributed only because the difference between the margin and the centre disappears by reason of the great distance?

Among the nebulæ of regular forms, the fourth and last class consists of Sir William Herschel's "nebulous stars;" *i. e.* actual stars surrounded by a milky nebulosity, which is very probably in relation with the central star and dependent on it. Whether the nebulosity which, according to Lord Rosse and Mr. Stoney, appears in some cases quite annular, (Phil. Trans. for 1850, Pl. xxxviii. figs. 15 and 16), should be regarded as self-luminous, and as forming a photosphere as in our sun,—or whether, (as seems less probable), it be merely illuminated by the central sun,—are points on which very different opinions prevail. Derham, and to a certain degree Lacaille, who at the Cape of Good Hope discovered several nebulous stars, believed the stars to be distant from and unconnected with the nebulæ on which they appeared projected. Mairan (1731) appears to have been the first who put forward the opinion of nebulous stars being surrounded with a luminous atmosphere of their own⁽⁴¹¹⁾. There are even larger nebulous stars (for example of the 7th magnitude, as No. 675 of the Catalogue of 1833),

of which the photosphere has two or three minutes diameter (⁴¹²).

A class of nebulæ very different from those which we have been describing, and which have always at least a faintly marked outline, consists of the larger nebulous masses of irregular form. These are characterised by very various and unsymmetrical shapes, as well as very imperfectly defined and confused outlines. They are mysterious phenomena "*sui generis*," and are what have principally given occasion to the opinions which have prevailed respecting the existence of cosmical cloud, and of self-luminous nebulous matter dispersed through the celestial regions and similar to the substratum of the zodiacal light. A most striking contrast is presented by viewing some of the irregular or amorphous nebulæ which cover several square degrees of the surface of the heavens, in comparison with the smallest of all the regular isolated oval nebulæ with which we are acquainted, *i. e.* the one situated between the constellations of Ara and Pavo in the southern hemisphere, and which has a luminous intensity equal to that of a telescopic star of the 14th magnitude (¹¹³). No two of the unsymmetrical, diffused nebulous masses resemble each other, "but," adds Sir John Herschel, after many years of observation, "they have one important character in common; they are all situated in or very near the borders of the Milky Way"; and may be "regarded as outlying, distant, and as it were detached fragments of the great stratum of the Galaxy" (⁴¹⁴). On the other hand, the regular symmetrical and usually well-defined small nebulæ are partly scattered generally over the heavens, and partly crowded into particular regions remote

from the Milky Way; such in the northern hemisphere are the regions of Virgo and Pisces. It is true that the great irregular nebulous mass in the sword of Orion is fully fifteen degrees from the visible margin of the Milky Way; but it may perhaps belong to the prolongation of that branch of the galaxy which runs from α and ε Persei, and appears to lose itself near Aldebaran and the Hyades, and of which we have already spoken (Vol. iii. p. 128). The finest stars in the constellation of Orion, which gave to it its ancient celebrity, are considered as belonging to the zone of very large, and probably comparatively near, celestial bodies, the prolongation of which forms a great circle passing through ε Orionis and α Crucis into the southern portion of the Milky Way (⁴¹⁵).

An earlier and very prevalent opinion (⁴¹⁶), as to the existence of a galaxy of nebulæ intersecting the galaxy of stars nearly at right angles, does not by any means appear to be confirmed by later and more exact observations on the distribution of the nebulæ of regular form over the vault of heaven (⁴¹⁷). There are, indeed, as has been already remarked, large assemblages of nebulæ near the northern galactic and a considerable number near the Southern Fish but from the many interruptions which occur we cannot say that we have found a zone of nebulæ passing through these two poles and forming a great circle of the sphere. William Herschel in 1784, at the conclusion of his first treatise on the structure of the heavens, had indeed developed such a view, but doubtfully, and with the caution which became so eminent an investigator of nature.

Of the irregular, or rather unsymmetrical nebulæ, some, (as those in the sword of Orion, near η Argûs, and in Sagitta-

rius and Cygnus), are remarkable for their extraordinary size; others, (as Nos. 27 and 51 of Messier's Catalogue), for the peculiarity of their forms.

In regard to the great nebula in the sword of Orion, we have already noticed the circumstance of its never having been mentioned by Galileo, although he had been so much occupied with the stars between the belt and sword (⁴¹⁸), and had even constructed a map of that region. What he terms *Nebulosa Orionis*, and which is drawn by him together with *Nebulosa Præsepe*, is expressly stated by him to be an assemblage of small stars (*stellarum constipatarum*) in the *head* of Orion. In the drawing in § 20 of the *Sidereus Nuncius*, which extends from the belt to α Orionis in the right leg, I recognise, above the star ι , the multiple star θ . The magnifying powers employed by Galileo were only from eight to thirty. As the nebula in the sword does not stand by itself, but forms, when viewed through imperfect telescopes, or in an unfavourable state of the atmosphere, a sort of halo round the star θ , it may be that from this circumstance its individual existence and form escaped the notice of the great Florentine observer, who, moreover, was otherwise disinclined to admit or assume the existence of nebulae (⁴¹⁹). It was fourteen years after Galileo's death, in the year 1656, that Huygens discovered the great nebula in Orion, and gave a rough drawing of it, which was published in 1659 in the "*Systema Saturnium*." His own words are:—"Whilst I was engaged in observing, with a refractor of 23-feet focal length, Jupiter's variable belts, a dark central zone in Mars, and some faint appearances in that planet, there was presented to me among the fixed stars a phenomenon which, so far as I am aware, has never been observed before, and can

only be accurately discerned by means of such large telescopes as that which I employ. In the sword of Orion, astronomers enumerate three stars placed very near to each other: as, in the year 1656, I happened to be looking through my telescope at the middle one of the three, I saw, instead of a single star, twelve, which, indeed, with telescopes is nothing extraordinary. Of these stars, three appeared almost in contact, and four others shone as through a bright haze, so that the space around them, as drawn in the accompanying figure, appeared much lighter than the rest of the sky. It happened to be very clear, and was quite dark, so that the appearance was as if there were an opening or interruption (hiatus). I have seen all this repeatedly since, and that up to the present time, so that this wonderful existence, whatever it may be, has probably always its seat there. I never saw anything similar in any other of the fixed stars.” (It would seem, therefore, that the nebula in Andromeda, described 54 years earlier by Simon Marius, was either unknown to Huygens, or had excited but little interest in his mind!) “Whatever other objects have been called *nebulae*,” he adds, “and even the Milky Way when looked at through telescopes, show nothing nebulous, and are merely multitudes of stars crowded together in clusters” (420). The animation and vivacity of this first description testify the magnitude and freshness of the impression produced; but how vast is the difference which separates this first graphical representation made in the middle of the 17th century,—and those, a little less imperfect, of Picard, Le Gentil, and Messier,—from the fine drawings of Sir J. Herschel (1837), and of William Cranch Bond, Director of the Observatory of Cambridge in the United States in 1848! (421).

The first named of these later astronomers had the great advantage (⁴²²) of observing the nebula in Orion, since 1834, with a twenty-foot reflector at the Cape of Good Hope at an altitude of 60° , and of thereby improving still further his earlier drawing of 1824—26 (⁴²³). The positions of 150 stars in the neighbourhood of θ Orionis, chiefly from the 15th to the 18th magnitudes, were also determined. The celebrated trapezium, which is not surrounded by any nebulosity, is formed of four stars of the 4th, 6th, 7th, and 8th magnitudes. The 4th star was discovered (1666?) by Dominique Cassini, at Bologna (⁴²⁴); the 5th (γ') in 1826, by Struve; and the 6th (α') which is of the 13th magnitude, by Sir John Herschel in 1832. The Director of the Observatory of the Collegio Romano, de Vico, announced at the beginning of the year 1839, that with his large refractor by Cauchoix he had found three more stars inside the trapezium. These stars have not been seen by John Herschel or Bond. The part of the nebula nearest to the almost unnebulous trapezium, and forming in the front part of the head the Regio Huygeniana, is spotty in its appearance, of a granular texture, and has been resolved into stars by the giant telescope of the Earl of Rosse, and by the great refractor of the Observatory of Cambridge, U.S. (⁴²⁵). Among our modern accurate observers, Lamont at Munich, Cooper in Ireland, and Lassell in England, have determined many positions of small stars. Lamont employed a magnifying power of 1200. Sir William Herschel thought that he had satisfactorily convinced himself, by the comparison of his own observations made with the same instruments from 1783 to 1811, that changes had taken place in the relative brightness and in the outlines of the great

nebula in Orion (⁴²⁶). Bouillaud and Le Gentil had asserted the same of the nebula in Andromeda. The continued investigations of the younger Herschel render these, as it was supposed well assured, cosmical alterations, at least exceedingly doubtful.

Great nebula round η Argûs.—This nebula is situated in that part of the Milky Way, so distinguished for its brightness, which extends from the feet of the Centaur through the Southern Cross to the middle portion of the constellation of the Ship. The lustre of this region of the heavens is so extraordinary that an accurate observer residing in India, Captain Jacob, remarks, in full accordance with my own experience during four years passed within the tropics, “that such is the general blaze from that part of the sky, that a person is immediately made aware of its having risen above the horizon, though he should not be at the time looking at the heavens, by the increase of general illumination of the atmosphere, resembling the effect of the young moon” (⁴²⁷). The nebula, in the middle of which the star η Argûs, which has become so celebrated on account of the changes of brightness which it has undergone (⁴²⁸), is situated, covers above $\frac{4}{7}$ ths of a square degree of celestial space. It consists of several amorphous masses of unequal intensity of light, and no where shows that mottled granular appearance which is considered to indicate resolvability. It encloses a singularly shaped vacuity covered with a very faint degree of light, and forming a lengthened lemmiscate-oval. A fine representation of the whole phenomenon, the fruit of two months measurements, is found in the Cape Observations of Sir John Herschel (⁴²⁹). This astronomer has determined in the nebula of η Argûs not less than 1216 positions of stars

mostly from the 14th to the 16th magnitude. The stars form a series which is continued far beyond the nebula into the Milky Way, where they are projected against, and detach themselves from, the blackest background of sky. They are, therefore, probably not connected with the nebula itself, and may be very distant from it. The whole of the adjacent portion of the Milky Way is, indeed, so rich in stars (not star-clusters), that between 9^h 50^m and 11^h 34^m R. A., there have been found by "star-gauging" 3138 stars on an average to each square degree. This number even rises to 5093 in the "sweeps" for 11^h 24^m R. A.; being more stars than are visible to the naked eye, (*i. e.* stars from the 1st to the 6th magnitude), for the horizon of Paris or that of Alexandria (430).

The nebula in Sagittarius.—This nebula is of considerable extent, and, as it were, composed of four distinct masses (R. A. 17^h 53^m N. P. D. 114° 21'), one of which is again subdivided into three. All are interrupted by places devoid of nebulous appearance, and the whole had been imperfectly seen by Messier (431).

The nebula in Cygnus.—Consists of several irregular masses, one of which forms a very narrow divided band passing through the double star η Cygni. The connection of these very dissimilar nebulous masses by a singular appearance of cellular texture was first perceived by Mason (432).

The nebula in Vulpes.—Was imperfectly seen by Messier, and is No. 27 of his list; it was discovered on the occasion of the observation of Bode's comet of 1779. The exact determination of the position (R. A. 19^h 52^m, N. P. D. 67° 43'), as well as the first drawing of this nebula, were given by Sir John Herschel. It received the name of

“Dumb-bell” from its apparent shape as seen with a reflector of eighteen inches aperture (Phil. Trans., 1833, No. 2060, fig. 26; Outlines, § 881). The resemblance to a Dumb-bell entirely disappeared when viewed with a 3-foot reflector of Lord Rosse (⁴³³), for whose recent and important representation of this nebula see Phil. Trans. 1850, Pl. xxxviii. fig. 17. It was resolved by the same telescope into numerous stars, interspersed amongst still subsisting nebulous appearance.

Spiral nebula in the northern Canis venaticus.—This nebula was first observed by Messier on the 13th of October, 1773 (on the occasion of the comet discovered by him): it is in the left ear of Asterion, very near the star η (Benetnasch) in the tail of the Great Bear, (No 51 Messier, and 1622 of the great Catalogue in the Phil. Trans. 1833, p. 496, fig. 25). It is one of the most remarkable phenomena in the firmament, as well on account of its wonderful configuration, as of the unexpected transforming effect exerted upon its appearance by Lord Rosse's 6-foot speculum. In the 18-inch reflector of Sir John Herschel this nebula appeared globular, and surrounded by a widely detached ring; thus affording as it were an image or counterpart of our sidereal stratum and Milky Way (⁴³⁴). In the spring of 1845, however, the great telescope of Lord Rosse transformed the entire object into a luminous spiral, in which the convolutions are not symmetrically disposed, but prolonged in one direction, and the two extremities, one near the centre and the other towards the exterior, terminate in dense, granular, rounded nuclei. Dr. Nichol has published a drawing of this object (the same which was presented by Lord Rosse to the meeting of the British Association at Cambridge in 1845) (⁴³⁵); but the most perfect representation is that by Mr. Johnstone Stoney in the Phil.

Trans. for 1850, Part 11, Pl. xxxv. fig. 1, Similar spiral forms are seen in No. 99 Messier with a single central nucleus, and in other northern nebulae.

We have next to speak in greater detail than could be done in the General View of Nature (⁴³⁶) of an object unparalleled in the entire firmament, and which greatly enhances the picturesque beauty, so to speak, of the southern celestial hemisphere. The two Magellanic clouds (which were probably first called by Portuguese and then by Dutch and Danish navigators, *Cape-Clouds*) (⁴³⁷), arrest the attention of the traveller, as I have myself experienced, in the most forcible manner, by their brightness, their remarkable isolated position, and their revolution at unequal distances round the southern pole. That the name which refers to Magellan's voyage of circumnavigation was not their earliest designation is proved by the express mention and description of these luminous clouds by the Florentine, Andrea Corsali, in his voyage to Cochin, and by Petrus Martyr de Anghiera, Secretary to Ferdinand of Arragon, in his work *de Rebus Oceanicis et Orbe Novo* (Dec. i. lib. ix. p. 96) (⁴³⁸). Both these notices belong to the year 1515, whereas Pigafetta, who accompanied Magellan, does not mention the "nebbiette" in the journal of the voyage previous to January 1521, when the ship *Victoria* made her way from the Patagonian Strait into the South Pacific Ocean. The older name of "Cape-Clouds" is certainly not to be attributed to the proximity of the still more southern constellation of the Table-Mountain, which was itself only introduced by Lacaille. The name may more probably refer to the real Table-Mountain, and to the phenomenon, long dreaded by seamen as portending tempest, of a small cloud

resting on its summit. We shall see presently that the nubeculæ of the southern heavens, after having long been noticed but without receiving any name, as navigation extended and commercial routes became more frequented, gradually obtained names derived from those routes.

The frequent navigation of the Indian sea adjacent to the shores of Eastern Africa, especially from the time of the Ptolemies and in the voyages in which advantage was taken of the Monsoons, first made navigators acquainted with the constellations near the southern pole. As has been already remarked, it is among the Arabians that we find as early as the middle of the tenth century, a name for the larger of the Magellanic clouds which Ideler has identified with the (white) Ox, *el-bakar*, of the celebrated astronomer Dervish Abdurrahman Sufi of Rai, a town in the Persian Irak. In the "Introduction to the Knowledge of the Starry Heavens," written at the Court of the Sultans of the Dynasty of the Buyides, he says:—"Below the feet of Suhel" (it is expressly the Suhel of Ptolemy, Canopus, which is here meant, although the Arabian astronomers also gave the name of 'Suhel,' to several other large stars in the constellation of "el Sefina" or the Ship), "there is a white patch, which is not seen either in Irak," (in the region of Bagdad), "nor in Nedschd," (Nedjed, the northern and more mountainous part of Arabia), "but is seen in southern Tehama, between Mecca and the point of Yemen, along the shore of the Red Sea" (439). The position of the "White Ox" relatively to Canopus is here assigned with sufficient accuracy for the unassisted eye; for the Right Ascension of Canopus is $6^{\text{h}} 20^{\text{m}}$, and the eastern margin of the larger Magellanic cloud is in $6^{\text{h}} 0^{\text{m}}$ Right Ascension. The visibility of

the nubecula major in northern latitudes cannot have been materially altered since the tenth century by the precession of the equinoxes, for in the course of the next ten centuries it reached its maximum distance from the north. Taking the most recent determination of the place of the larger cloud by Sir John Herschel, we find that in the time of Abdurrahman Sufi it was perfectly visible as far north as 17° N. Lat.; at present it is so nearly to 18° . The nubeculæ might therefore have been seen throughout the whole of the south-west of Arabia, the incense-producing country of Hadhramaut, as well as in Yemen, the ancient seat of civilization of Saba and of the early immigration of the Joctanides. The extreme southern point of Arabia, at Aden on the Straits of Bab-el-Mandeb, is in $12^{\circ} 45'$, and Loheia is only in $15^{\circ} 44'$ North Lat. The rise of many Arab settlements on the inter-tropical east coast of Africa, both north and south of the equator, also naturally led to a more complete and detailed acquaintance with the southern constellations.

Of civilised navigators, the first who visited the West Coast of Africa beyond the Line were Europeans, and first, and more especially, Catalonians and Portuguese. Undoubted documents, *i. e.* the Map of the World of Marino Sanuto Torsello, of the year 1306; the Genoese "Portulano Mediceo" of 1351; the "Planisferio de la Palatina," 1417; and the "Mappamondo" of Fra. Mauro Camaldolese, between 1457 and 1459, shew that 178 years before the reputed first discovery of the Cabo Tormentoso (the Cape of Good Hope) by Bartholomew Dias, in the month of May 1487, the triangular configuration of the southern extremity of the African continent was already known (⁴⁴⁰). After Gama's expedition, the rapidly increasing importance of the commercial route

round the Cape, forming the general object of all voyages along the western coast of Africa, led to the two clouds or nubeculæ being called by navigators the "Cape Clouds," as being remarkable celestial phenomena seen in Cape voyages.

On the east coast of America, the continued attempts to advance southward beyond the equator, and even to the southern extremity of the continent, from the expedition of Alonso de Hojeda, which Amerigo Vespucci accompanied in 1499, to the expedition of Magellan with Sebastian del Cano in 1521, and that of Garcia de Loyasa (⁴⁴¹) with Francisco de Hoces in 1525, had the effect of continually directing the attention of navigators to the southern constellations. According to the journals which we possess, and to the historical testimonies of Anghiera, this was especially the case in the voyage of Amerigo Vespucci and Vicente Yañez Pinzon, in which Cape St. Augustin, in $8^{\circ} 20' S.$ Lat. was discovered. Vespucci boasts of having seen three Canopuses (one dark, "Canopo fosco," and two "Canopi risplendenti"). According to the attempt made by Ideler, the ingenious author of works on Sidereal Nomenclature and on Chronology, to elucidate Vespucci's very confused description of the southern heavens in his letter to Lorenzo Pierfrancesco de Medici, Amerigo must have used the word "Canopus" in a manner as vague as did Arabian astronomers the word "Suhel." Ideler shows that the "Canopo fosco nella via latteæ," was no other than the black spot, or large "coal-bag," in the southern cross; and that the position of three stars supposed to be identified with α , β , and γ of the constellation of Hydrus, renders it highly probable that the "Canopo risplendente di notabile grandezza," was the

nubecula major, and the second "Canopo risplendente," the nubecula minor (⁴⁴²). It seems surprising that on becoming acquainted with these new celestial objects Vespucci should not have compared them, as at first sight all other observers have done, to "clouds": such a comparison appears to present itself almost irresistibly. Petrus Martyr de Anghiera, who was personally acquainted with all the discoverers of that remarkable epoch, and whose letters are written under the vivid impression received by him from their narrations, depicts in an unmistakeable manner the mild but unequal light of the nubeculæ: he says, "Assecuti sunt Portugallenses alterius poli gradum quinquagesimum amplius, ubi punctum (polum?) circumeuntes *quasdam nubeculas* licet intueri, veluti in lactea via sparsos fulgores per universi coeli globum intra ejus spatii latitudinem" (⁴⁴³). The great celebrity and long duration of Magellan's voyage of circumnavigation (from August 1519 to September 1522), and the length of time during which the numerous party belonging to it remained under the southern heavens, obscured the remembrance of earlier observation, and the name of "Magellanic clouds" extended itself among the maritime nations bordering on the Mediterranean.

We have taken a single example of the manner in which the extension of the geographical horizon towards the South opened a new field to contemplative astronomy. Navigators advancing under these new heavens felt peculiar interest and curiosity in four objects:—the search after a southern pole-star; the form of the Southern Cross, with its upright position when passing the meridian of the place of observation; the Coal-bags; and the revolving luminous clouds. From Pedro de Medina's "Arte de Navegar" (lib. v.

cap. 11), which appeared first in 1545, and was translated into many languages, we learn that as early as the first half of the sixteenth century meridian altitudes of the "Cruzero" were employed in determinations of latitude: measurement, therefore, soon followed simple contemplation. The first examination into the position of stars near the Antarctic pole was made by means of distances from known stars whose places had been determined by Tycho Brahe in the Rudolphine Tables: the credit of it belongs, as has been already remarked (⁴⁴⁴), to Petrus Theodori of Emden, and Friedrich Houtman of Holland, who sailed over the Indian seas in 1594. The results of their measurements were soon adopted in the star-catalogues and celestial globes of Blaeuw in 1601, Bayer in 1603, and Paul Merula in 1605. These were the feeble commencements of investigations into the topography of the southern heavens previous to Halley (1677), and previous to the meritorious astronomical endeavours of the Jesuit Jean de Fontaney, of Richaud, and of Noël. The histories of astronomy and of geography, in intimate connection with each other, bring before us the same memorable epochs as conducive alike to the completion of the general cosmical picture of the firmament, and of the outlines of the terrestrial continents.

The two Magellanic clouds, of which the larger covers forty-two and the smaller ten square degrees of the celestial vault, produce at first sight, as seen by the naked eye, the same impression as would be made by two detached bright portions of the Milky Way of corresponding dimensions. In strong moonlight the smaller cloud disappears entirely, while the larger one only loses a considerable portion of its light. The drawing given of them by Sir John Herschel

is excellent, and accords perfectly with my most vivid Peruvian recollections. It is to the arduous exertions of the same astronomer at the Cape of Good Hope in 1837, that we owe the first accurate analysis of these wonderful aggregations of the most various elements (⁴⁴⁵). He found therein single scattered stars in great number; groups of stars and globular star-clusters; and both regular oval, and irregular amorphous nebulae, more closely crowded than in the nebular zone of Virgo and Coma Berenicis. From the complex character of the nubeculae, therefore, they ought not to be regarded either (as is too often done) as extraordinarily large nebulae, or as detached portions of the Milky Way. In the Milky Way, round star-clusters, and more especially oval nebulae, are extremely rare phenomena (⁴⁴⁶), excepting in a small zone situated between the constellation of Ara and the tail of Scorpio.

The Magellanic clouds are neither connected with each other nor with the Milky Way by any perceptible nebulous appearance. The smaller nubecula is situated in what, excepting the vicinity of the star-cluster in Toucani (⁴⁴⁷), is a kind of starless desert; the larger Magellanic cloud is in a less scantily furnished part of the celestial vault. The structure and internal arrangement of the larger nubecula are so complicated, that masses are found in it (like No. 2878 of Herschel's Catalogue), in which the general form and character of the entire cloud are exactly repeated. The conjecture of the meritorious Horner, of the nubeculae having once been parts of the Milky Way, in which their former places can still be recognised, is nothing more than a myth; nor is the assertion of a progressive motion or change of position being perceptible in them from the time of Lacaille,

better founded. The indefiniteness of their edges as seen in telescopes of small aperture had caused the positions formerly assigned to them to be inexact, and it has even been remarked by Sir John Herschel that nubecula minor is entered almost one hour in Right Ascension out of its true place in celestial globes and star maps generally. According to the same authority, nubecula minor is situated between the meridians of $0^{\text{h}} 28^{\text{m}}$ and $1^{\text{h}} 15^{\text{m}}$, and between 162° and 165° north polar distance; and nubecula major in $4^{\text{h}} 40^{\text{m}}$ — $6^{\text{h}} 0^{\text{m}}$ R. A., and 156° — 162° N. P. D. Of stars, nebulæ, and clusters, he has given in Right Ascension and Declination no fewer than 919 in the larger, and 244 in the smaller nubecula. In order to distinguish the three classes of objects from each other I have counted up in the list:—

In nubecula major, 582 stars, 291 nebulæ, 46 star-clusters:

In nubecula minor, 200 stars, 37 nebulæ, 7 star-clusters.

The smaller number of nebulæ in the nubecula minor is striking; their proportion to the nebulæ in nubecula major being as 1 : 8, while the corresponding ratio of single stars in the two nubeculæ is about as 1 : 3. These tabulated stars, almost eight hundred in number, are mostly of the 7th and 8th magnitudes,—some being between the 9th and 10th. In the midst of the nubecula major there is a nebula noticed as early as by Lacaille, (30 Doradûs, Bode, No. 2941 of Sir John Herschel,) which is without a parallel in any part of the heavens. It hardly occupies $\frac{1}{500}$ th of the area of the entire nubecula, and yet within this space

Sir John Herschel has determined the positions of 105 stars from the 14th to the 16th magnitude, which are projected against or detach themselves from the altogether unresolved, uniformly shining, and unchequered nebulous ground (448).

Opposite to the Magellanic luminous clouds, and at a greater distance from the Southern Celestial Pole, there revolve around it the black spots or patches which at an early period, at the end of the fifteenth and beginning of the sixteenth centuries, attracted the attention of Portuguese and Spanish Navigators. They probably constitute, as already noticed, the "Canopo fosco" spoken of by Amerigo Vespucci, in his third voyage, among the "three Canopuses" of which he makes mention. I find the first certain indication of these spots in the first Decade of Anghiera's work, "De rebus Oceanicis." (Dec. 1, lib. ix., ed. 1533, p. 20, b.) "Interrogati a me nautæ qui Vicentium Agnem Pinzonum fuerant comitati (1499), an antarcticum viderint polum: stellam se nullam huic arcticæ similem, quæ discerni circa punctum (polum?) possit cognovisse inquirunt. Stellarum tamen aliam, ajunt, se prospexisse faciem densamque quandam ab horizonte vaporosam caliginem, quæ oculos fere obtenebraret." The word "stella" is here taken to mean generally a celestial form or object, and the narrators may have expressed themselves rather indistinctly respecting a "caligo" which "darkens the eyes." Pater Joseph Acosta of Medina del Campo speaks in a more satisfactory manner respecting the black patches and the cause of their appearance. In his *Historia Natural de las Indias* (lib. i. cap. 2,) he compares them, in respect to colour and form, to the dark part of the moon's disk. "As," said he,

“the Milky Way appears bright because it consists of denser celestial matter, and therefore radiates more light, so the *dark patches which are not seen in Europe* are entirely without light, because they form a region of the heavens which is void, *i. e.*, composed of very rare and highly transparent matter.” That a celebrated astronomer should have identified this description with the solar spots (449) is no less strange than that the missionary Richaud (1689) should have taken Acosta’s “*Manchas negras*” for the luminous Magellanic Clouds (450).

Richaud, like the oldest navigators, speaks of the “coal-sacks” in the plural; he names two, one in the Cross, and another in Robur Caroli: in other descriptions this last is even divided into two separate spots or patches. These are described by Feuillée in the first years of the 18th century, and by Horner in a letter written to Olbers from Brazil in 1804, as imperfectly defined and with confused edges (451). During my stay in Peru I never could make out in a manner satisfactory to myself the Coal-sacks in Robur Caroli, and being disposed to attribute my want of success to the low altitude of the constellation, I turned for information and instruction on the subject to Sir John Herschel, and to the Director of the Hamburgh Observatory, Hr. Rumker, both of whom had been in much higher southern latitudes. I found that notwithstanding all their endeavours neither of these gentlemen had ever succeeded any more than myself in finding anything which for definiteness of outline or intensity of blackness could be compared to the “Coal-sack” in the Cross. Sir John Herschel thinks that we ought not to speak of a plurality of coal-sacks unless we intend to regard

as such every darker portion of the heavens, even though it may present no definite boundary; (as between α Centauri and β and γ Trianguli (⁴⁵²), between η and θ Argûs; and especially, in the northern celestial hemisphere, the vacant space in the Milky Way between ϵ , α , and γ Cygni) (⁴⁵³).

The phenomenon of this class which has been longest known, and which is most striking to the unassisted eye,—viz. the dark patch in the Southern Cross, is situated on the eastern side of that constellation, and is pear-shaped, with a length of 8 and a breadth of 5 degrees. There is in this large space one star visible to the naked eye, (between the 6th and the 7th magnitude), and a large number of telescopic stars from the 11th to the 13th magnitudes. A small group of 40 stars occupies nearly the centre of the space (⁴⁵⁴). Paucity of stars and contrast with the surrounding brightness have been assigned as the causes of the sensible blackness of the space in question; and since the time of Lacaille (⁴⁵⁵) this explanation has been generally received. It has been more particularly supported by the results of “star-gauges and sweeps” taken around the space where the Milky Way appears as if covered by a black cloud. With equal fields of view the sweeps gave within the coal-sack from 7 to 9 telescopic stars, (never perfect vacuity or blank fields), while around and beyond the borders from 120 to 200 stars were counted. Whilst I remained under the southern tropic, and under the influence of the powerful impression made upon me by the aspect of the celestial canopy towards which my attention was continually drawn, the above explanation, from the effect of contrast, appeared to me, probably erroneously, to be an

unsatisfactory one. Sir William Herschel's considerations on the quite starless spaces in Scorpio and Ophiucus, which he terms "openings in the heavens," led me to the idea that perhaps in such regions the sidereal strata may be thinner or may even be entirely interrupted; that our optical instruments fail to reach the last strata, and that "we look as through tubes into the remotest regions of space." I have already alluded elsewhere to these "openings" (⁴⁵⁶); and the effects of perspective on such interruptions in the sidereal strata have very recently formed the subject of grave discussion. (⁴⁵⁷)

The consideration of the outermost and remotest strata of self-luminous worlds, the distances of nebulae, and all the subjects which have been crowded into the last of the seven sidereal or astrognostic sections of this work, fill our imagination with images of time and space surpassing our powers of conception. Great and admirable as have been the advances made in the improvement of optical instruments within the last sixty years, we have at the same time become sufficiently familiar with the difficulties of their construction not to give ourselves up to such daring, and, indeed, extravagant hopes, as those with which the ingenious Hooke was seriously occupied between 1663 and 1665 (⁴⁵⁸). Here, also, we advance further and more securely towards the goal by moderation in our anticipations. Each of the successive generations of mankind is in its turn enabled to rejoice in the greatest and highest results attainable by man's intellect freely exerted from the standing place to which art may then have risen. Without enunciating in determinate numbers the extent of space-pene-

trating power already achieved in telescopic vision, and without laying much stress upon such numbers, still our knowledge of the velocity of light teaches us, that in the faint glimmer proceeding from the self-luminous surface of the remotest heavenly body we have "the most ancient sensuous evidence of the existence of matter (⁴⁵⁹)."

β. The Solar Domain.

Planets and their satellites, comets, ring of zodiacal light, and meteoric asteroids.

When in the Uranological portion of the physical description of the Universe we descend from the heaven of the fixed stars to our solar and planetary system, we pass from the great and universal to the relatively small and special. The domain of the Sun is the domain of a single fixed star among the myriads which the telescope discloses to our view ; it is the limited space within which cosmical bodies of very different kinds, obeying the immediate attraction of one central body, revolve around the same in wider or narrower orbits, either alone or accompanied by other bodies similar to themselves and revolving round them. In the sidereal portion of Uranology which I have attempted to treat in the earlier part of the present volume, I have indeed described among the millions of telescopic fixed stars, one class, that of double stars, which also presents particular systems, either binary or consisting of more than two members ; but these, notwithstanding the analogy of their impelling forces, are yet in their nature different from our solar system. In them, self-luminous fixed stars move around a common centre of gravity which is not occupied by visible matter ; in the solar system, dark cos-

mical bodies revolve round one which is self-luminous ; or, to speak more precisely, round a common centre of gravity, which is sometimes included within, and sometimes falls without, the central body. "The great ellipse which the Earth describes round the Sun is reflected in a small but otherwise entirely similar ellipse, in which the centre of the Sun moves round the common centre of gravity of the Earth and Sun." Whether the planetary bodies, among which the interior and exterior comets must also be included, are not also partially capable of originating light of their own, besides that which they receive from the central body, is a question which in these general indications needs not to be further touched upon.

We have hitherto no direct evidence of the existence of dark planetary bodies revolving round other fixed stars. Should such exist, as was surmised long before Lambert by Kepler, the faintness of reflected light must probably for ever forbid their being seen by the inhabitants of the Earth. If the nearest fixed star, α Centauri, is distant from the Sun, 226,000 semi-diameters of the Earth's orbit, or 7523 semi-diameters of Neptune's orbit,—and if the solar distance of the aphelion of a comet of very wide elongation, that of 1680 (to which, although on very insecure grounds, a period of 8800 years has been attributed), is equal to 28 distances of Neptune,—the distance of α Centauri will still be 270 times more than the extent of our solar domain taken to the aphelion of that most distant comet. We see the reflected light of Neptune at 30 times the distance of the Earth from the Sun : if in more powerful telescopes to be hereafter constructed there should be discovered three more planets at distances successively increasing, so that the

outer one should be a hundred times the Earth's distance from the Sun, this would still not be an eighth part of the distance of the aphelion of the above mentioned comet, or the 2200th part (⁴⁶⁰) of that from which we should have to view the reflected light of a planet or satellite revolving round α Centauri. But it may be asked, is the assumption of the existence of planets or satellites revolving round the fixed stars unconditionally necessary. If we glance at the subordinate particular systems within our general planetary system, we find, notwithstanding the analogies which may be presented by those planets round which many satellites revolve, that there are also other planets, Mercury, Venus, and Mars, which have not even a single satellite. If we pass from what is simply possible and confine ourselves to what has been actually investigated, we shall be vividly impressed by the idea that the solar system, especially as the last ten years have disclosed it to us, affords the fullest picture of easily recognised direct relations of many cosmical bodies to one central one.

In the astronomy of measurement and calculation, the more limited space of the planetary system, by reason of this very limitation, offers, as compared with the consideration of the heaven of the fixed stars, incontestable advantages in respect to the evidence and certainty of the results obtained. Much of sidereal astronomy is simply contemplative; it is so in regard to star-clusters and nebulæ, and also the very insecurely grounded photometric classification of the fixed stars. The best assured and most brilliant department in astrognoſy, and which in our own time has received such exceeding improvement and enlargement, is

that of the determination of positions in Right Ascension and Declination, whether of single fixed stars, or of double stars, star-clusters, and nebulae. Measurable relations of a more difficult class, but yet susceptible of a greater or less degree of accuracy, are presented by the proper motion of stars;—the elements by means of which their parallax may be sought;—telescopic star-gaugings, throwing light on their distribution in space;—and the periods of variable stars and slow revolutions of double-stars. Subjects which by their nature escape from the domain of measurement, properly so called, such as the relative position and the forms of sidereal strata or annuli; the arrangement of the structure of the universe; the effects of rapidly transforming natural agencies (⁴⁶¹) in the blazing forth and speedily succeeding extinction of what have been called new stars, all affect the mind the more vividly and profoundly from the wide scope which they furnish to the fascinating exercise of the imaginative faculties.

We purposely abstain in the following pages from all considerations respecting the connection of our solar system with the systems of the other fixed stars; we do not propose to return to questions respecting the subordination and mutual dependence of different systems,—questions which appear to grow out of what are felt to be intellectual wants; as for example, whether our sun be not itself in a state of planetary dependence on a higher system, perhaps not even as a primary planet, but only as the satellite of a planet, like the moons of Jupiter in our own system. We limit ourselves to the home circle of the solar domain itself; and in doing so we enjoy the advantage that, with the exception of what relates

to the interpretation of the appearance of the surfaces, and to the gaseous envelopes of the different orbs, to the simple or divided tails of comets, the ring of zodiacal light, and the enigma of the phenomenon of meteoric asteroids,—almost all the results of observation are susceptible of reduction to numerical relations, and all present themselves as consequences of assumptions admitting of being brought to the test of strict demonstration.

Such demonstration does not fall within the scope of this “Sketch of a Physical Description of the Universe,” but the methodical presentation of the numerical results in a brief and collected form does belong to the plan of such a sketch. These results constitute the rich inheritance which, evermore growing by continual accession, is handed down from one century to another. A table containing the numerical elements of the planets (showing in the case of each planet its mean distance from the sun, its period of revolution, eccentricity of orbit, inclination to the ecliptic, diameter, mass, and density), gives in an exceedingly small space the standard of knowledge, or the intellectual height in this respect, to which the age has attained. If we throw ourselves back in imagination for a moment into the times of classical antiquity, and figure to ourselves Philolaus the Pythagorean (the instructor of Plato), Aristarchus of Samos, or Hipparchus, in possession either of a sheet with such a table of numbers, or of a graphical representation of the planetary orbits such as is given in our briefest elementary works, we could only compare the astonishment of these men, the heroes of the earlier more limited knowledge, to that of Eratosthenes, Strabo, or Ptolemy, if one of our maps of the

world, on Mercator's projection, of a few inches in size, could have been placed before them.

The return of comets in closed elliptic orbits, inasmuch as it is the result of the attracting force of the central body, must be held to indicate their comprehension within the boundary of the solar dominion. But since we are uncertain whether comets may not hereafter appear, the major axes of whose ellipses shall be found to exceed in length any of those which have yet been calculated, we can only say that the remotest cometary aphelion with which we are acquainted marks the smallest or least distant limit which can be assigned to the solar system, *i.e.* its minimum extension. We regard the solar system, therefore, as being characterised by the visible and measurable results of central forces acting within the system, and by cosmical bodies (planets and comets) which revolve in closed paths around the sun, and remain attached to it by a direct and positive connection. The attraction exerted by the sun in wider spaces beyond those returning and revolving bodies on other suns or fixed stars, does not belong to the considerations with which we are here engaged.

The solar domain comprehends, according to the state of our knowledge at the close of the first half of the nineteenth century, and arranging the planets in the order of their distances from the central body—

TWENTY-TWO PLANETS. (MERCURY, VENUS, EARTH, MARS; *Flora, Victoria, Vesta, Iris, Metis, Hebe, Parthenope, Irene, Astræa, Egeria, Juno, Ceres, Pallas, Hygiea*; JUPITER, SATURN, URANUS, NEPTUNE.)

TWENTY-ONE SATELLITES. (1 belonging to the

Earth, 4 to Jupiter, 8 to Saturn, 6 to Uranus, 2 to Neptune).

One hundred and ninety-seven *Comets*, whose paths have been calculated: amongst them are 6 interior, *i. e.* whose aphelia are included within the outermost planetary orbit, viz. that of Neptune.

The solar system comprises, besides the above-mentioned bodies, with great probability, the *ring of the Zodiacal Light*, situated perhaps between the orbits of Venus and Mars.

And, according to the opinion of many observers, the *host of meteoric asteroids* which intersect the Earth's path, more especially at particular points.

In the above enumeration of the 22 planets, of which 6 were known previous to the 13th of March 1781, the 8 greater planets are distinguished by larger type from the 14 smaller planets, sometimes called "co-planets," or "asteroids," whose intersecting orbits are situated between Mars and Jupiter.

In the modern history of planetary discoveries, the leading epochs have been the discovery by William Herschel at Bath on the 13th of March, 1781, of Uranus, being the first planet discovered beyond the orbit of Saturn, and recognised as a planet by its disk and by its motion;—the discovery by Piazzi, at Palermo, on the 1st of January, 1801, of Ceres, the first of the smaller planets;—the recognition by Encke, at Gotha, in August 1819, of the first "interior" comet;—and the announcement from calculations of planetary disturbances of the existence of Neptune by Le Verrier, at Paris, in August 1846, as well as its actual discovery by Galle, at Berlin, on the 23d of September of the same year.

Each of these important discoveries has not only had for its direct result the immediate enlargement and enrichment of the solar system as known to mankind, but it has also given occasion to numerous similar discoveries: to the recognition of 5 other interior comets (by Biela, Faye, de Vico, Brorsen, and D'Arrest, between 1826 and 1851; and of 13 small planets, three of which (Pallas, Juno, and Vesta), were discovered between 1801 and 1807, and after an interval of fully thirty-eight years, in rapid succession, following the happy and well-planned discovery of Astræa by Hencke, December 8, 1845, of nine others by Hencke, Hind, Graham, and de Gasparis, from 1845 to the middle of 1851. Attention to comets has so much increased, that in the last eleven years the paths of 33 newly discovered comets have been calculated, being nearly as many as were computed in the course of the forty preceding years of the present century.

I.

THE SUN AS A CENTRAL BODY

“THE luminary of the World (*lucerna Mundi*), enthroned in the midst,” as Copernicus (⁴⁶²) terms the solar orb,—according to Theon of Smyrna (⁴⁶³) the “all animating, pulsating heart of the Universe,”—is to our planet the great source of light and radiant heat, and the exciter not only of many terrestrial electro-magnetic processes, but also of the greater part of the processes of organic vital activity, and more especially of those of vegetable life. The Sun, if we desire to indicate its influences and effects with the greatest generality, may be said to produce changes on the surface of the Earth partly by attraction of mass, as in the ebb and flow of the ocean (if we abstract from the whole effect the portion due to lunar attraction); partly by light- and heat-exciting undulations, (transverse vibrations of the ether), operating both directly, and also by the fertilising intermixture of the aërial and aqueous envelopes of the planet, effected through the medium of the evaporation of the liquid element from seas, lakes, and rivers. To the solar agency are also due those atmospheric and oceanic currents occasioned by dif-

ferences of temperature, of which the latter have acted for thousands of years, and still continue to act though with less energy, in modifying the form and character of the terrestrial surface,—in some places by abrasion and denudation, in others by the accumulation of transported detritus. The sun's influence operates, moreover, in producing and maintaining the electro-magnetic activity of the crust of the Earth, and of the oxygen contained in the atmosphere; it acts sometimes silently and tranquilly in forces of chemical attraction, and in determining the varied processes of organic life in the endosmose of vegetable cells, and in the texture of muscular and nervous fibres;—and sometimes with more obvious and tumultuous energy, by calling forth in the atmosphere luminous processes, coloured flashing polar light, lightning, hurricanes, and water-spouts.

I have attempted the enumeration in a single brief sketch of the various solar influences, so far as they do not relate to the position of the axis and to the path of our globe, for the sake of bringing vividly into view, by means of the presentation of grand and varied phenomena which at first sight appear so heterogeneous, that character of my work which tends to depict physical nature in this “book of the Cosmos” as a WHOLE, moved, and as it were animated, by internal, often mutually compensating and counterbalancing, forces or powers. But the luminous undulations act not alone on the material world, decomposing and reuniting its substances in fresh combinations,—they do not merely call forth from the bosom of the earth the tender germs of plants,—elaborate in leaves the substance (chlorophyll) to which they owe their verdure, and in flowers their tints and fragrance,—and repeat a thousand, and again a thousand

times, the Sun's bright image in the sparkling play of the waves of the sea, and in the dew-drops on the blades of grass as the breeze sweeps over the meadow ;—the light of heaven, in the various degrees of its intensity and duration, also connects itself by mysterious links with man's inner being,—with his intellectual susceptibilities, and with the cheerful and serene, or the melancholy tone of his disposition :—“ *Cœli tristitiam discutit Sol et humani nubila animi serenat.*” (Plin. Hist. Nat. ii. 6).

In describing the several cosmical bodies, I commence in each case with the numerical data belonging to them, and place next whatever inferences the present state of our knowledge may enable us to draw respecting their physical constitution. The arrangement of the numerical results is nearly the same as in Hansen's excellent “*Uebersicht des Sonnensystems*” (⁴⁶⁴), but with additions and modifications, —inasmuch as, since the year 1837, when Hansen wrote, eleven planets and three satellites have been discovered.

The mean distance of the centre of the Sun from the Earth is, according to Encke's valuable correction of the Sun's parallax (Abhandl. der Berl. Akad. 1835, S. 309), 20682000 (German) geographical miles of 15 to a degree of the terrestrial equator (equal to 82728000 English geographical miles), each German mile containing according to Bessel's examination of ten measured (Kosmos, Bd. i. S. 421, Eng. Ed. p. xlii., Note 130), precisely 3807.23 toises, or 22843.33 Paris feet ; (in English measure 6086.76 British feet to a British geographical mile 60 to a degree.)

According to Struve's observations of aberration, light takes to reach the Earth from the Sun, or, in other words, to traverse the semi-diameter of the Earth's orbit, 8' 17".78

(Kosmos, Bd. iii. s. 91, and 127 Anm. 52, Eng. ed. p. 73, and Note 140), whence the true place of the Sun is $20''.445$ in advance of the apparent place.

The apparent diameter of the Sun at its mean distance from the Earth is $32' 1''.8$: only $54''.8$ more than the apparent diameter of the disk of the Moon at her mean distance from the Earth. At our perihelion, in the winter when we are nearest to the Sun, its apparent diameter is increased to $32'' 34''.6$; at the aphelion in the opposite part of the year, when we are farthest from the Sun, its apparent diameter is diminished to $31' 30''.1$.

The true diameter of the Sun is 192700 German, or 770800 English geographical miles ; or, more than 112 times greater than the diameter of the Earth.

The mass of the Sun is, according to Encke's calculation of Sabine's pendulum formula, 359551 times that of the Earth, or 355499 times the mass of the Earth and Moon taken together (Vierte Abh. über den Cometen von Pons in den Schr. der Berl. Akad. 1842, S. 5) ; this would make the density of the Sun only about one quarter (more exactly 0.252), of that of the Earth.

The Sun has 600 times more volume, and according to Galle, 738 times more mass, than all the planets together. In order to convey in some degree a sensible image of the magnitude of the body of the Sun, it has been remarked that if we were to imagine the globe of the Sun entirely hollowed out, and the Earth placed in its centre, there would still be room for the Moon's orbit, even though the semi-diameter of the said orbit were to be increased by upwards of 40000 (160000 English) geographical miles.

The Sun rotates round its axis in $25\frac{1}{2}$ days ; its equator

is inclined $7\frac{1}{2}^{\circ}$ to the Ecliptic. According to Laugier's very careful observations (Comptes rendus de l'Acad. des Sciences, T. xv. 1842, p. 941), the time of rotation is 25.34 days (or 25 days, 8 hours, 9 minutes), and the inclination of the Equator is $7^{\circ} 9'$

The conjectures respecting the physical character of the Sun, at which modern astronomy has gradually arrived, are founded on long and careful observation of changes seen to take place in the luminous disk. The order of succession and the connection of these changes (*i. e.* the apparent formation of the solar spots and the relation of their centres or nuclei of deep black to surrounding ashy grey penumbras), have led to the supposition that the actual body of the solar orb is itself almost entirely dark, but encompassed at a considerable distance by a luminous envelope, in which funnel-shaped openings are produced by the action of currents from below upwards, and that the black nuclei of the spots are portions of the dark body of the Sun seen through these openings. In order to make this explanation (which is here noticed in a cursory manner and only with the greatest generality), account more satisfactorily for the various particulars of the observed phenomena, there are assumed, in the present state of our knowledge, three solar envelopes: first, an inner cloud-like vaporous envelope; over this the luminous envelope (photosphere); and above this again (and as apparently indicated more particularly in the phenomena of the total solar eclipse of the 8th of July, 1842), an external vaporous envelope, either dark or only very faintly illuminated (⁴⁶⁵).

As happy anticipations and imaginations, long antecedent to all actual observation, sometimes contain the germ of true views, (Grecian antiquity is full of instances of such

speculations which after ages have realised), so we find as early as the middle of the fifteenth century, in the writings of Cardinal Nicolaus, of Cusa, in the second book of the treatise "De docta ignorantia," the opinion clearly expressed, that the body of the Sun is only an earthy kernel surrounded by a luminous shell as by a fine veil, and having in the middle (between the dark kernel and luminous shell?) a mixture of water-bearing clouds and clear air similar to our atmosphere; and that the power of radiating forth the light which animates vegetation on the surface of the Earth belongs not to the earthy kernel or nucleus of the Sun, but to its bright surrounding covering. This view of the physical constitution of the Sun, which has hitherto attracted so little notice in the history of astronomy (⁴⁶⁶), has a great resemblance to the views which prevail at the present time.

I have shown in an earlier volume, in the notice of "historical epochs in the physical contemplation of the Universe" (⁴⁶⁷), that the spots on the Sun were first seen and described in print, not by Galileo, Scheiner, or Harriott, but by Johann Fabricius of East Friesland. Both the discoverer, and also Galileo, as is shown by his letter to the Principe Cesi, written on the 25th of May, 1612, knew that the solar spots belonged to the Sun itself; nevertheless, ten and twenty years later, a Canon of Sarlat, Jean Tarde, and a Belgian Jesuit, maintained that the spots were transits of small planets: by the one called *Sidera Borbonia*, and by the other *Sidera Austriaca* (⁴⁶⁸). Scheiner was the first to adopt the use in observations of the Sun of the blue and green shade-glasses (⁴⁶⁹) which had been suggested 70 years before by Apian (Bienewitz), in the "*Astronomicum Cæsareum*," and had long been made use of by the Belgian navigators; the

non-employment of which had greatly contributed to occasion Galileo's loss of sight.

As elicited by actual observation after the discovery of the solar spots, I find the earliest and most definite expressions as to the necessity of assuming the Sun to be a dark globe surrounded by a luminous envelope (photosphere), from the pen of Dominique Cassini in 1671⁽⁴⁷⁰⁾ According to him the solar disk which we see is "a luminous ocean surrounding the solid and dark nucleus of the Sun; tumultuous movements taking place in the luminous envelope allow us from time to time to see the mountain summits of the non-luminous body of the Sun itself. They are the black nuclei in the centre of the solar spots." The ash-coloured penumbras surrounding the nuclei still remained without any attempt at explanation.

An ingenious, and since often confirmed observation, made by Alexander Wilson, the Astronomer of Glasgow, on a large solar spot on the 22d of November, 1769, led him to an explanation of the penumbras. Wilson discovered that as a spot moves towards the Sun's limb, the penumbra on the side towards the centre of the Sun becomes gradually narrower and narrower as compared with that on the opposite side. He inferred, very justly, from the ratios of these dimensions, that the nucleus of the spot (the part of the dark body of the Sun becoming visible through the funnel-shaped excavation of the luminous envelope), is situated deeper than the penumbra, and that the penumbra is formed by the steep declivities or side walls of the funnel⁽⁴⁷¹⁾. This mode of explanation, however, offered no reply to the question why the penumbra should be lightest near the dark nucleus?

Our Berlin Astronomer, Bode, without being acquainted with the earlier memoir of Wilson, developed, in his peculiarly lucid and popular manner, perfectly similar views, in his "Thoughts on the Nature of the Sun and the origin of its spots" ("Gedanken über die Natur der Sonne und die Entstehung ihrer Flecken"). Bode had also the further merit of having facilitated the explanation of the penumbra by assuming, almost as in the anticipatory conjectures of Cardinal Nicolaus of Cusa, an additional stratum of cloudy vapour between the photosphere and the dark body of the Sun. This hypothesis of two distinct envelopes leads to the following inferences: if, in the smaller number of cases, an opening is formed in the photosphere only, and not at the same time in the inner vaporous stratum which is supposed to be only imperfectly illuminated by the brighter outer one, then this inner envelope will reflect towards the earth only a very mitigated light, and thus there is produced a grey penumbra without any black nucleus. But if in the tempestuous meteorological processes taking place on the surface of the Sun the opening penetrates both envelopes (*i. e.* both the luminous and the cloudy one), then there appears in the ash-coloured penumbra, a nucleus "shewing a more or less intense blackness according to the character of the surface of the body of the Sun at the part exposed by the opening" (472). The shade round the nucleus is a part of the external surface of the inner vaporous stratum, and as the latter, by reason of the funnel shape of the whole excavation, has a smaller opening than the photosphere, so the path of the rays which on both sides pass along the edges of the interrupted strata, and arrive at the eye of the observer, explains the difference first perceived by Wilson to take place gradually in the relative

breadths of the opposite sides of the penumbra, as the distance of the nucleus from the centre of the Sun's disk increases. When, as Laugier has more than once remarked, the penumbra spreads over the black nucleus itself, so that the latter disappears altogether, the cause is that the opening of the inner cloudy envelope is closed, whilst that in the photosphere remains open.

A solar spot visible in 1779 to the naked eye fortunately led the genius of William Herschel, happy alike in observation and combination, to the subject now before us. The results of his great examination, in which the details of several cases are treated according to a very definite nomenclature established by himself, are given in the *Philosophical Transactions* of 1795 and of 1801. He proceeds as usual in his own manner, and merely names Alexander Wilson once. His view is in its generality identical with that of Bode; his interpretation of the visibility and dimensions of the nucleus and the penumbra (*Phil. Trans.* 1801, p. 270 and 318, Tab. xviii. fig. 2), is based on the assumption of an opening in two envelopes; but besides these he places between the envelope and the body of the Sun (p. 302), a clear and transparent atmosphere, in which dark clouds (or at least only faintly illuminated by reflection) are suspended at a considerable height,—as three hundred (English) geographical miles. Wm. Herschel seems, indeed, inclined to believe the photosphere also to be only a stratum of unconnected phosphoric clouds with very uneven surfaces. It seems to him that an elastic fluid of an unknown nature rises from the crust or surface of the dark body of the Sun, occasioning in the upper region, when it acts most feebly, only small pores or punctures, and when it acts most energetically and tempe-

tuously, large openings with their dark centres or nuclei surrounded by penumbras or "shallows."

The black nuclei of the solar spots, which are seldom round, but, on the contrary, almost always characterised by corners, jagged edges, and re-entering angles, are often surrounded by penumbras in which the same figure is repeated on a larger scale. There is no perceptible gradual transition from the colour of the nucleus to that of the penumbra, or from the penumbra, which has sometimes a filamentous appearance, to the photosphere. Capocci, and a very diligent observer, Pastorff, (at Buckholz, near Frankfurt on the Oder), have given very exact drawings of the angular forms of nuclei, (Schum. Astr. Nachr. No. 115, S. 316, No. 133, S. 291, and No. 144, S. 471). William Herschel and Schwabe saw the dark nuclei crossed by shining veins of light, and even by, as it were, "luminous bridges,"—phenomena of a cloud-like nature belonging to the second stratum which produces the penumbras. These singular forms, probably the consequences of ascending currents, the tumultuary formation and appearances of spots, faculæ, furrows, and projecting ridges (the crests of luminous waves), are regarded by the astronomer of Slough as indicating powerful evolution of light; while on the other hand he considers the absence of solar spots and their accompanying phenomena to indicate comparative feebleness of combustion, and consequently a less degree of beneficial action on the temperature of our planet and on vegetation. These conjectures led Wm. Herschel to attempt to bring into comparison and connection the absence of solar spots in the years 1676—1684 (according to Flamstead); from 1686 to 1688 (according to Dominique Cassini); from

1695 to 1700 ; and from 1795 to 1800 ; with the prices of corn and the complaints which had been made of bad harvests (473). Unfortunately, however, the knowledge of the numerical elements required to furnish the base of even a conjectural solution of such a problem must always be wanting ; not only, as Herschel himself justly remarked, because the price of corn in one part of Europe cannot afford a standard whereby to judge of the state of vegetation over the whole continent, but also and more especially, because we can by no means infer from a diminution of the mean temperature of the year extending even over the whole of Europe, that in that year the globe generally had received a less quantity of warmth than usual from the Sun. Dove's investigations on the non-periodic variations of temperature have tended to show that "oppositions," or contrary states of weather, are always placed laterally side by side, in the same, or almost the same, parallels of latitude. Thus our continent and the temperate part of North America are usually opposed to each other in this respect, so that if we have an abnormally severe winter, the winter there will be milder than in ordinary years, and *vice versâ*. Seeing the unquestionable influence of the mean amount of summer heat on the cycle which vegetation passes through, and therefore on the success of cereal crops, we must regard such compensations in the distribution of temperature, over parts of the globe united by easy and convenient communication by sea, as productive of highly beneficial consequences to mankind.

While William Herschel attributed to the activity of the central body, manifested in the processes of which the solar spots are results, the effect of an increase in the temperature

of the Earth, Batista Baliani, nearly two centuries and a half before, in a letter to Galileo, described these spots as cooling agencies (⁴⁷⁴). A similar inference has been drawn from the essay made by the diligent astronomer Gautier at Geneva (⁴⁷⁵), to compare four periods of frequency and paucity of spots on the sun's disk (from 1827 to 1843) with the mean temperatures shewn by 33 European and 29 American stations; but the residual quantity on the side of the supposed cooling power of the solar spots, (scarcely $0^{\circ}\cdot42$ Centigrade, or less than $0^{\circ}\cdot8$ Fahrenheit), is so small, that even for the particular localities it may be attributed to errors of observation or to the influence of the direction of the wind. We remark in this comparison indications of the opposite affections of the two sides of the Atlantic, in accordance with Dove's general inferences.

It still remains to speak of the third and outermost of the three solar envelopes which have been referred to; it is supposed to be above the photosphere, and to be cloudy and of imperfect transparency. The remarkable phenomena of red mountain- or flame-like forms, which, during the total solar eclipse of the 8th of July, 1842, were seen, though not for the first time yet much more clearly than before, and observed simultaneously by several of the most practised observers, have led to the hypothesis or assumption of such a third envelope or covering. Arago, with great acumen, and after a thorough examination of the observations, has enumerated in a treatise on the subject (⁴⁷⁶), the grounds which appear to necessitate this assumption. He has at the same time shewn that similar rose-coloured marginal protuberances have been already described on occasions of total or annular eclipses of the sun since 1706 (⁴⁷⁷). On the recent occasion, July 8, 1842, when the disk of the

Moon covered the entire solar disk, (its apparent diameter being at that time greater than that of the Sun,) there was seen not only a⁽⁴⁷⁸⁾ white shining appearance forming a corona or bright circle surrounding the Moon, but also, as if attached in the limb or margin of the Moon, two or three rose-tinted elevations, which some observers compared to mountains, others to reddened masses of ice, and others to motionless jagged or pointed flames. Arago, Laugier, and Mauvais at Perpignan, Petit at Montpellier, Airy on the Superga near Turin, Schumacher at Vienna, and many other astronomers, agreed perfectly with each other in respect to the main features of the general phenomenon, notwithstanding the great diversity of the telescopes employed. The elevations were not seen in all cases at the same moment of absolute time, and at some places they were even observed with the naked eye. Their heights were also differently estimated by the different observers: the surest estimation is probably that of Petit; the director of the Observatory at Toulouse: it was 1' 45'', which, if the protuberances were really solar mountains, would correspond to elevations of 40,000 geographical miles: this is almost seven times the diameter of our globe, while the solar diameter is only 112 times that diameter. The consideration of the whole of these phenomena has led to the very probable hypothesis of these roseate forms being undulations or protuberances of the third envelope, or masses of cloud illuminated and coloured by the photosphere⁽⁴⁷⁹⁾. Arago, in putting forward this hypothesis, expresses at the same time the conjecture, that the darkness of the deep blue sky at great terrestrial altitudes, the intensity of which I had myself measured on the highest Cordilleras,—(instrumental means for such measurements

were indeed, and even still are, very imperfect,)—may render it possible to obtain frequent observations of those mountain-like clouds belonging to the outermost vaporous solar atmosphere (⁴⁸⁰).

It is only at two periods of the year, viz. on the 8th of June and 9th of December, that the solar spots describe on the Sun's disk neither convex nor concave curves, but straight lines parallel to each other and to the solar equator; and if we examine the zones in which the spots are most frequent, we find as a characteristic circumstance that they are rarely seen in the equatorial zone itself, from about 3° North to 3° South latitude, and that they are entirely wanting in the neighbourhood of the poles. They are on the whole most abundant in a belt between 11° and 15° north of the equator, and generally more frequent in the northern than in the southern hemisphere; or, as Sömmering thinks, are to be seen farther from the equator in the northern than in the southern hemisphere. (Herschel, *Outlines*, § 393; *Cape Observations*, p. 433.) Galileo had already assigned 29° of north and south heliocentric latitude for the extreme limits of the spots. Sir John Herschel has extended these limits to 35° ; as has also Schwabe. (*Schum. Astr. Nachr.*, No. 473.) Single spots have been found by Laugier (*Comptes Rendus*, T. xv. p. 944), as far as 41° , and by Schwabe even as far as 50° . A spot described by La Hire in 70° North latitude must be regarded as a phenomenon of most rare occurrence.

The above described distribution of the spots on the Sun's disk, their rarity on the equator itself and in the polar regions, and their arrangement parallel to the equator, have given occasion to Sir John Herschel to conjecture that obstacles

which the third, or outermost, vaporous envelope may oppose at some points to the escape of heat, may give rise in the solar atmosphere to currents from the poles to the equator, similar to those which, from the different velocity of rotation under different parallels of latitude, cause on our globe the trade-winds and the calms which prevail in the more immediate vicinity of the equator. Particular spots are sometimes so permanent as to return continually for six entire months, as the large spot of 1779. Schwabe was able to trace the same group eight times in the year 1840. A black nucleus which is figured in the Cape Observations of Sir John Herschel, (of which I have so extensively availed myself), was found by exact measurement to be of such magnitude, that if our entire earth had been thrown into the opening in the photosphere, there would still have remained on either side a vacant space of more than 920 geographical miles. Sömmering calls attention to the circumstance that there are certain meridians or bands of longitude in which during many years he never saw a solar spot. (*Thilo de Solis maculis a Sœmmeringio observatis*, 1828, p. 22.) The very different periods of rotation which have been assigned to the Sun are not by any means to be attributed solely to inaccuracy of observation; they proceed from the circumstance that some spots change their places upon the Sun's disk. Laugier has devoted a particular examination to this subject, and has observed spots from which rotations of 24·28 and 26·46 days might be severally derived. Our knowledge of the actual time of the Sun's rotation can, therefore, only be affirmed to correspond to the mean result derived from a great number of observed spots, which by the permanence of their form and the in-

variability of their distances from other spots visible at the same time, afford an apparently satisfactory degree of security.

Although solar spots may much oftener than is generally supposed be distinctly recognised by the unassisted eye of an observer looking for them, yet after careful investigation we find, between the beginning of the 9th and of the 17th centuries, at the utmost, not more than two or three notices of their appearance upon which we can depend. I reckon as such the supposed presence of Mercury upon the sun's disk for a period of eight days, in the year 807, recorded in the annals of the kings of the Franks, which were ascribed first to an astronomer belonging to the Benedictine order, and afterwards to Eginhard; the transit of Venus over the Sun, lasting 91 days, said to be observed under the Caliph Al Motassem in 840; and the "Signa in Sole" in the year 1096, according to the Staindelii Chronicon. The historical records of occasions on which the Sun has been darkened,—or, as it would be more accurately expressed, when there has been during a longer or shorter time a diminution of the light of day,—have induced me for a long time past to institute particular inquiries into such meteorological, or possibly cosmical, phenomena (⁴⁸¹). As extensive series of solar spots (those observed by Hevelius on the 20th of July, 1643, covered a third part of the Sun's disk) are always accompanied by numerous *faculae*, I am but little inclined to ascribe to their occurrence obscurations during which stars were sometimes visible as in total eclipses of the Sun.

The diminutions of daylight related by annalists may, I think, be classed under three heads according to three wholly

different causes to which they may by possibility be due. Total eclipses of the Sun are excluded, were it only from the recorded continuance of the obscurations for several hours,—whereas, according to Du Sejours' calculation, the longest possible duration of a total solar eclipse is 7' 58" at the equator, and in the latitude of Paris only 6' 10"). The three causes to which I allude are: 1, disturbances in the process by which light is evolved, or a less intensity in the photosphere; 2, impediments to the radiation of solar light and heat arising in the external opaque vaporous veil or covering surrounding the photosphere, by the formation in it of unusually large and dense clouds; 3, extraneous admixtures in our own atmosphere chiefly of an organic character, as "trade wind dust," "inky rain," or the Chinese "sand-rain," described by Macgowan as lasting several days. The causes mentioned under heads 2 and 3 require no enfeeblement of the (perhaps) electro-magnetic, luminous process in the Sun's atmosphere, (a perpetual Aurora or polar light) (⁴⁸²); the third is open to the objection that it is opposed to the visibility of stars in the middle of the day, which is so often spoken of in the too scanty descriptions given of the circumstances accompanying these mysterious phenomena.

Arago's discovery of chromatic polarisation has tended not only to strengthen the belief of a third and outermost covering of the Sun, but also to confirm the conjectures which have been formed respecting the physical constitution of the central body of our planetary system. "A ray of light arriving at our eyes from the remotest regions of space tells us in the polariscope, as it were of itself, whether it is

reflected or refracted, whether it emanates from a solid, from a liquid, or from a gaseous body, and even announces its degree of intensity." (Kosmos, Bd. i. S. 35, Bd. ii. S. 370; English Ed., Vol. i. p. 37, and Vol. ii. p. 329.) It is essential to distinguish between natural light as it proceeds directly from the sun, the fixed stars, or gas-flames, and is polarized by reflection from a glass plate under an angle of $35^{\circ} 25'$,—and the polarized light which radiates spontaneously as such from certain substances (glowing solids as well as liquids). The polarised light given out by the last-mentioned class of bodies proceeds very probably from their interior; on passing from a denser body into the thinner surrounding atmospheric strata, it is refracted at the surface, and a part of the refracted ray returns inwards and becomes polarized *by reflection*, while the other portion presents the properties of light polarised *by refraction*. The chromatic polariscope distinguishes between these two kinds of light by the opposite position of the coloured complementary images. Arago has shewn by careful experiments extending back to before 1820, that radiant solid bodies,—*e. g.*, a red-hot iron ball, or glowing, shining, molten metal in a liquid state,—give out simply natural light in the rays which issue from them in a perpendicular direction, whereas the luminous rays which arrive at our eyes under very small angles from their edges are polarized. If we now turn the polariscope, by which these two kinds of light are distinguished from each other, to gas-flames, no polarisation is discovered, however small may be the angles at which the rays emanate. Although light may be produced in the interior of the gaseous body, yet, in

the small degree of density of gaseous strata, the longer path traversed by the very oblique rays does not appear to lessen their number and strength; nor does the transition to another medium on issuing forth at the surface appear to produce polarisation by refraction. Now as the Sun's light coming from its margin in a very oblique direction, and at very small angles, also shews no trace of polarisation when examined by the polariscope, it follows from this important comparison that the Sun's brightness does not proceed from its solid body nor from any liquid substance, but from a gaseous self-luminous envelope. We have here a highly important physical analysis of the photosphere.

The polariscope has also led to the conclusion that the Sun's light is not greater at the centre of the disk than at the edges. If the two complementary coloured images of the Sun, the red and the blue, are so placed over each other that the margin of the one image coincides with the centre of the other, a perfect white is produced. If the intensity of light in the different parts of the solar disk were not the same,—if, for example, the centre of the sun were more luminous than the limb,—then in the partial superposition of the images the conjoined segments of the blue and red disks would appear not of a pure white but of a pale red, because the blue rays would only be able to neutralize a portion of the more abundant red rays. Remembering, then, that in the gaseous photosphere of the Sun, quite in opposition to what takes place in solid or liquid bodies, the smallness of the angles at which the luminous rays come to us from the edges of the Sun's disk does not lessen their number, while the same visual angle comprehends a greater

number of luminous points at the margin than at the centre, we see that we cannot reckon on the compensation which, if the Sun were a solid body, as a glowing iron ball, would take place at the edges, between the effects of smallness of radiation-angle, and the comprehension of a greater number of luminous points within the same angle of vision. If, then, there were no additional circumstance to be taken into account, it would follow that the gaseous self-luminous envelope, *i. e.* the solar disk seen by us, should, in contradiction to the indications of the polariscope, which show equal intensity of light in the centre and at the limb, be brighter at the edges than at the centre. That this is not so must be attributed to the outermost opaque or imperfectly transparent vaporous envelope or veil which surrounds the photosphere, and dims the light from the centre less than the rays from the margins which traverse the envelope by a longer path (⁴⁸³). Bouguer and Laplace, Airy, and Sir John Herschel, are opposed to the views taken by Arago: they hold the intensity of the light of the edges to be less than that of the centre, and the last-named of these distinguished physicists and astronomers remarks (⁴⁸⁴), "granting the existence of such an atmosphere" (or external vaporous envelope) "its form in obedience to the laws of equilibrium must be that of an oblate spheroid, the ellipticities of whose strata differ from each other and from that of the nucleus. Consequently the equatorial portions of this envelope must be of a thickness different from that of the polar, density for density, so that a different obstacle must be thereby opposed to the escape of heat from the equatorial and polar regions of the Sun." Arago is at the present moment occupied with experiments,

designed not only for testing his own views, but also for reducing the results of observation to exact numerical proportions.

The comparison of the Sun's light with the two most intense artificial lights which have yet been produced, gives (according to the still very imperfect state of photometry) the following numerical results. In the ingenious experiments by Fizeau and Foucault, Drummond's light (produced by the flame of an oxy-hydrogen lamp directed upon lime) is to the light from the Sun's disk as 1 to 146. The intensity of the light produced between two charcoal points by a Bunsen's pile in Davy's experiment, with a battery of 46 small plates, was to the solar light as 1 : 4.2, and with large plates as 1 : 2.5, or more than one-third of the Sun's light (⁴⁸⁵). If we still hear with astonishment that Drummond's dazzling light appears as a black spot when projected on the Sun's disk, we may regard with the higher admiration the genius of Galileo, in drawing, in 1612, from a series of inferences respecting the smallness of the distance from the Sun at which Venus would cease to be visible to the naked eye, the conclusion, that the blackest nucleus of a solar spot is brighter than the brightest part of the full moon (⁴⁸⁶).

Taking the intensity of the whole light of the Sun as equal to 1000, William Herschel estimated that of the penumbras on the average as 469, and that of the black nuclei themselves as 7. According to this assumption, which of course can only be regarded as a very conjectural one, and taking with Bouguer the light of the Sun to be 300000 times as strong as that of the full moon, a black nucleus would still possess 2000 times more light than the full

moon. The degree of illumination of the nuclei of the solar spots as seen by us,—(*i. e.* of the dark body of the Sun illuminated by reflection from the sides of the opening in the photosphere and from the inner vaporous envelope which produces the penumbras, and by the light of the terrestrial atmospheric strata through which we look),—has been shown in a very remarkable manner by some observations made during transits of Mercury. Compared with the Planet, whose dark nocturnal, or unilluminated side is then turned towards the earth, the darkest nuclei of spots in its vicinity appeared of a light brownish grey (⁴⁸⁷). An excellent observer, Hofrath Schwabe, of Dessau, had his attention particularly drawn to this difference between the darkness of the planet and of the nuclei of the solar spots, on the occasion of the transit of Mercury on the 5th of May, 1832. When observing in Peru the transit of the same planet, which took place on the 9th of November, 1802, I unfortunately was so much occupied with noticing the distances from the wires, that the comparison of the disk with dark solar spots which it almost touched, escaped me. That the spots radiate sensibly less heat than the other portions of the Sun's disk, was shown as early as 1815, by Professor Henry, of Princeton in the United States, by means of very delicate experiments, in which the image of the Sun and that of a large spot were projected on a screen, and the difference of temperature was measured by a thermo-electric apparatus (⁴⁸⁸).

Whether the calorific are distinguished from the luminous rays by different lengths in the transverse undulations of the ether,—or whether they are identical with the luminous rays, but only excite in our organs the sensation of light at a

certain rapidity of vibrations which produces very high temperatures,—in either case the Sun, as the chief source of light and heat, may elicit and animate magnetic forces on our planet, and especially in its gaseous envelope, the atmosphere. The early knowledge of thermo-electric phenomena in crystallised bodies (tourmaline, boracite, and topaz), and Oersted's great discovery in 1820, according to which every conductor of electricity exerts, during the time that the electric current is passing through it, a determinate action upon a magnetic needle, gave practical manifestation of the intimate relations subsisting between heat, electricity, and magnetism. The ingenious Ampère, who ascribed all magnetism to electric currents situated in a plane perpendicular to the axes of the magnets, based on the idea of this relationship between heat, electricity, and magnetism the hypothesis, that terrestrial magnetism, (*i. e.* the magnetic charge of the Earth), is produced by electric currents passing round the planets from east to west, and that the solar heat being the exciter of these currents, the diurnal variation of the magnetic declination is the result of the change of temperature produced by the diurnal change in the Sun's altitude. The thermo-electric experiments of Seebeck, in which differences of temperature in the points of connection of a circle, made of bismuth and copper, or other dissimilar metals, cause a deflection of the magnetic needle, supported Ampère's views.

A new and brilliant discovery of Faraday's, the following out of which by the author is taking place almost simultaneously with the printing of these pages, throws an unexpected light on this important subject. Whereas earlier investigations

of this great physicist had made it appear that all gases are diamagnetic—*i. e.* that they arrange themselves east and west like bismuth and phosphorus (oxygen gas, however, the most feebly so),—his last train of researches, the commencement of which goes back to 1847, shews that oxygen, unlike all other gases in this respect, comports itself like iron in taking a north and south axial direction; and farther, that it loses part of its paramagnetic force by rarefaction and increase of temperature. As the diamagnetic quality of the other constituents of the atmosphere—nitrogen and carbonic acid gas—is not modified by expansion or by increase of temperature, we have only to consider the atmosphere of oxygen, which surrounds the Earth like a dome of thin sheet iron and receives magnetism from it. The half of the dome which is turned towards the sun becomes less paramagnetic than the opposite one, and, as by the Earth's rotation and revolution round the Sun, the boundaries between these two half domes are continually shifting their place, Faraday is inclined to derive a part of the variations of magnetism on the surface of our globe, from these thermic relations. The assimilation, by adequate experimental research, of one kind of gas, oxygen, to iron, is an important discovery of the time in which we live (489), and is of the higher importance, because it is probable that oxygen constitutes almost the half of all the ponderable matter belonging to the accessible portions of our planet. Without the assumption of magnetic poles in the sun, or of proper magnetic forces in the solar rays, the central body of our system may excite magnetic activity on our planet simply by its powerful agency as a source of heat.

The attempts which have been made to show, by meteo-

rological observations continued for several years at single stations, that one side of the sun (*ex. gr.* the side which was turned towards the earth on the 1st of January, 1846) has a stronger heating power than the opposite side (⁴⁹⁰), have, like the so-called proofs of the decrease of the sun's diameter deduced from the earlier Greenwich Observations of Maskelyne, led to no certain result. The periodicity of the solar spots, reduced to definite numerical ratios by Hofrath Schwabe, of Dessau, appears to rest on a better foundation. Among the astronomers now living who are provided with excellent instruments, no other one has been able to devote to this subject such persevering attention as Schwabe has done. During the long space of twenty-four years he has often examined the sun's disk for upwards of 300 days in each year. His observations of the solar spots from 1844 to 1850 not being yet published, I have been indebted to his friendship for the opportunity of consulting them, and at the same time for answers to many questions which I proposed to him. I close the present section, on the physical constitution of the central body of our system, with the results with which his kindness has enriched the astronomical portion of my work:—

“The numbers contained in the following table leave no room to doubt that, at least from the year 1826 to 1850, the solar spots have shown a period of about ten years, with maxima in 1828, 1837, and 1848, and minima in 1833 and 1843. I have had no opportunity of becoming acquainted with any continuous series of earlier observations, but I readily admit that the period may be a variable one (⁴⁹¹):—

| Year. | Groups. | Days free from Spots. | Days of Observation. |
|-------|---------|-----------------------|----------------------|
| 1826 | 118 | 22 | 277 |
| 1827 | 161 | 2 | 273 |
| 1828 | 225 | 0 | 282 |
| 1829 | 199 | 0 | 244 |
| 1830 | 190 | 1 | 217 |
| 1831 | 149 | 3 | 239 |
| 1832 | 84 | 49 | 270 |
| 1833 | 33 | 139 | 267 |
| 1834 | 51 | 120 | 273 |
| 1835 | 173 | 18 | 244 |
| 1836 | 272 | 0 | 200 |
| 1837 | 333 | 0 | 168 |
| 1838 | 282 | 0 | 202 |
| 1839 | 162 | 0 | 205 |
| 1840 | 152 | 3 | 263 |
| 1841 | 102 | 15 | 283 |
| 1842 | 68 | 64 | 307 |
| 1843 | 34 | 149 | 312 |
| 1844 | 52 | 111 | 321 |
| 1845 | 114 | 29 | 332 |
| 1846 | 157 | 1 | 314 |
| 1847 | 257 | 0 | 276 |
| 1848 | 330 | 0 | 278 |
| 1849 | 238 | 0 | 285 |
| 1850 | 186 | 2 | 308 |

“In almost all the years except those of the minima I observed large spots visible to the naked eye—I mean spots whose diameters are above 50'', which is the size at which they begin to be discernible by a keen-sighted unassisted eye. The largest spots appeared in the years

1828, 1829, 1831, 1836, 1837, 1838, 1839, 1847, and 1848.

“The spots are undoubtedly in close relation to the formation of *faculæ*. I have seen abundant instances of the disappearance of spots being followed by the appearance in the same places of *faculæ* and ‘*Narben*’ (scars, cicatrices), and also of new spots showing themselves in the *faculæ*. Each spot is surrounded by more or less intensely luminous cloud. I do not believe that the spots on the sun have any influence on the temperature of the year. I record the indications of the barometer and thermometer three times a day, but as yet the means deduced therefrom have not suggested any sensible connection between climatic conditions and the number of spots. Even if single cases were to show such an apparent connection, it still would not deserve to have any importance attached to it, until confirmed by temperature results from many other parts of the Earth. If the solar spots should really have any minute influence on our atmosphere, my table would perhaps rather seem to indicate that the years when the spots were most numerous had fewer clear days than those in which spots were less frequent (Schwabe in Schum. Astron. Nachr., No. 638, S. 221).

“William Herschel gave the name of *faculæ* to the brighter luminous streaks which show themselves only towards the margin, and that of *Narben* to the veins or streaks which are only seen towards the middle of the sun’s disk (Astron. Nachr., No. 350, S. 243). I think I have convinced myself that ‘*Faculæ*’ and ‘*Narben*’ proceed from the same condensed luminous cloud, which at the margin of the sun’s disk stands out brighter, but in the middle of

the disk appears in the form of Narben, or less bright than the general surface. I prefer calling all brighter places on the sun's disk "luminous cloud," dividing them according to their forms into masses and streaks. This luminous cloud is distributed irregularly over the sun's surface, and sometimes, when it shows itself most prominently, even gives to the solar disk a *marbled* appearance. It is often distinctly visible on the whole of the sun's margin, sometimes even up to the poles; but it always appears most strongly in the two zones which the spots more particularly affect, and this even at times when there are no spots there. On such occasions these two bright zones of the sun's disk remind one vividly of Jupiter's belts.

"Ridges are the less bright parts intervening between the streaks of bright cloud, and showing always a shagreen-like aspect, reminding one of sand in which all the grains are alike in size. On this shagreen-like surface we sometimes see extraordinarily small, faint, grey (not black) points (pores), which are again traversed by exceedingly fine, dark, small veins (Astr. Nachr., No. 473, S. 286). Such pores, when in masses, form grey cloud-like spaces, and even the penumbras of the solar spots. In these latter we see pores and black points extend, mostly in radiating lines, from the nucleus to the circumference of the penumbra; and hence arises the frequent agreement in form between the nucleus and the penumbra."

The explanation and connection of these varying phenomena will perhaps first become known in their full importance to the investigators of nature, when, at some future day, and under the long-continued serenity of a tropical sky during an interval of several months, there shall be ob-

tained, by the help of photographic apparatus, combined with mechanical clockwork movement, an uninterrupted series of graphical representations of solar spots (⁴⁹²). Meteorological processes taking place in the gaseous envelopes of the dark solar body cause the phenomena which we term solar spots and condensed luminous clouds. There, as well as in the meteorology of our own planet, the disturbances are probably so varied and complicated in their kind, and so intricate in respect to the causes in which they originate, and which are partly general and partly local, that it is only by long-continued observation, aiming at the greatest attainable completeness, that we can hope to resolve even a portion of the still obscure problems which they present.

II.

THE PLANETS.

BEFORE we enter into descriptions of each of these bodies viewed individually, I propose to present some general and comparative considerations respecting the entire class to which they belong. These considerations will embrace, in conformity to the state of discovery at the present moment, 22 primary planets, and 21 subordinate bodies, moons or satellites. They do not apply to other classes of bodies in our planetary or solar system, among which comets whose orbits have been calculated are already ten times as numerous. Planets have, generally speaking, only a slight degree of scintillation, because they shine by the solar light reflected from their disks. (The difference in this respect between disks and luminous points has been explained in pp. 68 and xxviii. of the First Part of the present volume.) In the pale radiance of the illuminated moon, and in the reddened light of its darkened disk, which shows itself with peculiar strength within the tropics, the solar light, as seen by the observer stationed on the Earth, has suffered a two-fold change of direction. That the Earth and other planets are

capable of evolving a faint light of their own, not derived from reflection,—as is sometimes evidenced by remarkable phenomena appearing in the part of Venus which is not turned towards the sun,—has been already remarked in the first volume of the present work (⁴⁹³).

We propose to consider the planets in regard to their number, the order of succession of their discovery, their volume as compared with each other and with their distances from the sun, and according to their relative densities, masses, times of rotation, excentricities and inclinations of axis, as well as to the characteristic diversity of those within and those beyond the zone of the small planets. Among these subjects of comparative consideration I have, in accordance with the nature of my work, devoted particular care to the selection of the most accurate numerical data for the epoch at which these pages are printed—*i. e.*, the results of what are supposed to be the best assured as well as the most recent investigations.

a. Primary Planets.

1. *Number and epoch of discovery.*—Of the seven cosmical bodies which, by their continually varying relative positions and distances apart, have ever since the remotest antiquity been distinguished from the “unwandering orbs” of the heaven of the fixed stars, which to all sensible appearance preserve their relative positions and distances unchanged, five only—Mercury, Venus, Mars, Jupiter, and Saturn—wear the appearance of stars: “*quinque stellas errantes;*” while the sun and moon, from the size of their disks, their importance to man, and the place assigned to

them in mythological systems (⁴⁹⁴), were classed apart. Thus, according to Diodorus (ii. 30), the Chaldeans recognised only five planets; Plato, also, in the *Timæus*, on the only occasion on which he refers to the planets, says expressly—"Around the Earth reposing in the centre of the Cosmos move in seven orbits the moon, the sun, and five other stars to which the name of planets has been attached" (⁴⁹⁵). So, also, in the ancient Pythagorean representation of the structure of the heavens, according to Philolaus, among the ten divine bodies or celestial orbs which circle round the central fire (the hearth of the Universe, *εστια*), the five planets (which are named) (⁴⁹⁶) revolve immediately below the heaven of the fixed stars; then follow the sun, moon, earth, and *ἀντιχθων* (anti-earth). Ptolemy himself still continues to speak of five planets only. The enumeration of the series of seven planets as distributed by Julius Firmicus (⁴⁹⁷) among the Decans, as represented in the zodiac of Bianchini (examined by me elsewhere (⁴⁹⁸), and probably belonging to the third century of our era), and as contained in Egyptian monuments of the times of the Cæsars, belongs not to ancient astronomy, but to later periods, when astrological fancies had become everywhere prevalent (⁴⁹⁹). That the moon should have been included in the series of the seven planets need not surprise us, since, with the exception of a remarkable view of attraction taken by Anaxagoras (*Kosmos*, Bd. ii. S. 348 and 501, Anm. 27; Eng. edit. p. 308, and Note 467), its more immediate dependence on the Earth is scarcely ever alluded to by the ancients. On the other hand, in a notice of the supposed structure of the universe mentioned by Vitruvius (⁵⁰⁰), and by Martianus Capella (⁵⁰¹), but without naming its author,

the two planets which we call inferior planets, Mercury and Venus, are regarded as satellites of the sun, which is itself supposed to revolve round the Earth. There is as little reason for terming such a system an Egyptian one (⁵⁰²) as for confounding it with Ptolemy's epicycles, or Tycho Brahe's view of the universe.

The names by which the five star-like planets were designated by the nations of antiquity are of two kinds—mythological or names of divinities,—and significant or descriptive, taken from real or supposed physical properties. It is the more difficult to determine, from the only sources of information hitherto open to us, what may have been derived in this respect originally from the Egyptians, and what from the Chaldeans, because Greek writers have handed down to us not the original names themselves as they were in use among other nations, but only Greek equivalents, which they modified according to their own particular views. What knowledge was possessed by the Egyptians before the Chaldeans, and whether the latter are to be regarded merely as the highly-gifted scholars of the former (⁵⁰³), are questions which touch on the important but obscure problems of the earliest civilization of the human race, and the beginning of scientific development of thought on the banks of the Nile, or on those of the Euphrates. Although the Egyptian denominations of the 36 Decans are known, only one or two of the Egyptian names of the planets have come down to us (⁵⁰⁴).

It is remarkable that the mythological names of the planets, which are also given by Diodorus, are the only ones used by Plato and Aristotle; whereas later, for example in the book "de Mundo," falsely ascribed to Aristotle, we find both kinds of appellations—the mythological and the

descriptive or expressive—intermixed; *φαινων* for Saturn, *στιλβων* for Mercury, and *πυρόεις* for Mars (⁵⁰⁵). If, as we learn from passages in the Commentary of Simplicius (p. 122) to Aristotle's 8th book "de Cælo," and from Hyginus, Diodorus, and Theon of Smyrna, Saturn, the outermost of all the planets then known, received, singularly enough, the title of Sun, it can only have been because its position and the length of its revolution were supposed to raise it to the rank of ruler over the other planets. Descriptive appellations, however ancient some of them may have been, and probably the same as were used by the Chaldeans, are yet first found in frequent use among Greek and Roman writers in the time of the Cæsars. Their prevalence was connected with the influence of astrology. The planetary signs, with the exception of a round disk for the sun, and the crescent or sickle for the moon, on Egyptian monuments, are of very late origin; according to Letronne's researches, they even do not go back beyond the tenth century (⁵⁰⁶). They are even not found upon stones having gnostic inscriptions. Later copyists have introduced them into gnostic and alchemistic manuscripts; but they are hardly ever found in the oldest manuscripts which we possess of the Greek astronomers, Ptolemy, Theon, or Cleomedes. The earliest planetary signs, some of which (those for Jupiter and Mars) have been derived, as Salmasius has observed with his wonted sagacity, from alphabetical characters, were very different from those which we now employ, the particular forms of which are little, if at all, older than the 15th century. It is undoubted, and is proved by a passage borrowed by Olimpiodorus from Proclus (ad Tim. ed. Basil. p. 14), as well as by a late scholion to Pindar (Isthm. V. 2), that the symbolising custom of dedicating certain metals to

the different planets belonged already to the Neo-platonic Alexandrine representations of the 5th century. (Compare Olympiod. Comment. in Aristot. Meteorol. cap. 7, 3 in Ideler's edition of the Meteor. T. ii. p. 163; also T. i. pp. 199 and 251).

Although the number of visible planets known to the ancients amounted, according to the first limitation of the term, only to five, and subsequently, when the larger discs of the Sun and Moon were added, to seven; yet it was already conjectured that besides these visible planets there existed others, unseen because possessing only a fainter degree of lustre. This opinion is pointed out by Simplicius as an Aristotelian one: "It may be that lunar eclipses are sometimes caused by such dark bodies moving round the common centre as well as by the Earth." Artemidorus of Ephesus, whom Strabo often refers to as a geographer, believed in the existence of a countless number of such dark revolving cosmical bodies. The old imaginary anti-earth (*ἀντιχθων*) of the Pythagoreans does not belong to the sphere of these conjectures. It and the Earth were supposed to have a parallel concentric movement; it was an idea devised to spare the Earth, which was supposed to perform around the central fire a planetary revolution in 24 hours, from having also to execute a movement of rotation, and, indeed, represented no doubt the opposite hemisphere, or the antipodal half of our planet (⁵⁰⁷).

If from the entire number of planetary bodies now known to us, 43 primary planets and satellites, being six times as many as were known to the ancients, we take the 36 which have been discovered since the invention of the telescope, and divide them chronologically according to the periods of

their discovery, we find that *nine* were first seen in the 17th century, *nine* again in the 18th, and *eighteen* in the first half of the present or 19th century.

Chronological table of planetary discoveries, or of primary planets and satellites, since the invention of the telescope, in 1608 :—

A. The Seventeenth Century.

Four satellites of Jupiter : by Simon Marius, at Ansbach, Dec. 29, 1609 ; and by Galileo, at Padua, Jan. 7, 1610.

Compound form of Saturn : Galileo, Nov. 1610 ; the two side anses seen by Hevelius, 1656 ; final recognition of the true form of the ring by Huygens, Dec. 17, 1657.

The 6th satellite of Saturn (Titan) : Huygens, March 25, 1655.

The 8th satellite of Saturn (the outermost one, Japetus) : Domin. Cassini, Oct. 1671.

The 5th satellite of Saturn (Rhea) : Cassini, Dec. 23, 1672.

The 3d and 4th satellites of Saturn (Tethys and Dione) : Cassini, end of March 1684.

B. Eighteenth Century.

URANUS : William Herschel, March 13, 1781, at Bath.

The 2d and 4th satellites of Uranus : William Herschel, Jan. 11, 1787.

The 1st satellite of Saturn (Mimas) : W. Herschel, Aug. 28, 1789.

The 2d satellite of Saturn (Enceladus) : W. Herschel, Sept. 17, 1789.

The 1st satellite of Uranus : W. Herschel, Jan. 18 1790.

The 5th satellite of Uranus: W. Herschel, Feb. 9, 1790.

The 6th satellite of Uranus: W. Herschel, Feb. 28, 1794.

The 3d satellite of Uranus: W. Herschel, March 26, 1794.

C. Nineteenth Century.

CERES*: Piazzi, at Palermo, Jan. 1, 1801.

PALLAS*: Olbers, at Bremen, March 28, 1802.

JUNO*: Harding, at Lilienthal, Sept. 1, 1804.

VESTA*: Olbers, at Bremen, March 29, 1807.

(An interval of 38 years occurred without any planetary discovery.)

ASTRÆA*: Hencke, at Driesen, Dec. 8, 1845.

NEPTUNE: Galle, at Berlin, Sept. 23, 1846.

The 1st satellite of Neptune: W. Lassell, at Starfield, near Liverpool, Nov. 1846; Bond, at Cambridge, U.S.

HEBE*: Hencke, at Driesen, July 1, 1847.

IRIS*: Hind, London, Aug. 13, 1847.

FLORA*: Hind, London, Oct. 18, 1847.

METIS*: Graham, at Markree Castle, April 25, 1848.

The 7th satellite of Saturn (Hyperion): Bond, at Cambridge, U.S., 16-19th Sept. 1848; Lassell, at Liverpool, 19-20th Sept. 1848.

HYGEIA*: De Gasparis, at Naples, April 12, 1849.

PARTHENOPE*: De Gasparis, at Naples, May 11, 1850.

The second satellite of Neptune: Lassell, at Liverpool, August 14, 1850.

VICTORIA*: Hind, London, Sept. 13, 1850.

EGERIA*: De Gasparis, at Naples, Nov. 2, 1850.

IRENE*: Hind, London, May 19, 1851; and De Gasparis, at Naples, May 23, 1851.

In the above chronological review, (508) the primary planets are distinguished from the secondary planets or satellites by a difference of type. An asterisk has been appended to each member of that class of primary planets which form a peculiar and very extended group, as it were a ring of 132 millions of geographical miles in breadth, situated between Mars and Jupiter, and are commonly called the smaller planets, and sometimes telescopic planets, co-planets, asteroids or planetoids. Of these, 4 were discovered in the first seven years of the present century, and 10 in the course of the six years which have just terminated—a result due less to the improvement which has taken place in telescopes, than to the diligence and skill of observers, and in particular to the improved star maps, which have been so greatly enriched by the addition of stars of the 9th and 10th magnitudes. Moving points are now more easily distinguished from among the adjacent unmoving or fixed stars (See First Part of the present volume, p. 98-99; and in the original German, S. 155). The number of the primary planets has been exactly doubled since the publication of the first volume of Kosmos (509), so quickly have discoveries succeeded each other, so rapid has been the advance in the extension and completion of the topography of our planetary system.

2. *Distribution of planets into two groups.*—If, in the solar domain, we regard the region of the small planets situated between the orbits of Mars and Jupiter, but nearer on the whole to the former than to the latter, as a *dividing*

zone in space, or as forming, as it were, a *middle* group; then, as has been already remarked, the *inner* planets—those which are nearer to the Sun—viz. Mercury, Venus, Earth, and Mars—present many points of resemblance to each other and of contrast to the *outer* planets—Jupiter, Saturn, Uranus, and Neptune—situated further from the Sun, beyond the dividing zone. The middle group of the three, or that of the small planets, scarcely occupies half the interval between the orbits of Mars and of Jupiter. In the space between these two greater planets it is the part nearest to Mars which, so far as our present knowledge enables us to judge, is most richly furnished; for if, in the zone of the asteroids, we consider the extreme ones on either side—Flora and Hygeia—we find that Jupiter is more than three times farther from Hygeia than Flora is from Mars. This middle group is strongly distinguished from the others by the intersecting, highly inclined, and excentric orbits, and by the very small dimensions of the planets of which it consists. The inclination of the orbits to the ecliptic rises in Juno to $13^{\circ} 3'$, in Hebe to $14^{\circ} 47'$, in Egeria to $16^{\circ} 33'$, and in Pallas even to $34^{\circ} 37'$; while in this same middle group it falls as low as $5^{\circ} 19'$ in Astrea, $4^{\circ} 37'$ in Parthenope, and even as $3^{\circ} 47'$ in Hygeia. The small planets whose orbits have less than 7° of inclination are, in descending order, Flora, Metis, Iris, Astræa, Parthenope, and Hygeia; but in none of these are the inclinations as small as in Venus, Saturn, Mars, Neptune, Jupiter, and Uranus. In excentricity of orbit some of the small planets exceed and some fall short of Mercury (0.206), Juno, Pallas, Iris, and Victoria having 0.255, 0.239, 0.232, and 0.218; while Ceres, Egeria, and Vesta, have respectively

0.076, 0.086, 0.089, being excentricities inferior to that of the orbit of Mars (0,093), but without making so near an approach to a circular orbit as the planets Jupiter, Saturn, and Uranus. The diameters of the telescopic planets are so small as to render their measurement very difficult and uncertain. From the observations of Lamont at Munich, and of Mädler with the Dorpat refractor, it is probable that the largest of them all does not exceed at the utmost 145 German, or 580 English geographical miles, being $\frac{1}{5}$ th of the diameter of Mercury, and $\frac{1}{12}$ th of that of the Earth.

If we call the four planets nearest to the Sun, between the ring of Asteroids or small planets and the central body, *inner* planets, and the four planets which are furthest from the sun (being placed between the ring of the asteroids and the unknown extremities of the solar domain) *outer* planets, we find the inner planets all of moderate magnitude, comparatively dense, slow in their movements of rotation round their axes, (the periods being nearly similar in all, differing little in any case from 24 hours), and, with the exception of the Earth, wholly destitute of satellites. The four *outer* planets,—Jupiter, Saturn, Uranus, and Neptune,—on the other hand, are much larger, five times less dense, rotate twice as rapidly round their axes, are more flattened at the poles, and richer in satellites in the average proportion of 20 to 1. Of the four inner planets the Earth is the largest (the diameters of Mercury and Mars are respectively $\frac{2}{3}$ ths and $\frac{1}{2}$ of the Earth's diameter); while the outer planets, on the other hand, are from 4.2 to 11.2 times larger than the Earth. The density of the Earth being taken as unity, the densities of Venus and Mars agree with it to less than $\frac{1}{10}$ th, and the density

of Mercury (according to the mass of that planet as determined by Encke) is only a little greater. On the other hand, none of the outer planets exceed $\frac{1}{4}$ in density; Saturn is even only $\frac{1}{7}$ th, being little more than half as dense as the other outer planets and the sun. The outer planets present to us a phenomenon unique in the entire solar system—*i. e.*, the wondrous appearance of a solid ring encircling its primary planet, but detached from it and suspended freely in space. They also present to us atmospheres which, by the peculiarities of the condensations taking place in them, appear to our eyes as variable, and in Saturn sometimes even as interrupted, streaks or belts.

Although, in the important division of the planets into two groups of interior and exterior planets, the facts of absolute magnitude, density, compression at the poles, velocity of rotation, and presence or absence of moons or satellites, show a general connection with the solar distances, or with the semi-major axes of the orbits, yet this connection or dependence can by no means be asserted in respect to each individual member of these groups. As I have already before remarked, we as yet know of no inherent necessity, no mechanical natural law, which—as the fine law which links together the squares of the times of revolution and the cubes of the major axes—should represent the above-named elements of magnitude, density, &c., for the succession of the several planetary bodies in each group, in connection with or dependence on their respective solar distances. Although it is true that the planet which is nearest to the sun (Mercury) is also the densest, and even six or eight times as dense as the exterior planets, Jupiter, Saturn, Uranus, and Neptune; yet the order of succession between Venus, Earth, and

Mars, and between Jupiter, Saturn, and Uranus, is very far from being a regular one. We see that, in general, the absolute magnitudes, as Kepler had already remarked (*Harmonice Mundi*, V. iv. p. 194; *Kosmos*, Bd. i. S. 389; Eng. ed. p. xvi. Note 38), increase with the distance; but this, though generally true, is not true of each case in particular, for Mars is less than the Earth, Uranus less than Saturn, Saturn less than Jupiter, and Jupiter, the largest of all the planets known to us, is immediately preceded by a group of planets whose disks are scarcely measurable from their minuteness. The velocity of rotation does indeed increase generally with the solar distance; but yet the rotation of Mars is slower than that of the Earth, and that of Saturn slower than that of Jupiter.

The world of forms can, I repeat, be only depicted according to the actual relations of space existing in nature, not as the necessary object of intellectual deduction or of an already recognised causal sequence. In this respect no natural law has been discovered in celestial space, any more than in the geographical position of the culminating points of mountain chains, or in the particular configuration of continents on the surface of our globe. They are facts in Nature which have issued from the conflict of tangential and attracting forces of manifold character, acting under conditions which remain unknown to us. We here find ourselves approaching with eager but unsatisfied curiosity the mysterious domain of formation. The questions before us relate, in the strict sense of the words, to universal events, to cosmical processes taking place in intervals of time to us immeasurably small.

If the planets have been gradually formed from revolving rings of vaporous matter, when this matter began to

condense towards different points of predominating attraction, it must have passed through an almost infinite succession of states in order to form some simple and other intersecting orbits; and planets varying so greatly in magnitude, ellipticity, and density, some accompanied by, and others destitute of moons, and even in one case a series of satellites united in a solid ring. The present form of things, and the exact numerical determination of their mutual relations, have not as yet conducted us to a knowledge of the states previously passed through, nor to a clear insight into the conditions under which they have arisen. Yet these conditions are not therefore to be termed accidental, as man is prone to call all which he cannot yet explain genetically.

3. *Absolute and apparent magnitudes, and external figure.*—The diameter of the largest of all the planets, Jupiter, is 30 times as great as that of Mercury (the smallest of all the planets having securely measurable disks), and almost 11 times as great as that of the Earth: as compared with the Sun, its diameter is nearly as 1:10—a ratio nearly similar, inversely, to that between it and the Earth. It has been stated, perhaps erroneously, that the difference of size between meteoric stones, which many are inclined to regard as small planetary bodies—and Vesta, which, according to a measurement of Mädler's, has a diameter of 264* geographical miles (320† geographical miles less than the diameter of Pallas, according to Lamont)—is not more considerable than the difference of size between Vesta and the Sun. According to these proportions, there should be meteoric

* 66 German geographical miles.

† 80 German geographical miles.

stones of 517 German feet in diameter: igneous meteors have certainly been seen of 2600 feet in diameter before the explosion.

The connection between the degree of compression at the poles and the velocity of rotation is most strikingly shown by a comparison between the Earth, as a planet of the *inner* group, and Jupiter and Saturn belonging to the outer group of planets. For the Earth, period of rotation $23^{\text{h}} 56^{\text{m}}$, compression $\frac{1}{299}$; for Jupiter, period of rotation $9^{\text{h}} 55^{\text{m}}$, compression, according to Arago, $\frac{1}{17}$,—according to John Herschel, $\frac{1}{5}$; for Saturn, period of rotation $10^{\text{h}} 29^{\text{m}}$, compression $\frac{1}{6}$. But Mars, whose rotation is *slower* than that of the Earth by 41 minutes, has, even assuming a much smaller result than that adopted by William Herschel, still a probably much greater compression than the Earth. May this anomaly, since the form of the superficies of an elliptic spheroid should correspond to the velocity of rotation, be founded on a different law of increasing density from the surface to the centre in the two planets, or in the possible circumstance of the consolidation of the fluid surface of some planets having taken place before they had assumed the figure corresponding to their velocity of rotation? On the form of the ellipticity of our planet depend, as theoretical astronomy demonstrates, the important phenomena of the retrogression of the equinoctial points, or the apparent progression of the heavenly bodies, termed the “Precession of the Equinoxes,” “Nutation” (libration of the Earth’s axis)—and the change of the obliquity of the ecliptic.

The apparent diameters of the planets are determined by their absolute magnitudes, and by their distances from the Earth: the following is the order of arrangement which

corresponds to their absolute or true magnitudes, beginning with the smallest :—

The group of the smaller planets, of which Pallas and Vesta appear to be the largest : then—

| | |
|----------|----------|
| Mercury. | Neptune. |
| Mars. | Uranus. |
| Venus. | Saturn. |
| Earth. | Jupiter. |

At their respective mean distances from the Earth, Jupiter has an apparent equatorial diameter of 38'' 4; the equatorial diameter of Venus, which is nearly of the same magnitude as the Earth, being only 16'' 9; and that of Mars 5'' 8. At the inferior conjunction, however, of Venus, the apparent diameter of the disk increases to 62''; whereas that of Jupiter, when in opposition, only increases to 46''. It is here necessary to remark that the place in the orbit of Venus at which that planet appears brightest falls between its inferior conjunction and its greatest digression from the sun; at which time the narrow bow of light, by reason of its greatest proximity to the Earth, gives its most intense light. On the average, Venus shines brightest, and, in the absence of the sun, even casts shadows when she is 40° east or west of the sun; her apparent diameter is then only 40'', and the greatest breadth of her illuminated portion scarcely 10'.

Apparent diameters of 7 planets :—

| | | | | | |
|----------------------------|-------|------------------|-------|----|------------|
| Mercury, at mean distance, | 6''·7 | (oscillates from | 4''·4 | to | 12'') |
| Venus | '' | 16·9 | (| '' | 9·5 '' 62) |
| Mars | '' | 5·8 | (| '' | 3·3 '' 23) |

| | | |
|----------------------------|--------|----------------------------------|
| Jupiter, at mean distance, | 38''·4 | (oscillates from 30''·0 to 46'') |
| Saturn | 17·1 | (" " 15·0 " 20) |
| Uranus | 3·9 | |
| Neptune | 2·7 | |

Volumes of the planets relatively to that of the Earth:—

| | | | |
|---------|-------|----|-----------|
| Mercury | . . . | as | 1 : 16·7 |
| Venus | . . . | " | 1 : 1·05 |
| Earth | . . . | " | 1 : 1 |
| Mars | . . . | " | 1 : 7·14 |
| Jupiter | . . . | " | 1414 : 1 |
| Saturn | . . . | " | 735 : 1 |
| Uranus | . . . | " | 82 : 1 |
| Neptune | . . . | " | 108 : 1 ; |

while the volume of the Sun is to that of the Earth as 1407124 : 1. Small alterations in the measurements of the diameters increase the resulting volumes in the ratio of the cubes.

These planetary bodies, which, by their changes of place, enliven and vary in an agreeable manner the aspect of the starry heavens, produce on us an impression which is in each case the conjoint result of the magnitudes of their disks and their proximity, of the colour of their light, the scintillation of some among them in particular positions, and the peculiar manner in which their different surfaces reflect the solar light. Whether the intensity and quality of their light may be further modified by a feeble evolution of light from their own surfaces, is a problem which still remains to be solved.

4. *Arrangement of the planets according to their*

distances from the Sun.—The following table gives all the planets discovered hitherto, with their mean distances from the central body, taking, as has always been customary in astronomy, the mean solar distance of the Earth (20682000 German, or 82728000 Eng. geographical miles) as unity. In describing the planets separately, their greatest and least distances from the sun will be given—*i. e.* their distances when in aphelion and in perihelion, or when the planet, in the course of its motion in the ellipse of which the sun occupies the focus, is respectively at either end of the major axis (the line of the apsides), viz. the end which is farthest from, or that which is nearest to, the focus. By the *mean* solar distance of a planet, which is that which we are now speaking of, we understand the mean between the greatest and the least distance, or half the major axis of the planet's orbit. The numerical data already given, and also those which follow, are taken for the most part from Hansen's careful recapitulation of the planetary elements, in Schumacher's *Jahrbuch* for 1837. Where the data are related to time, they apply, in the case of the older-known and larger planets, to the year 1800, but in that of Neptune to 1851: the Berlin *Astronomische Jahrbuch* for 1853 has also been made use of. For the statements relating to the smaller planets I am indebted to the friendship of Dr. Galle; they all refer to very recent epochs.

Distances of the planets from the Sun:—

| | |
|-------------------|---------|
| Mercury | 0·38709 |
| Venus | 0·72333 |
| Earth | 1·00000 |
| Mars | 1·52369 |

Small Planets.

| | |
|----------------------|----------|
| Flora | 2·202 |
| Victoria | 2·335 |
| Vesta | 2·362 |
| Iris | 2·385 |
| Metis | 2·386 |
| Hebe | 2·425 |
| Parthenope | 2·448 |
| Irene | 2·553 |
| Astræa | 2·577 |
| Egeria | 2·579 |
| Juno | 2·669 |
| Ceres | 2·768 |
| Pallas | 2·773 |
| Hygeia | 3·151 |
| Jupiter | 5·20277 |
| Saturn | 9·53885 |
| Uranus | 19·18239 |
| Neptune | 30·03628 |

The simple observation of the rapid diminution of the periods of revolution from Saturn and Jupiter to Mars and Venus, had, on the assumption of the planets being attached to revolving spheres, led very early to conjectures respecting the distances of these spheres from each other. As no methodical system of observation and measurement appears to have existed among the Greeks prior to Aristarchus of Samos and the establishment of the Alexandrian Museum, there arose great diversities in the hypotheses formed concerning the order of the succession of the planets and their relative distances; whether, according to the most

prevailing system, these distances were taken from the Earth fixed in repose in the centre, or, according to the Pythagoreans, from the "Hearth of the Universe," the Hestia. Great fluctuations of opinion took place more particularly in respect to the position of the Sun—viz. its position relatively to the inferior planets and to the Moon (⁵¹⁰). The Pythagoreans, in whose view *number* was the source of knowledge and constituted the essence of things, applied their theory of numbers, and their all-pervading doctrine of numerical proportions, to the geometric consideration of the five early recognised regular bodies, to the musical intervals of tones determining harmony and forming different families of sound, and even to the structure of the Universe itself—deeming that the moving, and, as it seemed, oscillating planets, causing waves of sound, must, by the harmonic ratios of their intervals of space, call forth a "music of the spheres." "This music," they added, "would be audible to the human ear, were it not that because it is perpetual, and because, therefore, man is accustomed to it from earliest infancy, it remains unheeded" (⁵¹¹). The harmonic portion of the Pythagorean doctrine of numbers accorded well with the figurative representation of the Cosmos in the spirit of the *Timæus* of Plato; for "to Plato the Cosmogony appeared the work of the union effected between opposite primeval causes by the power of Harmony" (⁵¹²). Plato even personified the Harmony of the Universe or music of the spheres by placing in each of the planetary orbs Syrens, by whose songs, and by the support of the stern daughters of Necessity, the three Fates, the perpetual gyratory movement of the spindles of the Universe was maintained (⁵¹³). Representations of this kind of the

Syrens, or sometimes in their place the Muses, as celestial songstresses, have been preserved in several remains of antique art, particularly on cut stones. In Christian antiquity, and throughout the middle ages, from Basil the Great to Thomas Aquinas and Petrus Alliacus, we find frequent allusions,—most often, however, in terms of censure,—to this idea of the Harmony of the Spheres (514).

All the Pythagorean and Platonistic views of the Universe, both the geometric and the musical, re-awoke at the end of the sixteenth century in the imaginative Kepler. He built up the planetary system, first in the *Mysterium cosmographicum*, on the basis of five regular solids which could be placed in the intervals between the planetary spheres; and next, in the *Harmonice Mundi*, according to the intervals of musical notes (515). Persuaded of the conformity to law of the relative distances of the planets, he thought to solve the problem which he had thus proposed to himself by a happy combination of his earlier and his later views. It is remarkable that Tycho de Brahe, who, on all other occasions, we find so rigidly attached to actual observation, had, before Kepler, expressed the opinion, contested by Rothmann, that the revolving cosmical bodies may, by agitating the celestial air (that which we now call the “resisting medium”), produce musical sounds (516). It appears to me, however, that the analogies between the relations of musical tones or notes and the distances of the planets, however long and laboriously traced or sought after by Kepler, yet in the mind of that ingenious thinker never passed out of the domain of abstractions. He, indeed, at one time rejoices in having discovered, to the greater glory of the Creator, musical relations of num-

ber in cosmical relations of space. In a kind of poetic rapture, he makes Venus, together with the Earth, play “major,” “Dur,” when in aphelion, and “minor,” “Moll,” in perihelion; and even says that the highest tone of Jupiter and that of Venus must unite in the “Moll,” or “minor consonance.” But, notwithstanding all these frequently employed, and yet merely figurative or symbolical, expressions, Kepler says distinctly—“*Jam soni in cœlo nulli existunt, nec tam turbulentus est motus, ut ex attritu auræ cœlestis eliciatur stridor*” (*Harmonice Mundi*, lib. v. cap. 4). Here, then, is again mention of the rare and serene celestial air (*aura cœlestis*).

The comparison of the intervals between the planets, with the regular solids which he considered ought to fit into those intervals, had encouraged Kepler to extend his hypotheses even to the heaven of the fixed stars (⁵¹⁷). On the discovery of Ceres and of the other small planets, Kepler’s Pythagorean combinations were vividly recalled to recollection, on account of his previously almost forgotten expressions respecting the probable existence of a yet unseen planet in the great gap between Mars and Jupiter: (*motus semper distantiam pone sequi videtur: atque ubi magnus hiatus erat inter orbes, erat et inter motus*).

In his Introduction to the *Mysterium cosmographicum*, Kepler says—“I have become bolder, and now place a new planet between Jupiter and Mars, as well as”—a less happy hypothesis, and one which long remained unnoticed (⁵¹⁸)—“another planet between Venus and Mercury: probably it is the extraordinary smallness of both which has caused them to remain unseen” (⁵¹⁹). Subsequently Kepler found that he did not require these new planets for the arrangement of his solar

system according to the properties of his five regular solids ; it was only necessary to do a little violence to the distances of the old planets. (“Non reperies novos et incognitos Planetas, ut paulo antea, interpositos, non ea mihi probatur audacia ; sed illos veteres *parum admodum luxatos.*”—Myst. Cosmogr. p. 10). The intellectual tendencies of Kepler had so great an analogy with those of the Pythagoreans, and still more with those manifested in the *Timæus* of Plato, that as Plato (*Cratyl.* p. 409) found in the seven planetary spheres the differences of colours, as well as those of musical notes, so Kepler (*Astron. opt. cap. 6, p. 261*) made experiments, in which he attempted to imitate, on a variously illuminated table, the colours of the planets. Even the great Newton, ever so faithful to Reason, and so severe in all his inductions, was yet, as Prevost has already remarked, inclined to refer the dimensions of the seven colours of the spectrum to the diatonic scale (⁵²⁰).

The hypothesis of the existence of still unknown members of the planetary series of the solar system reminds us of the ancient Greek opinion of there being far more than five planets, that being only the number of those which had been observed, while many others remained hidden by their position, and the feebleness of their light. Such a statement has been ascribed in particular to Artemidorus of Ephesus (⁵²¹). Another ancient Hellenic, and perhaps even Egyptian belief, appears to have been “that the celestial bodies which we now behold have not all been always seen by man.” Such a physical, or rather historical, myth is connected with the particular form of vain-gloriousness which leads some nations and races to attribute to themselves an extraordinary degree of antiquity. Thus the pre-

hellenic Pelasgian inhabitants of Arcadia called themselves "Proselenes," because they boasted of having come into the country before the Moon accompanied the Earth. Pre-hellenic and pre-lunar were synonymous. The appearance of a heavenly body was described as a celestial event, as Deucalion's flood was a terrestrial event. Apuleius (*Apolonia*, Vol. ii. p. 494, ed. Oudendorp; *Kosmos*, Bd. ii. S. 439, Anm. 53; Eng. ed. p. lvii. Note 293) made Deucalion's flood extend to the Gætulian Mountains of Northern Africa. In Apollonius Rhodius—who, according to the favourite manner of Alexandrian writers, delighted in imitating ancient modes of speech—it is said of the early settlement of the Egyptians in the valley of the Nile—"As yet not all the heavenly bodies journeyed over the celestial vault; the children of Danaus had not yet appeared, nor Deucalion's race" (522). This important passage elucidates the boast of the Pelasgic Arcadians.

I conclude these considerations respecting the distances and dimensions of the planets, with what has been termed a law, although it does not indeed deserve the name, and which Lalande and Delambre have called a play upon numbers, and others a mnemonic contrivance, or help to the memory. Our meritorious Berlin astronomer, Bode, had been much occupied with this subject, especially at the time of the discovery of Ceres by Piazzi, which discovery, it should be remembered, was in no way effected by means of this supposed law, but was rather occasioned by an error of the press in Wollaston's star-catalogue. If the discovery were to be regarded as the fulfilment of a prophecy, then Kepler's prediction, spoken of above, which is more than a century and a half antecedent to Titius and Bode, ought

not to be forgotten. Although, in his popular and highly useful "Introduction to the Knowledge of the Starry Heavens," Bode had himself said distinctly that he had taken the law of the distances from a translation of Bonnet's "Contemplation de la Nature" made by Professor Titius at Wittenberg, yet it has been commonly called Bode's law, and the name of Titius has been seldom mentioned in connection with it. In a note appended by the latter to the chapter on the Structure of the Universe (⁵²³), he says—"If we examine the distances of the planets, we find in almost all a proportion between their distances apart and the increase of their corporeal magnitudes. If the distance from the Sun to Saturn gives 100 parts, then Mercury is distant 4 such parts from the Sun, Venus $4 + 3 = 7$ parts from the Sun, the Earth $4 + 6 = 10$, Mars $4 + 12 = 16$. But from Mars to Jupiter we come to a departure from this progression previously so exact (!). Beyond Mars there follows a space of $4 + 24 = 28$ such parts; but here we find neither primary planet nor satellite. Can we suppose that the Great Architect has left this space void? We must not doubt that it is occupied; it may be by the hitherto undiscovered satellites of Mars, or perhaps Jupiter may have additional satellites that have never yet been seen by any telescope. From this unknown interval (unknown as to that which occupies it) the space to Jupiter is $4 + 48 = 52$. Then follows Saturn at the solar distance of $4 + 96 = 100$ parts—an admirable proportion." Titius, therefore, was inclined to occupy the interval between Mars and Jupiter not with the one, but (as is actually the case) with several bodies; but he conjectured them to be satellites, not planets.

It is nowhere said how the translator and commentator of

Bonnet arrived at the number 4 for the orbit of Mercury. Perhaps he only selected it in order to have for Saturn, which was then the most distant known planet (its distance is 9·5, therefore nearly 10·0), exactly 100 parts in connection with the easily divisible numbers 96, 48, 24, &c. This is more probable than that he should have made the series by beginning with the nearer planets. Even in the last century, this law of doubling, beginning not from the Sun but from Mercury, could not be affirmed to agree sufficiently with the true distances of the planets as then known to us. The distances of Jupiter, Saturn, and Uranus, do indeed in reality approach very nearly to the rate of doubling; but since the discovery of Neptune, which is much too near to Uranus, the defect of the progression has become strikingly obvious (524).

What has been called the law of Vicarius Wurm of Leonberg, and has been sometimes distinguished from that of Titius and Bode, is a simple correction of the latter law, applied by Wurm to the solar distance of Mercury and to the difference between the solar distances of Mercury and Venus. With a nearer approximation to the truth, he makes the solar distance of Mercury 387, and that of Venus 680, the Earth being 1000 (525). On the occasion of the discovery of Pallas by Olbers, Gauss, in a letter to Zach (Oct. 1802), already passed a striking and just sentence on the so-called law of distances. He says—"Contrary to the nature of all truths which deserve the name of laws, that of Titius applies only in a very cursory manner to most of the planets, and (which does not appear to have been before remarked) not at all to Mercury. It is clear that the series 4, 4 + 3, 4 + 6, 4 + 12, 4 + 24, 4 + 48, 4 + 96, 4 + 192,

with which the distances should agree, is not even a continuous series at all. The number preceding $4+3$ ought to be not 4 —*i. e.* $4+0$ —but $4+1\frac{1}{2}$. So between 4 and $4+3$ there should be an indefinite number of intermediate quantities; or, as Wurm expresses it, for $n=1$ the result of $4+3 \times 2^{n-2}$ is not 4 , but $5\frac{1}{2}$. Attempts to discover such approximate agreements in Nature are, however, by no means to be censured; the greatest men of all periods have been fond of such *lusus ingenii*.”

5. *Masses of the Planets.*—The masses of the planets are investigated by means of their satellites (where such exist), of their mutual perturbations, or of the effects suffered or produced by a comet of short period. Thus in 1841 Encke determined, from the perturbations undergone by the comet which bears his name, the previously unknown mass of Mercury. The same comet affords a prospect of future corrections for the mass of Venus. The perturbations of Vesta are made use of for Jupiter. The mass of the Sun being taken as unity, we have (according to Encke’s fourth memoir on the comet of Pons, in the “*Schriften der Berliner Akademie der Wissenschaften*” für 1842, S. 5):—

| | | | | | |
|-----------------------------|---|---|---|---|---------------------|
| Mercury | . | . | . | . | $\frac{1}{4865731}$ |
| Venus | . | . | . | . | $\frac{1}{401839}$ |
| Earth | . | . | . | . | $\frac{1}{359551}$ |
| Earth and Moon together | . | . | . | . | $\frac{1}{355499}$ |
| Mars | . | . | . | . | $\frac{1}{2680337}$ |
| Jupiter with his satellites | . | . | . | . | $\frac{1}{1047879}$ |
| Saturn | . | . | . | . | $\frac{1}{3501.6}$ |
| Uranus | . | . | . | . | $\frac{1}{24603}$ |
| Neptune | . | . | . | . | $\frac{1}{14446}$ |

Still larger, although remarkably near to the truth, was the mass ($\frac{1}{93\frac{1}{2}}$) deduced for Neptune by Le Verrier from his ingenious calculations previous to the actual discovery of the planet by Galle. The following is the arrangement of the planets according to their masses, beginning with the least (omitting the smaller planets, Ceres, Pallas, Juno, &c.), and proceeding in increasing order :—Mercury, Mars, Venus, Earth, Uranus, Neptune, Saturn, and Jupiter.

It will be seen that this order of succession (as in the case of the volumes and densities) is by no means identical with that of the distances from the central body.

6. *Density of the Planets.*—Employing the previously given volumes and masses, we obtain for the densities of the planets (taking respectively the densities of the Earth and that of Water as unity) the following numerical ratios :—

| Planets. | Ratio to the density of the Earth. | Ratio to the density of Water. |
|-----------------|------------------------------------|--------------------------------|
| Mercury | 1·234 | 6·71 |
| Venus | 0·940 | 5·11 |
| Earth | 1·000 | 5·44 |
| Mars | 0·958 | 5·21 |
| Jupiter | 0·243 | 1·32 |
| Saturn | 0·140 | 0·76 |
| Uranus | 0·178 | 0·97 |
| Neptune | 0·230 | 1·25 |

In the above table the comparison of the densities of the different planets with that of water is based on the density of our own globe. This was given by Reich's experiments with the torsion-balance made at Freiberg, 5·4383; the analogous earlier experiments of Cavendish give, according

to the more exact re-calculation of Francis Baily, the very similar result of 5.448, and Baily's own experiments 5.660. We see that the density of Mercury, according to Encke's determination of its mass, is near that of the other planets of medium magnitude.

The above table reminds us again of the division, to which I have already repeatedly alluded, of the planets into two groups separated from each other by the zone of the small planets. The differences between the densities of Mars, Venus, the Earth, and even Mercury, are very small, and there is nearly as great a similarity between those of the far less dense remoter planets—Jupiter, Neptune, Uranus, and Saturn. The density of the Sun (0.252), that of the Earth being taken as =1 (1.37, therefore, when Water is taken as =1) is a little greater than the densities of Jupiter and Neptune. The following is the order of succession of the sun and planets arranged according to increasing density (⁵²⁶):—Saturn, Uranus, Neptune, Jupiter, Sun, Venus, Mars, Earth, Mercury.

Although the densest planets are, on the whole, those nearest to the sun, yet, taken individually, the densities of the several planets are by no means proportional to their solar distances, as Newton was inclined to assume (⁵²⁷).

7. *Sidereal period of revolution and rotation round the axis.*—We shall content ourselves here with giving the sidereal, or true periods of revolution of the planets in relation to the fixed stars or to some particular point in the heavens. In the interval of time occupied by such a revolution the planet performs 360 complete degrees round the sun. The sidereal revolutions are very distinct from the tropical and synodical, of which the former relate to the return of the vernal equinox, and the latter to the difference

of time between two successive conjunctions or oppositions.

| Planets. | Sidereal periods of revolution. | Rotation. | | | |
|----------|---------------------------------|-----------|----|----|----|
| | days. | d. | h. | m. | s. |
| Mercury. | 87·96928 | . | . | . | . |
| Venus | 224·70078 | . | . | . | . |
| Earth | 365·25637 | 0 | 23 | 56 | 4 |
| Mars | 686·97964 | . | 0 | 37 | 20 |
| Jupiter | 4332·58480 | 0 | 9 | 55 | 27 |
| Saturn | 10759·21981 | 0 | 10 | 29 | 17 |
| Uranus | 30686·82051 | . | . | . | . |
| Neptune. | 60126·7 | . | . | . | . |

In another, and perhaps still more readily intelligible form, the true periods of revolution are—

| | Days. | Hours. | Minutes. | Seconds. |
|---------|-------|--------|----------|----------|
| Mercury | 87 | 23 | 15 | 46 |
| Venus | 224 | 16 | 49 | 7 |
| Earth | 365 | 6 | 9 | 10·7496 |

From the last-named of these periods (that of the Earth) the tropical period of revolution, or the length of the solar year, is found to be 365·24222, or 365^d, 5^h, 48^m, 47^s·8091 : by the effect of the precession of the equinoxes the length of the solar year becomes 0^s·595 shorter in the course of 100 years :—

| | Years. | Days. | Hours. | Minutes. | Seconds. |
|---------|--------|-------|--------|----------|----------|
| Mars | 1 | 321 | 17 | 30 | 41 |
| Jupiter | 11 | 314 | 20 | 2 | 7 |
| Saturn | 29 | 166 | 23 | 16 | 32 |
| Uranus | 84 | 5 | 19 | 41 | 36 |
| Neptune | 164 | 225 | 17 | | |

The rotation is most rapid in the very large exterior planets which have long periods of revolution, and slower in the smaller planets which are nearer to the sun. The period of revolution varies considerably in the asteroids, or small planets between Mars and Jupiter, and will be stated subsequently in the account given of each; it is sufficient at present to remark that it is longest in Hygeia and shortest in Flora.

8. *Inclination of the planetary orbits and axes of rotation.*—Next to the masses of the planets the inclination and excentricity of their orbits are among the most important elements on which the perturbations depend. Their comparison in the several series of the inner, the small middle, and the outer planets (from Mercury to Mars, from Flora to Hygeia, and from Jupiter to Neptune), presents similarities and contrasts which lead to considerations respecting the formation of these bodies, and their secular variations or changes connected with long periods of time. The planets which revolve in such different elliptic orbits are all situated in different planes. In order to render a numerical comparison possible they are referred to a fundamental plane, either fixed, or moveable according to a given law. It is considered most convenient to take for this plane either the ecliptic (the path which the Earth really passes over), or the equator of the terrestrial spheroid. In addition to these planes, the subjoined table contains the inclinations of the axes of rotation of the planets to their own orbits, so far as these are known on the evidence of tolerably secure investigation :—

| Planets. | Inclination of the Planetary Orbits to the Ecliptic. | Inclination of the Planetary Orbits to the Earth's Equator. | Inclination of the Axes of the Planets to their Orbits. |
|---------------|--|---|---|
| Mercury . . . | 7° 0' 5".9 | 28° 45' 8" | |
| Venus . . . | 3 23 28 .5 | 24 33 21 | |
| Earth . . . | 0 0 0 | 23 27 54.8 | 66° 32 |
| Mars . . . | 1 51 6 .2 | 24 44 24 | 61 18 |
| Jupiter . . . | 1 18 51 .6 | 23 18 28 | 86 54 |
| Saturn . . . | 2 29 35 .9 | 22 38 44 | |
| Uranus . . . | 0 46 28 .0 | 23 41 24 | |
| Neptune . . . | 1 47 | 22 21 | |

The small planets have been omitted, because they will be treated subsequently as a detached group. With the exception of Mercury, which is situated so near the sun, and the inclination of whose orbit to the ecliptic (7° 0' 5".9) is very nearly the same as that of the sun's equator (7° 30'), we see that the inclinations of the other seven planetary orbits oscillate between 0 $\frac{3}{4}$ ° and 3 $\frac{1}{2}$ °. In respect to the position of each planet's axis of rotation relatively to its own orbit, it is Jupiter which approaches most nearly to the extreme case of perpendicularity. In Uranus, on the other hand, to judge by the inclination of the paths of the satellites, the axis of rotation of the planet almost coincides with the plane of its orbit.

As it is on the inclination of the Earth's axis to the plane of its orbit, therefore on the obliquity of the ecliptic (*i. e.* on the angle which the apparent path of the sun makes at its intersection with the terrestrial equator,) that the distribution and duration of the seasons, the altitudes of the sun in different latitudes, and the length of the day depend; so

this element is of the most essential importance in determining "astronomical climates"—*i. e.* the temperature of the globe, so far as that temperature is a function of the altitude attained by the sun at noon, and of the length of the time during which the sun remains above the horizon. With a considerably greater obliquity of the ecliptic, or supposing the terrestrial equator to be perpendicular to the Earth's orbit, every place on the Earth would once a year have the sun in its zenith, even under the poles, and for a longer or shorter time would not see the sun rise. Under every latitude the difference of summer and winter (as well as of the length of day) would reach the maximum of contrast. In every part of the Earth the climates would be in the highest degree of the description which we call "excessive;" their extreme character would be only very slightly modified by the extraordinarily complicated series of rapidly changing currents of air which would be produced. In the reverse case, that of the obliquity of the ecliptic being null, or the terrestrial equator coinciding with the ecliptic, the difference of seasons and of length of day would everywhere cease, because the sun's apparent course would be uninterruptedly in the equinoctial line. The inhabitants of the poles would never cease to see the sun on the horizon. "The mean annual temperature of any point on the Earth's surface would also be that of each day in the year at the same place" (528). Such a state of things has been called one of perpetual spring, though the constant equality of day and night seems the only reason for the term. If it existed on the Earth, a great part of the regions which we now call the temperate zone, being deprived of the degree of summer heat which now stimulates and supports vegetation, would be transferred

to the always equable, but by no means desirable or agreeable, "vernal climate" which prevails under the equator on the chain of the Andes near the limits of perpetual snow, and from which I suffered much on the desert mountain plains—the Paramos (⁵²⁹)—at elevations between ten and twelve thousand French, or about eleven and thirteen thousand English feet, above the sea. The temperature of the air in these regions always oscillates in the day-time between $4\frac{1}{2}^{\circ}$ and 9° Reaumur, or 42° and 52° Fahrenheit.

The ancient Greeks were much occupied with rough measurements of the obliquity of the ecliptic, and with conjectures respecting its variability, and respecting the influence of the inclination of the terrestrial axis on climate, and on the luxuriance of organic development. These speculations were more especially pursued by Anaxagoras, by the Pythagorean school, and by *Cenopides* of Chios. The passages which illustrate them, so far as they have come down to us, are indeed scanty and vague; but they enable us to perceive that the development of organic life, and the first appearance of animals, were imagined to have been cotemporaneous with the epoch at which the terrestrial axis began to incline, which inclination also altered the habitability of the planet in particular zones. According to Plutarch (*de Plac. Philos.*, ii. 8), Anaxagoras believed "that the World, after it had began and had brought forth living beings from its bosom, spontaneously inclined itself towards the noon or southern side." To the same effect, *Diogenes Laertius* (ii. 9) says, when speaking of the opinions of the Clazomenian philosopher—"The stars had first begun to revolve, as it were, round a dome, so that what appeared the pole was vertically above the Earth; but subsequently they assumed an oblique

direction." The obliquity of the ecliptic was regarded as a cosmical *event*, an alteration which took place suddenly no allusion was made to a subsequent progressive change.

The description of the two extreme or opposite cases, to which the planets Uranus and Jupiter approximate most nearly, is suited to remind us of the alterations which the increasing or decreasing obliquity of the ecliptic would produce in the meteorological relations of our planet, and in the development of organic forms, if this increase and decrease were not restricted within very narrow limits. The recognition of these limits has been the object of the great labours of Leonhard Euler, Lagrange, and Laplace, and may be regarded as one of the most brilliant achievements of theoretical astronomy in modern times, and of the degree of perfection to which the higher analysis has been brought. The limits in question are indeed so narrow, that Laplace, in the *Exposition du Système du Monde*, ed. 1824, p. 303, stated that the obliquity of the ecliptic only oscillates $1\frac{1}{2}^{\circ}$ on either side of its mean position. This is equivalent to saying that the torrid zone, or the tropic of Cancer, which is its northern boundary, can only approach by that quantity nearer to the part of the Earth in which we live (⁵³⁰), or that, leaving out of view the effects of the many other causes of meteorological perturbations, Berlin might be gradually transferred from its present isothermal line to that of Prague. The implied elevation of the mean annual temperature would hardly be more than one degree of the centigrade thermometer (1.8° Fah.) (⁵³¹). Biot, though also believing the variations of the obliquity of the ecliptic to be restricted within narrow limits, yet deems it more advisable not to attempt at present to assign to them definite numerical values. He says—"L₂

diminution lente et séculaire de l'obliquité de l'écliptique offre des états alternatifs qui produisent une oscillation éternelle comprise entre des limites fixes. La théorie n'a pas encore pu parvenir à déterminer ces limites ; mais d'après la constitution du système planétaire, elle a démontré qu'elles existent et qu'elles sont *tres peu étendues*. Ainsi à ne considérer que le seul effet des causes constantes qui agissent actuellement sur le système du monde, on peut affirmer que le plan de l'écliptique *n'a jamais coïncidé* et ne *coïncidera jamais* avec le plan de l'équateur, phénomène qui, s'il arrivait, produirait sur la terre le (prétendu !) printemps perpétuel" (Biot, Traité d'Astronomie Physique, 3me éd. 1847, T. iv. p. 91).

While the Nutation of the terrestrial axis discovered by Bradley depends solely upon the influence of the Sun and the Earth's own satellite upon the compressed form of our planet at its poles, the increase and decrease of the obliquity of the ecliptic is a consequence of the varying positions of all the planets. These are at present so distributed that their joint action on the Earth's path or orbit produces a diminution of the obliquity, which diminution amounts at the present time, according to Bessel, to $0''\cdot457$ annually. After the lapse of several thousand years the places of the planetary orbits and their nodes (points of intersection on the ecliptic) will be so different that the advance, or precession, of the equinoxes will be changed into a retrogression, and thereby produce an increase of the obliquity of the ecliptic. Theory teaches that this increase and decrease occupy periods of very unequal duration. The oldest astronomical observations which have been preserved to us with exact numerical data extend back to the year 1104 B.C., and testify the

high antiquity of Chinese civilisation. There are remains of Chinese literature scarcely a century less ancient; and a regular historic chronology reaches back (according to Edouard Biot) to 2700 years before our era (⁵³²). Under the Regency of Tscheu-kung, brother of Wu-wang, the length of the sun's meridian shadow (⁵³³) was measured at the summer and winter solstice, with an 8-foot gnomon, at the town of Lo-jang, to the south of the Yellow River, in latitude $34^{\circ} 46'$ (the present name of the town is Ho-nang-fu, in the Province of Ho-nan.) These measurements gave the obliquity of the ecliptic $23^{\circ} 54'$; being $27'$ greater than it was in 1850. The observations of Pytheas and Eratosthenes at Marseilles and Alexandria are six and seven centuries later. We possess four results respecting the amount of the obliquity of the ecliptic previous to our era, and seven results intermediate between that period and Ulugh Beg's observations at the Observatory of Samarcand. The theory of Laplace agrees admirably, having differences which are sometimes plus and sometimes minus, with the observations extending over a period of almost 3000 years. We are more fortunate in the knowledge of the early Chinese measurements of the length of the solar shadow, as the writing containing the account escaped, we know not how or why, from the great destruction of books which took place from motives of fanaticism, by the orders of the Emperor Shi-hoang-ti of the Tsin dynasty, 246 years before our era. As, according to the researches of Lepsius, the commencement of the 4th Egyptian dynasty, which began with the reigns of the pyramid-building kings, Chufu, Shafra, and Menkera, was 23 centuries anterior to the solstitial observation at Lo-jang, we may assume with very great probabi-

lity—seeing the high degree of intellectual cultivation of the Egyptian nation, and its early construction of calendars—that similar measurements had been made at least as early in the Valley of the Nile; but none such have come down to us. Even the Peruvians—although they had made less advances than the Mexicans and the Muyscas (inhabitants of the mountains of New Granada) in the improvement of calendars and intercalation—had gnomons in which the style was surrounded by a circle drawn upon a very even surface. These gnomons were placed in the interior of the great temple of the Sun at Cuzco, as well as in many other parts of the Peruvian empire: the one at Quito, situated almost directly under the equator, used to be decorated with flowers at festivals held at the equinoxes, and was regarded with particular honour (534).

9. *Excentricity of the planetary orbits.*—The form of the elliptic orbits is determined by the greater or less distance of the two foci from the centre of the ellipse. This distance—or the degree of excentricity of the planetary orbits expressed in parts of their semi-axes—varies from 0·006 in Venus (differing, therefore, very little from a circle) and 0·076 in Ceres, to 0·205 in Mercury and 0·255 in Juno. The least excentric orbits are successively those of Venus, Neptune, and the Earth, the last of which is now diminishing at the rate of 0·00004299 in a hundred years, while the minor axis is increasing; then follow Uranus, Jupiter, Saturn, Ceres, Egeria Vesta, and Mars. The most excentric orbits are those of Juno (0·255), Pallas (0·239), Iris (0·232), Victoria (0·217), Mercury (0·205), and Hebe (0·202). In some planets—as Mercury, Mars, and Jupiter—the excentricities are increasing; while in others—as

Venus, the Earth, Saturn, and Uranus—they are decreasing. The following table gives the excentricities of the larger planets according to Hansen for the year 1800 ; the excentricities of the 14 small planets will be given subsequently, together with the other elements of their orbits, for the middle of the 19th century :—

| | | | | | |
|---------|---|---|---|---|-----------|
| Mercury | . | . | . | . | 0·2056163 |
| Venus | . | . | . | . | 0·0068618 |
| Earth | . | . | . | . | 0·0167922 |
| Mars | . | . | . | . | 0·0932168 |
| Jupiter | . | . | . | . | 0·0481621 |
| Saturn | . | . | . | . | 0·0561505 |
| Uranus | . | . | . | . | 0·0466108 |
| Neptune | . | . | . | . | 0·0087195 |

The movement of the major axis (line of the apsides) in planetary orbits, whereby the place of the perihelion is altered, takes place always in one direction. It is a change in the position of the line of the apsides which would require more than a hundred thousand years to complete its cycle, and is to be thoroughly distinguished from the changes of form or of ellipticity suffered by the orbits. The question has been mooted whether, in the course of several thousand years, the increasing value of this element could modify in a considerable degree the temperature of the Earth, in respect to its amount and distribution in the different parts of the day and of the year? Whether there might not be found in these regularly and continually acting astronomical causes a partial solution of the great geological problem of the remains of tropical vegetable and animal forms in the present cold zone? The same mathematical

reasonings which have excited apprehensions, in respect to the position of the apsides,—the form of the planetary elliptical orbits (according as they approximate to a circle on the one hand, or to a comet-like degree of excentricity on the other),—the inclination of the axes of the planets,—the variation of the obliquity of the Ecliptic,—or the influence of the precession of the equinoxes on the length of the year,—also afford, when carried to a higher degree of analytical development, cosmical grounds which counterbalance such apprehensions. The major axes and the masses are constant. Periodical return prevents the indefinite accretion of particular perturbations. The excentricities of the two greatest planets, Jupiter and Saturn, besides being in themselves very moderate in amount, undergo, by reason of a reciprocal and compensating influence, alternate increase and decrease, which are restricted within known and determinate and generally narrow limits.

By the alteration in the position of the line of the apsides (⁵³⁵), the point at which the Earth is nearest to the Sun tends gradually to change towards the opposite period of the year. If at present the perihelion falls in the beginning of January, and the aphelion six months later, or in the beginning of July, the progressive change of position, or turning movement, of the line of the apsides or major axis of the Earth's orbit, may cause the aphelion, or maximum distance of the Earth from the Sun, to fall in those months which form the winter of the northern hemisphere, and the perihelion, or minimum distance, in our summer; so that in January the Earth would be 700000 German, or 2800000 English, geographical miles (about $\frac{1}{30}$ th of the mean distance between the two bodies) farther from the Sun than in July,

which is the converse of what now takes place. At first sight it might seem as if the transference of the period of the greatest proximity of the Earth to the Sun to the opposite season of the year (to our summer instead of our winter) must produce great climatic alterations; but, in fact, supposing such a transference to have been effected, it would follow that the Sun would no longer linger for seven additional days in the northern hemisphere, and would no longer, as at present, pass through the portion of the Ecliptic from the autumnal to the vernal equinox in a space of time shorter by a week than that which it requires for traversing the other half of its path, or from the vernal to the autumnal equinox. The difference of temperature (we here regard, exclusively, astronomical climates, setting aside all physical considerations respecting the relative proportions of sea and land in the different parts of the surface of our globe)—the difference of temperature, I say, apprehended as liable to ensue from a change of the line of the apsides, would disappear almost entirely, from the counterbalancing circumstance, that the point at which our planet is nearest to the Sun is at the same time always that at which it moves most rapidly (⁵³⁶). The fine theorem first enounced by Lambert (⁵³⁷), according to which the quantity of heat which the Earth receives from the Sun in each part of the year is proportional to the angle described in the same interval of time by the radius vector of the Sun, contains within itself, to a certain degree, a satisfactory reply to the supposition of great climatic change.

We have said that the altered direction of the line of the apsides can exert but little influence on the temperature of the globe; and it may be added that, according to Arago

and Poisson (⁵³⁸), the probable alterations of the ellipse formed by the Earth's path are comprised within such narrow limits, that they can only modify the climates of the different terrestrial zones to a very moderate extent, and, moreover, very gradually, and in very long periods. Although the analysis by which these limits are exactly determined is not yet quite completed, yet it has at least shown that the excentricity of the Earth will never be transformed into that of Juno, Pallas, or Victoria.

10. *Strength of the Sun's light on the different planets.*—If we make the strength of the Sun's light on the surface of the Earth = 1, we find for—

| | | | | | | |
|---------|---|---|---|---|---|-------|
| Mercury | . | . | . | . | . | 6·674 |
| Venus | . | . | . | . | . | 1·911 |
| Mars | . | . | . | . | . | 0·431 |
| Pallas | . | . | . | . | . | 0·130 |
| Jupiter | . | . | . | . | . | 0·036 |
| Saturn | . | . | . | . | . | 0·011 |
| Uranus | . | . | . | . | . | 0·003 |
| Neptune | . | . | . | . | . | 0·001 |

Owing to the great excentricities of the orbits of some of the planets, the intensity of light on their surface differs much at their greatest and least distance from the Sun. Thus it is in—

| | | | |
|------------------------------|--------|--------------|----------|
| Mercury, when in perihelion, | 10·58; | in aphelion, | 4·59 |
| Mars | „ | 0·52; | „ 0·36 |
| Juno | „ | 0·25; | „ 0·09 : |

while the Earth, from the small excentricity of its ellipse, has in perihelion 1·034, and in aphelion 0·967. If the

light of the Sun is nearly 7 times more intense at the surface of Mercury than on that of the Earth, it must be 368 times less intense on Uranus. The ratio of warmth is not here considered, because it is a complicated phenomenon depending on the existence or non-existence of planetary atmospheres, their heights, and special constitution. I will merely allude to the conjecture of Sir John Herschel respecting the temperature at the surface of the moon, "which," he thinks, "may perhaps considerably exceed that of the boiling-point of water" (539).

β. Satellites.

General comparative considerations respecting subordinate planets or satellites have been already given with some degree of fulness in the "Picture of Nature" in the 1st volume of Kosmos (S. 99—104, German; p. 86—91, English). At that time (March 1845) only 11 planets and 18 satellites were known. Of asteroids—also called telescopic or small planets—only four had been discovered—viz. Ceres, Pallas, Juno, and Vesta. At the present moment (August 1851) the number of primary planets exceeds that of secondary planets or satellites; for we now know 22 of the former, and 21 of the latter. After a thirty-eight years' interruption of planetary discoveries, from 1807 to December 1845, the discovery of Astræa by Hencke was the first of a long succession by which 10 new small planets have become known to us. Of these, Hencke at Driesen recognised two (Astræa and Hebe); Hind, in London, four (Iris, Flora, Victoria, and Irene); Graham, at Markree Castle, one (Metis); and De Gasparis, at Naples, three (Hygeia, Parthenope, and Egeria). The recognition of the

outermost of all the large planets, Neptune, announced by Le Verrier at Paris, and seen by Galle at Berlin, followed ten months after that of Astræa. Discoveries now succeed each other with such rapidity, that, after the lapse of a few years, a topography of the solar system appears as antiquated as do statistical descriptions of countries after a similar interval.

Of the 21 satellites at present known, 1 belongs to the Earth, 4 to Jupiter, 8 to Saturn (the last discovered of these, Hyperion, the 7th according to distance, was discovered nearly simultaneously on the two sides of the Atlantic by Bond and Lassell), 6 to Uranus (of which the 2d and the 4th are the most securely ascertained), and 2 to Neptune.

The satellites which revolve round the primary planets constitute subordinate systems, in which the planets appear as the central bodies of domains of various and very different dimensions, in which the great solar domain is, as it were, repeated on a smaller scale. According to our present knowledge, the domain of Jupiter has a diameter of 520000 (2080000 Eng.), and that of Saturn 1050000 (4200000 Eng.) geographical miles. In the time of Galileo, when the expression of "Mundus Jovialis" was often used to describe the planet Jupiter and its attendant satellites, these analogies between the solar system and the subordinate systems included within its limits, contributed much to the more rapid and more general reception of the Copernican views. Such analogies also remind us of the repetition of form and position which are often presented to us in organic life.

The distribution of the satellites comprised within the

solar domain is so unequal, that whilst, on the whole, the proportion of the primary planets which have no such attendants to those which are so accompanied is as 3 to 5, the latter class, with the single exception of the Earth, all belong to the outer planetary group, situated beyond the intersecting orbits of the asteroids or small planets. The only satellite in the group of the inner planets situated between the Sun and the asteroids—viz. our Moon—is strikingly large in proportion to the diameter of its primary planet. This proportion is $\frac{1}{3} \cdot \frac{1}{8}$; whereas the largest of all the satellites of Saturn (the 6th, Titan) is probably only $\frac{1}{15} \cdot \frac{1}{5}$, and the largest of Jupiter's satellites (the 3d) $\frac{1}{25} \cdot \frac{1}{8}$ of their respective primaries. We must distinguish in this consideration between relative and absolute magnitude. Our Moon, which is *relatively* so large, is *absolutely* smaller than any of the four satellites of Jupiter; the diameter of the former being 454, and the diameters of the latter respectively 776, 664, 529, and 475 German geographical miles (or the Moon 1816, and Jupiter's satellites 3104, 2656, 2116, and 1900 English geographical miles). The magnitude of the 6th satellite of Saturn differs very little from that of the planet Mars (the diameter of which is 892 German, or 3568 English geographical miles) (540). If the question of telescopic visibility depended solely on the diameter of the satellite, and was not also conditional on the proximity to the disk of its primary planet, and the remoteness and nature of its light-reflecting surface, we should have to regard the 1st and 2d of Saturn's satellites (Mimas and Enceladus), and two of the satellites of Uranus, which have been repeatedly seen, as the smallest of

all known satellites. It is, however, safer to designate them merely as the smallest luminous points. At present there appears more reason to believe that the smallest of all planetary bodies, meaning thereby both primary planets and satellites, are to be sought for among the small or telescopic planets (⁵⁴¹).

The density of satellites is by no means always inferior to that of their primary planets, as is the case in our Moon (whose density, compared to that of the Earth, is as 0·619 to 1), and in Jupiter's 4th satellite. The densest of these satellites, the 2d, is, on the other hand, denser than Jupiter; while the 3d and largest appears to have the same density as the planet itself. Nor do the masses increase with the distance: if the planets have arisen from revolving rings, peculiar causes, which may perhaps ever remain hidden from us, must have occasioned in the various cases larger or smaller, and denser or rarer, accumulations around a nucleus.

The orbits of satellites belonging to the same group have very different excentricities. In the system of Jupiter, the orbits of the 1st and 2d satellites are almost circular; while of those of the 3d and 4th the excentricities amount to 0·0013 and 0·0072. In the system of Saturn, the orbit of the satellite which is nearest to the planet (Mimas) is considerably more excentric than the orbit of Enceladus, or than that of Titan, which has been so accurately determined by Bessel. The excentricity of this, the 6th satellite of Saturn, and the largest and earliest discovered, is only 0·02922. According to all these data, which are deserving of considerable confidence, Mimas is the only satellite whose orbit is more excentric than that of our Moon (0·05484).

Of all known satellites, the Moon is the one whose orbit is the most excentric as compared with that of the primary planet round which it revolves. (Respecting the distances of satellites from their central planets, see *Kosmos*, Bd. i. S. 102; Eng. ed. p. 88-89.) The distance of Saturn's nearest satellite, Mimas, is at present estimated not at 20022, but at 25600 German geographical miles (80088 and 102400 English); whence the resulting distance from Saturn's Ring is somewhat above 7000 German (28000 Eng.) geographical miles, reckoning the breadth of the Ring at 6047 German, or 24188 English, and the distance of the Ring from the surface of the planet 4594 German, or 18376 English, geographical miles⁽⁵⁴²⁾. The orbits of satellites present also remarkable anomalies in regard to position, though there is at the same time a certain agreement in this respect in the system of Jupiter, whose satellites all move very nearly in the plane of the equator of their central planet. In the group of Saturn's satellites, 7 revolve nearly in the plane of the Ring, while the outermost or 8th, Japetus, is inclined $12^{\circ} 14'$ to that plane.

In these general considerations respecting the planetary spheres, we have descended from the higher (probably not the highest) system⁽⁵⁴³⁾—that of the Sun—to the subordinate partial systems of Jupiter, Saturn, Uranus, and Neptune. As a tendency to generalisation is, as it were, inborn in thoughtful and imaginative man,—as an unsatisfied cosmical anticipation seems to present to him, in the movement of translation of our solar system in space⁽⁵⁴⁴⁾, the idea of an ascending relation and subordination; so, on the other hand, the possibility has been suggested that Jupiter's satellites

may be in their turn the central bodies, around which revolve other secondary cosmical bodies which remain unseen by reason of their smallness. Thus individual members of the partial systems, which are principally found in the outer group of primary planets, would have other similar systems subordinated to them. Man's love of systematic arrangement is, it is true, gratified by repetitions of form in descending or ascending order, in images which are the creatures of his own fancy; but in severer and more earnest investigations it is forbidden to confound an ideal with the actual Cosmos, or to mingle the possible with the more sure results of observation.

SPECIAL NOTICE OF THE SEVERAL PLANETS AND THEIR SATELLITES AS PARTS OF THE SOLAR DOMAIN.

THE especial object of a physical description of the Universe is, as I have already remarked, the assemblage, both in the sidereal and telluric range of phenomena, of all the most important numerical results resting on adequate and accurate investigation up to the present time—viz. the middle of the nineteenth century. The forms and the movements of the physical Universe are here depicted as Created, Existing, Measured. Neither the bases on which the obtained numerical results repose,—nor the cosmogonic conjectures which, in the varying states of mechanical and physical knowledge, have arisen in different ages respecting the mode of formation,—nor questions relating to the mysterious act of Creation itself,—belong, in a strict sense, to the domain of these empirical deductions (Kosmos, Bd. i. S. 29—31, 63, and 87 ; Eng. ed p. 30—33, 57, and 75).

The Sun.

I have stated in the preceding pages (Bd. iii. S. 378—405 ; Eng. ed. p. 267—295) both the numerical results and the views now prevailing respecting the physical constitution of the central body of our system. It only remains to give, from observations made since those pages were written, some

additional remarks on the red or roseate appearances referred to in pages 278—280 of the English translation. The important phenomena presented by the solar eclipse of the 28th July, 1851, which was total in the East of Europe, have added fresh force to the opinion expressed by Arago in 1842, that the red mountain- or cloud-like projections on the margin of the darkened solar disk belong to the gaseous outermost envelope of the Sun (⁵⁴⁵). These projections were gradually *uncovered* by the receding west limb of the Moon as that body continued its course to the eastward (Annuaire du Bureau des Longitudes pour 1852, p. 457), and, on the other hand, disappeared on the opposite side as they were gradually *covered* by the advancing eastern limb of the Moon.

The intensity of the light of these marginal projections was so considerable that it was possible to recognise them in the telescope through thin veiling clouds, and even with the naked eye within the corona.

The shape of some of these mostly ruby- or peach-red forms was seen to undergo rapid and sensible alteration during the short continuance of the total eclipse: one of the projections appeared bent at the top, and showed itself to many observers as an overhanging column of smoke in proximity to a freely suspended detached cloud (⁵⁴⁶). The elevation of the projections was estimated for the most part at from 1' to 2': in one case it seems to have been even greater. Besides these pointed elevations, of which from three to five were counted, there were also seen long, narrow, crimson-coloured bands, often dentated at the edges, appearing as if resting against the margin of the Moon (⁵⁴⁷).

The part of the Moon's limb which was not projected on the Sun's disk (⁵⁴⁸) was again most distinctly seen.

Near the part of the Sun's margin where the largest overhanging red gibbosity appeared, a group of solar spots was visible,—situated, however, a few minutes distant from the margin. On the opposite side, not far from the faint easternmost marginal projection, there was also a solar spot near the Sun's limb. The actual distances, however, implied by the few minutes of space on the Sun's disk here spoken of, would oppose our assuming that the funnel-shaped openings or depressions indicated by the spots furnished the matter for these red gaseous exhalations; but since the entire surface of the Sun, when viewed with strong magnifying powers, shows visible punctures or pores, there is the greatest probability in favour of the opinion, that the same exhalations of vapour or gas which, in ascending from the body of the Sun, produce the funnel-shaped openings seen by us as solar spots (⁵⁴⁹), issue forth either through these openings or through the pores, and being illuminated by the photosphere, present to our view variously-shaped roseate clouds or columns of vapour in the third or outermost solar envelope.

Mercury.

If we remember how much, from the earliest times, the Egyptians (⁵⁵⁰) were occupied with the planet Mercury (Set—Horus), and the Indians with their Budha (⁵⁵¹),—how, under the clear sky of Western Arabia, the star-worship of the tribe of the Asedites (⁵⁵²) was directed exclusively to Mercury,—and that Ptolemy, in the 9th book of the *Almagest*, was even able to avail himself of fourteen observations of that planet, extending back to 261 years before our era, and belonging in part to the Chaldeans

(553),—we shall be surprised that Copernicus, who lived to attain his 70th year, should have had to complain on his death-bed that, much as he had tried, he had never seen Mercury. Nevertheless, the Greeks designated this planet, and justly so, “the strongly sparkling” (*σπιλβων*) (554), on account of its occasional intense light. Like Venus, it presents to us phases or varying forms in its illuminated portion; and appears to us sometimes as a morning, and sometimes as an evening star.

Mercury, at its mean solar distance, is little more than 8 millions of German, or 32 millions English, geographical miles from the Sun, being exactly 0·3870938 parts of the Earth’s mean distance from the Sun. From the great eccentricity of its orbit (0·2056163), the distance of Mercury from the Sun is, in perihelion, $6\frac{1}{4}$, and in aphelion 10 millions of German geographical miles (25 and 40 millions English). It completes its revolution round the Sun in 87 mean terrestrial days, 23 hours, 15 minutes, and 46 seconds. By the somewhat uncertain observations of the shape of the southern horn of the sickle, and by noticing a dark streak which was blackest towards the east, Schröter and Harding estimated its time of rotation at 24 hours 5 minutes.

According to Bessel’s determinations made on the occasion of the transit of Mercury on the 5th of May, 1832, its true diameter is 671 German, or 2684 English geographical miles (555)—*i. e.* 0·391 parts of the Earth’s diameter.

The mass of Mercury was assigned by Lagrange from very hazardous assumptions respecting the reciprocities of ratios of densities and distances. Encke’s comet of short period first afforded a means of correcting this

important element. Encke has determined the mass of Mercury at $\frac{1}{4865751}$ of the Sun's mass, and about $\frac{1}{13.7}$ of that of the Earth. Laplace, in accordance with Lagrange, had made $\frac{1}{2025810}$, but the true mass is only about $\frac{1}{14}$ ths of that quantity. This correction refutes at the same time the previous hypothetical statement of the rapid increase of planetary density with increasing proximity to the Sun. If, with Hansen, we take the volume of Mercury at $\frac{6}{100}$ ths of that of the Earth, the resulting density of Mercury, as compared to that of the Earth, is only as 1.22 : 1. "These determinations," adds my friend, their author, "are only to be considered as first attempts, which, however, approximate much more nearly to the truth than Laplace's assumption." Ten years ago, the density of Mercury was still assumed to be almost three times greater than that of the Earth (2.56 or 2.94), that of the Earth being = 1.00.

Venus.

The mean distance of Venus from the Sun is 0.7233317 in parts of the Earth's solar distance, or 15 German or 60 English millions of geographical miles. The sidereal or true period of revolution of Venus is 224 days, 16 hours, 49 minutes, 7 seconds. No other planet approaches so near to the Earth as does Venus: it may approach us within $5\frac{1}{4}$ German, or 21 English, millions of geographical miles; but it may also be as remote as 36 German, or 144 English, millions of geographical miles: and hence the great variability of its apparent diameter, but which by no means determines solely the intensity of its brightness⁽⁵⁵⁷⁾. The excentricity of Venus's orbit is only 0.00686182, expressed

in parts of the semi-major axis. The diameter of this planet is 1694 German, or 6776 English, geographical miles; its mass $\frac{1}{401839}$; its volume 0.957, and its density 0.94, as compared to the Earth.

Of the transits of the two inferior planets, first announced by Kepler in his Rudolphine Tables, it is that of Venus which, by the aid it affords towards the determination of the Sun's parallax and the distance of the Earth from the Sun thence derived, is most important in its bearings on the theory of the entire planetary system. According to Encke's complete investigation of the transit of Venus which happened in 1769, the Sun's parallax is $8''.57116$ (Berliner Jahrbuch für 1852, S. 323). On the proposal of a distinguished mathematician—Professor Gerling, of Marburg—since 1849, a new investigation respecting the Sun's parallax has been undertaken by the orders of the Government of the United States of North America. It is designed to obtain the parallax by means of observations of the planet Venus near its eastern and western elongation, as well as by micrometric measurements of the differences in Right Ascension and Declination of well-determined fixed stars, made at places on the Earth's surface differing considerably in latitude and longitude (Schum. Astr. Nachr. No. 599, S. 363; and No. 613, S. 193). The astronomical expedition charged with the prosecution of this undertaking, and which is commanded by a highly-informed officer—Lieutenant Gilliss, of the United States Navy—has proceeded to Santiago de Chile.

The rotation of Venus upon its axis was long the subject of many doubts. Dominique Cassini, in 1669, and Jacques Cassini, in 1732, found 23 hours 20 minutes as its period;

while Bianchini (⁵⁵⁸) at Rome, in 1726, assumed the slow rotation of $24\frac{1}{2}$ days. The more exact observations of De Vico, in the years 1840—42, have given from the mean of a great number of “spots of Venus,” 23 hours, 21 minutes, 21.93 seconds.

These spots, which appear on the boundary dividing the illuminated from the shaded portion of the planet when Venus appears as a bow, are seen only rarely, and are faint and for the most part variable; so that both the Herschels, father and son, have believed them to belong, not to the solid surface of the planet, but more probably to an atmosphere surrounding it (⁵⁵⁹). The variable shape of the horns of the bow, especially of the southern, has been used by La Hire, Schröter, and Mädler, partly for estimating the heights of the mountains, and partly and more particularly for determining the rotation. The phenomena are not such as to require for their explanation such elevations as were assumed by Schröter at Lilienthal—of 5 German, or 20 English, geographical miles; but, on the contrary, only such altitudes as the mountains of our own globe present in both continents (⁵⁶⁰). In the little that we know of the aspect of the surfaces or of the physical constitution of the two planets nearest to the Sun (Mercury and Venus), an exceedingly curious enigma is presented by the appearance of an ash-coloured light, or an evolution of light not derived from any other body, which has been occasionally observed on the dark part of Venus by Christian Mayer, William Herschel (⁵⁶¹), and Harding. The great distance renders it unlikely that the reflected light of the Earth should be the cause in Venus as it is in the Moon.

No compression at the poles has yet been observed

in either of the two inferior planets—Mercury or Venus.

Earth.

The mean distance of the Earth from the Sun is 12032 times greater than the Earth's diameter—therefore 20682000 German, or 82728000 English, geographical miles, this quantity being considered uncertain to about 90000 German, or 360000 English, geographical miles, or $\frac{1}{230}$ th of its amount. The time of the sidereal revolution of the Earth round the Sun is 365^d. 6^h. 9^m. 10^s. 7496. The excentricity of the Earth's orbit amounts to 0.01679226, its mass is $\frac{1}{359551}$, and its density in proportion to water is as 5.44 to 1. Bessel's investigation of ten measurements of degrees gave the terrestrial ellipticity $\frac{1}{299153}$; the length of a German geographical mile of 15 to a degree at the equator 3807.23 toises; and the equatorial and polar diameters respectively 1718.9 and 1713.1 such miles, or 6875.6 and 6852.4 English geographical miles (Kosmos, Bd. i. S. 421, Anm. 100; Eng. ed. p. xlii. Note 130). I confine myself here to numerical data of figure and motion; all that relates to the physical constitution of the Earth is reserved for the last—*i. e.* the telluric portion of the Cosmos.

The Earth's Satellite.

The mean distance of the Moon from the Earth is 51800 German, or 207200 English, geographical miles; its sidereal period of revolution 27 days, 7 hours, 43 minutes, and 11.5 seconds; the excentricity of its orbit 0.0548442; its diameter 454 German, or 1816 English, geographical miles,

being nearly $\frac{1}{4}$ of the Earth's diameter; its volume $\frac{1}{54}$ th of that of the Earth; its mass, according to Lindenau, $\frac{1}{87.73}$ (according to Peters and Schidloffsky, $\frac{1}{81}$) of the mass of the Earth; and its density 0.619, or almost $\frac{2}{3}$ ths the density of the Earth. The Moon has no sensible flattening at the poles, but has an extremely small elongation or swelling towards the Earth (the amount of which is determined by theory). The rotation of the Moon round its axis is performed (as is probably the case with all satellites in reference to their respective primary planets) in exactly the same time as that in which it completes its revolution round the Earth.

The solar light reflected from the surface of the Moon is in every zone fainter than the solar light reflected in the daytime from a white cloud. When taking lunar distances from the Sun for determinations of geographical longitude, it is not unfrequently found difficult to distinguish the Moon's disk among the more intensely illuminated cumuli. On mountains between thirteen and seventeen thousand feet high, where, in the clearer mountain air, only light, feathery cirrous clouds are to be seen, I found it much easier to distinguish the Moon's disk, both because cirrus from its slighter texture reflects less of the Sun's light, and the light of the Moon loses less in passing through thin atmospheric strata. The ratio of the intensity of the Sun's light to that of the full moon deserves a fresh investigation, as Bouguer's generally received determination ($\frac{1}{300000}$) differs so strikingly from the indeed more improbable one of Wollaston ($\frac{1}{800000}$) (562).

The yellow light of the Moon appears white by day, because the strata of air through which we see it being blue, present the complementary colour to yellow (563). Accord-

ing to the many and various observations made by Arago with his polariscope, the light of the Moon contains polarised light, which is most distinctly traceable during the first quarter of the Moon and in the grey spots on its surface : for example, in the large, dark, sometimes somewhat greenish, wall-surrounded plain called the Mare Crisium. Such plains are mostly traversed by long low ridges of hills, offering those angles of inclination of the surface which are required for the polarisation of the reflected solar light. The dark tone of colour of the adjacent parts seems, moreover, to render the phenomenon still more sensible by contrast. As regards the shining central mountain of the group called Aristarchus, on which observers have repeatedly imagined that they saw volcanic action taking place, it showed no stronger polarisation of light than did other parts of the Moon's surface. In the full moon no mixture of polarised light was perceived ; but during a total lunar eclipse (31st May, 1848) Arago remarked undoubted signs of polarisation in the reddened disk of the Moon,—a phenomenon of which we shall have occasion to speak presently (*Comptes rendus*, T. xviii. p. 1119).

That the light of the Moon does produce heat is (like so many others due to my celebrated friend Melloni) among the most important and most surprising discoveries of our century. After many unsuccessful attempts, from La Hire to those of the acute Forbes (⁵⁶⁴), Melloni, by means of a lens (*lentille à échelons*) of three feet diameter, made for the Meteorological Institution on the Cone of Mount Vesuvius, succeeded, in different phases of the Moon, in observing most satisfactory indications of an elevation of temperature. Mosotti, Lavagna, and Belli, Professors of the Universities

of Pisa and Pavia, witnessed these experiments, the results of which varied according to the Moon's age and altitude. To what amount, expressed in fractional parts of the centigrade thermometer, the increase of temperature produced in Melloni's thermoscopic pile corresponded, had not then (in the summer of 1846) been examined (⁵⁶⁵).

The ashy grey light seen on the Moon's disk, when for some days before and after the new moon the part illuminated by the Sun is only a narrow bow, is earthlight on the Moon—"the reflection of a reflection." The less the Moon appears illuminated as viewed from the Earth, the more illuminated is the Earth as viewed from the Moon. But the earthlight received on the Moon is $13\frac{1}{2}$ times stronger than the moonlight received on the Earth, and is bright enough to be perceived by us on a second reflection. In this faint light the telescope can distinguish both the larger spots, and also bright shining points—mountain-summits in the lunar landscapes; and, even when more than half the Moon's disk reflects to us the full illumination of the Sun, a faint grey light can still be seen on the remaining portion by the aid of the telescope (⁵⁶⁶). These phenomena are particularly striking when viewed from the high mountain plateaus of Quito and Mexico. Since Lambert's and Schröter's writings, the opinion has prevailed, that the very various degrees of intensity of the grey light of the Moon at different times proceed from the stronger or fainter return of the solar light from the surface of the Earth, according as this is reflected from connected continental masses full of sandy or rocky deserts, grassy steppes, and tropical forests, or from extensive oceanic surfaces. Lambert, on the 14th of February, 1774, made,

with a comet-finder having a very light field, the remarkable observation of a change of the grey or ashy light of the Moon into an olive-green colour, verging somewhat towards yellow. The moon, which then stood vertically over the Atlantic Ocean, received on its nocturnal side the green earthlight sent to it in a cloudless sky from the forest-covered regions of South America (⁵⁶⁷).

The meteorological state of our atmosphere modifies the intensity of this earthlight, which has to traverse the double path from the Earth to the Moon, and from the Moon again to our eyes. "Thus," as Arago has remarked (⁵⁶⁸), "when at some future day better photometric instruments shall be employed, we shall be able to read, as it were, in the Moon the *mean state* of transparency of our atmosphere." The first correct explanation of the nature of the ashy light of the Moon was given in a letter written by Kepler (*ad Vitellionem Paralipomena quibus Astronomiæ pars optica traditur*, 1604, p. 254) to his highly venerated former instructor Mästlin, and put forward by the latter in 1596, on the occasion of the thesis publicly defended at Tübingen. Galileo (in the *Sidereus Nuncius*, p. 26) spoke of the reflected earthlight as of a thing which he had himself discovered several years before; but in reality, a hundred years prior to Kepler and Galileo, the true explanation of the earthlight visible to us on the Moon had not escaped the all-embracing genius of Leonardo di Vinci. His long-forgotten manuscripts have afforded the proof of this (⁵⁶⁹).

In total lunar eclipses it happens in some exceedingly rare cases that the Moon disappears wholly: it did so, according to Kepler's earliest observation (⁵⁷⁰), on the 9th of

December, 1601 ; and in more recent times, on the 10th of June, 1816, in London, when it could not be discerned even with telescopes. A peculiar, not sufficiently explained, state of the several strata of the atmosphere in regard to transparency must be the cause of this equally rare and curious phenomenon. Hevelius remarks expressly, that, in a total eclipse on the 25th of April, 1642, the sky was covered with sparkling stars, the air being perfectly clear, and yet, with the very various magnifying powers which he employed, the Moon's disk continued without a trace of visibility. In other also very rare cases, only some portions of the Moon are faintly visible. In ordinary cases the disk appears, during a total eclipse, of a reddish hue, the colour being, indeed, of the most various degrees of intensity, passing even, when the Moon is far removed from the Earth, into a fiery glowing red. Whilst, more than half a century ago (29th of March, 1801), I was lying at anchor off the Island of Baru, not far from Cartagena de Indias, and observing a total lunar eclipse, I was exceedingly struck by seeing how much brighter the reddened disk of the Moon appears in the sky of the tropics than in my northern native land (⁵⁷¹). The whole phenomenon is known to be the result of the refraction of the rays, since, as Kepler very correctly expresses it (*Paralip. Astron. pars optica*, p. 893), the Sun's rays are inflected in their passage through the Earth's atmosphere (⁵⁷²), and thrown into the cone of shadow. The disk, whether it be of paler or darker red, is never uniform in colour throughout. Some parts always show themselves of deeper tint than others, and the change of colour takes place progressively. The Greeks had a peculiar theory

respecting the colours which the darkened moon should exhibit, according to the different hours at which the eclipse commences (573).

In the long-continued controversy respecting the probability or improbability of an atmospheric envelope to the Moon, exact observations of occultations of stars have shown that no refraction takes place at the Moon's edge; and Schröter's assumptions (574) of a lunar atmosphere and lunar twilight are thus refuted. The comparison of the two values which may be derived for the Moon's semi-diameter, on the one hand from direct measurement, and on the other from the duration of the occultation of a fixed star, (*i. e.* the length of time which the Moon takes to pass over the star), shows that, at the moment when the Moon's limb comes in contact with the star, the starlight is not deflected from its rectilinear course by an amount sensible to our eyes. If there were refraction at the margin of the Moon's disk, the second determination of the semi-diameter must come out less than the first by twice the amount of such refraction; whereas it has been found, by repeated trials, that the two determinations agree so nearly that it has not been possible to find any decided difference between them (575). The immersion or disappearance of a star behind the Moon, which can be observed with particular precision on the dark margin, takes place suddenly, and without any gradual diminution of the star's brightness; and the same is the case with the emersion or reappearance of a star. The few exceptions which have been remarked may have had for their cause accidental changes in our own atmosphere.

If, then, the Moon is without any gaseous envelope, the

entire absence of any diffused light must cause the heavenly bodies, as seen from thence, to appear projected against a sky *almost black* in the daytime (576). No undulation of air can there convey sound, song, or speech. The Moon, to our imagination which loves to soar into regions inaccessible to full research, is a desert where silence reigns unbroken.

The phenomenon which is sometimes remarked in occultations of stars by the Moon, of a pausing or "cleaving" of the star to the Moon's limb or margin (577), cannot well be regarded as a consequence of the "irradiation," which, from the great difference in the intensity of their light, causes the part of the Moon illuminated directly by the Sun, when only a narrow bow, to appear to the eye as if it encompassed the remaining dark portion. In a total lunar eclipse Arago saw most distinctly a star cleave during the conjunction to the dimly-illuminated red disk of the Moon. Whether the phenomenon here alluded to is to be regarded as the effect of physiological causes (578), or of aberration arising from the refrangibility and sphericity of the eye (579), is still a subject of discussion between Arago and Plateau. The cases in which it is affirmed that in an occultation a disappearance and a reappearance, and then again a disappearance, have been seen, may very well indicate an outline of the moon accidentally deformed by mountain precipices and deep chasms.

The great differences visible in the reflected light in different parts of the illuminated lunar disk, and especially the irregularity of the line which separates the illuminated from the unilluminated portion of the disk in phases intermediate between new and full moon, gave occasion in very early times to the formation of intelligent views respecting

the inequalities of the surface of our satellite. Plutarch, in his small but very remarkable treatise on "the Face in the Moon," says expressly, that in the spots which we see we may surmise the existence partly of deep clefts and valleys, and partly of mountain summits "which cast long shadows like Mount Athos, whose shadow reaches to Lemnos" (580). The spots cover about two-fifths of the whole disk. Under favourable circumstances of the Moon's position and the state of the atmosphere, it is quite possible to distinguish with the naked eye the ridges of the Apennines, the dark wall-surrounded plain of Grimaldi, the detached Mare Crisium, and Tycho, with the mountain-ridges and craters crowded around it (581). It has been said, not without probability, that it was in particular the aspect of the Apennine chain which occasioned the Greeks to regard the spots in the Moon as mountains, and, as has just been remarked, to refer in connection therewith to the shadow of Mount Athos, which, at the solstice, reached to the Brazen Cow in Lemnos. Another very fanciful opinion respecting the spots on the Moon was that of Agesianax, contested by Plutarch, according to which the Moon's disk was supposed to reflect back to us catoptrically, as in a mirror, the forms and outlines of our continents and of the "outer (Atlantic) Sea." An opinion quite similar to this seems to have continued as a popular belief in Western Asia to the present day (582).

By the careful employment of large telescopes we have gradually succeeded in obtaining a topographical representation of the Moon based on actual observation; and, as in Opposition, the whole of one side of the Earth's satellite presents itself to our examination, we know more of the

general and simply superficial configuration of the mountain-groups of the Moon, than we do of the orography of the half of the Earth's surface, which comprises the interior of Asia and Africa. Generally speaking, we regard the darker parts of the Moon's disk as the plains and depressions, and the brighter parts, which reflect most solar light, as the more elevated and mountainous parts. Kepler's old denomination of sea and land has long been given up; and even Hevelius, notwithstanding the similar nomenclature to which he gave currency, already doubted the correctness of such an interpretation, and the truth of the contrast it implied. The circumstance that, on careful examination with very different illumination, all parts of the so-called lunar "seas" have shown themselves completely uneven, and because polyhedric, or full of angles, therefore giving much polarised light, has been adduced as being particularly at variance with the supposition of the presence of liquid surfaces. Arago has noticed, however, in regard to this reasoning, that some of these surfaces might, notwithstanding their inequalities, belong to a not over-deep sea-bottom covered with water; since in our own planet we find that the uneven rocky bed of the ocean can be distinctly seen on looking down from a great height, because the intensity of the light which ascends from below surpasses that of the light which is radiated from the surface of the sea (*Annuaire du Bureau des Longitudes pour 1836*, p. 339—343). In the forthcoming work of my friend—his "Astronomy and Photometry"—the probable absence of water on the surface of our satellite will be deduced from other optical reasons which we do not enter upon here. Of the low "plains," the largest are in the northern and eastern parts of the Moon's disk. Among

them, the not very definitely bounded Oceanus Procellarum has the greatest extent (90000 German geographical square miles). In connection with the Mare Imbrium (16000 German square miles), the Mare Nubium, and in some degree with the Mare Humorum, and inclosing insular highlands (the Riphæan Mountains, Kepler, Copernicus, and the Carpathians), the eastern darker portion of the Moon's surface forms the most decided contrast with the more brightly beaming south-western region, in which mountain is crowded against mountain (583). In the north-western region there are two more detached and isolated basins—the Mare Crisium (3000 German geographical square miles), and the Mare Tranquillitatis (5800 such miles).

The colour of these so-called seas is not always grey. The Mare Crisium has a grey tint mixed with dark green, and the Mare Serenitatis and Mare Humorum are likewise green. Near the Hercynian Mountains, the isolated part inclosed within the circumvallation called Lichtenberg, has, on the other hand, a pale-red tint; and so, also, has Palus Somnii. Annular depressions without central mountains have most often a dark steel-grey tint verging towards bluish. The causes of these different tints of colour in the rocky or other less coherent substances forming the surface, are exceedingly enigmatical.

A great wall-surrounded plain called Plato (by Hevelius, Lacus niger major), on the north of the "Alps," and still more, Grimaldi in the equatorial region, and Endymion, near the north-western margin, are the three darkest places in the whole lunar disk; and the brightest of all is Aristarchus, of which, when it is on the portion of the Moon not

otherwise directly illuminated by the Sun, the points sometimes shine almost like stars. All these alternations of light and shade affect an iodized plate, and, with strong magnifying powers, are represented on Daguerreotypes with admirable fidelity. I possess myself such a light-picture of the Moon, of two inches' diameter, in which the so-called seas and annular mountains are clearly recognised: it was prepared by a distinguished artist, Mr. Whipple, of Boston.

If, in some of the "seas" (Crisium, Serenitatis, and Humorum) we are struck with the circular form, we find the same repeated still more frequently, and indeed almost universally, on the mountainous part of the Moon's disk, particularly in the configuration of the enormous masses of mountain which fill the southern hemisphere from the pole nearly to the equator, where the mass terminates in a point. Many of the annular mountains and wall-surrounded plains (the largest containing, according to Lohrmann, above a thousand square miles) form connected series running in the direction of meridians, between 5° and 40° South latitude (584). The northern polar region contains comparatively a very small proportion of these crowded mountain rings; but between 20° and 50° North latitude, near the western margin of the northern half of the Moon's disk, they form a connected group. The Mare Frigoris approaches to within a few degrees of the North Pole itself; and thus this part, like the whole of the level north-eastern space, inclosing only a small number of isolated annular mountains, (Plato, Mairan, Aristarchus, Copernicus, and Kepler), presents a great contrast to the more mountainous Southern Pole. Near the latter, lofty summits shine, in the

strictest sense of the words, throughout whole lunations in “perpetual light;” they are truly “islands of light,” and can be recognised with very low magnifying powers (585).

As exceptions to the generally prevailing lunar type of circular and annular forms, we find, almost in the middle of the northern half of the Moon’s disk, some true mountain-chains (Apennines, Caucasus, and Alps). They range nearly from south to north, through almost 32° of latitude, in the form of a very flattened bow a little curved towards the west. Here we see countless mountain ridges, and some exceedingly pointed summits crowded together. Only a few annular mountains and crater-like depressions (Conon, Hadley, and Calippus) are interspersed, and the whole resembles more nearly the conformation of our terrestrial mountain-chains. The lunar Alps, which are inferior in elevation to the lunar Caucasus and Apennines, present a remarkably broad cross valley, which intersects the chain from S.E. to N.W. It is surrounded by summits which surpass in altitude the Peak of Teneriffe.

A comparison between the elevations on the Moon and on the Earth, viewed relatively to the diameters of the two bodies, gives the remarkable result, that while the satellite is four times less than the planet, its highest summits are only 600 toises (3837 Eng. feet) lower than the highest summits of the Earth; so that the lunar mountains are $\frac{1}{454}$ of the Moon’s diameter, and the terrestrial mountains $\frac{1}{1481}$ of that of the Earth. Of the 1095 elevations which have been measured on the Moon, I find 39 which are higher than Mont Blanc, and 6 above 18000 Paris feet (19184 English). The measurements are made either by determining the distance, reckoned from the limit

between the bright and dark parts of the Moon, of the illuminated mountain summits appearing as points of light on the dark part, or by the length of the shadows. The first method was that employed by Galileo, as is evident from his letter to Pater Grienberger on the *Montuosità della Luna*.

According to Mädler's careful determinations made by measuring the lengths of the shadows, the culminating points of the Moon near the southern margin, very near to the pole, are, in descending series — Dörfel and Leibnitz, 3800 toises (24300 English feet); the annular mountain, Newton, where a part of the deep excavation is never shone upon either by the light of the Sun or that of the Earth, 3569 toises (22822 Eng. feet); Casatus, east of Newton, 3569 toises (22822 Eng. feet); Calippus, in the Caucasus chain, 3190 toises (20400 Eng. feet); and the Apennines between 2800 and 3000 toises (17900 and 19180 Eng. feet). It must here be remarked, that, from the total want of a general zero line of level (a plane equidistant from the centre of the body, like the surface of the sea in our own planet), the absolute heights are not strictly intercomparable: the six numerical results given above express, properly speaking, only the differences between the summits and the nearest plains or low points⁽⁵⁸⁷⁾. It is certainly a striking circumstance that Galileo attributed to the highest mountains in the Moon an elevation of "incirca miglia quatro"—about four geographical miles of 60 to the terrestrial equatorial degree, or 3800 toises, the height actually assigned above to the lunar mountains Dörfel and Leibnitz. According to the hypsometric knowledge possessed by him, Galileo estimated this height as superior to that of any terrestrial mountain.

An exceedingly curious and enigmatical phænomenon in the surface of our satellite, and one which seems to belong to an optical effect of luminous reflection, and not to a hypsometric difference, is presented by the narrow streaks of light which disappear in an oblique illumination, and, contrary to the lunar spots, are most visible in the full moon. These streaks form radiating systems. They are not lines of mountains, they do not cast any shadows, and they run in uniform intensity of light from the plains to elevations twelve or thirteen thousand feet and upwards. The most extensive of these radiating systems is that which proceeds from Tycho, and in which more than a hundred streaks of light, mostly of several miles in breadth, can be distinguished. Similar systems, surrounding Mounts Aristarchus, Kepler, Copernicus, and the Carpathians, are almost all connected with each other. It is difficult to conjecture from analogy or induction what is the particular alteration of surface which occasions these bright shining bands, radiating from particular annular mountains.

The circular type—which we have already noticed as prevailing almost everywhere upon the Moon's surface, (in the wall-surrounded plains which often inclose central mountains, and in the great annular mountains and their craters, of which 22 have been counted in Bayer, and 33 in Albategnius, crowded closely together)—gave occasion to the profound thinker, Robert Hooke, to seek for the cause of this phenomenon in the reaction of the interior of the Moon against its exterior; or, as he expressed it, as “the effect of subterranean fires and elastic vapours breaking forth even to ebullition, sending up to the surface bubbles or blisters.” Experiments by boiling thick calcareous solu-

tions appeared to him to confirm his view ; and the circumvallations with their central mountains were compared by him to “ the forms of Etna, the Peak of Teneriffe, Hecla, and the volcanoes of Mexico described by Gage” (588).

Galileo, as he himself relates, had been reminded, by a circular wall-surrounded plain in the Moon (probably from its magnitude), of the configuration of entire countries surrounded by mountains. I have found a passage (589) in which he compares these lunar forms with the great closed basin of Bohemia. In fact, several of the circular wall-surrounded plains of the Moon are but little less extensive, for they have diameters of from 25 to 30 German geographical miles (100 to 120 English) (590). On the other hand, the proper annular or ring mountains scarcely exceed 2 or 3 German (8 to 12 Eng.) geographical miles in diameter. Conon in the Apennines is 8 English geographical miles across ; and a crater belonging to the brightly shining district of Aristarchus has even a diameter of only 400 toises (or about 450 yards), just half the breadth of the crater of Ruchu-Pichincha in the mountains of Quito, measured trigonometrically by myself.

As we are here dwelling on comparisons with well-known terrestrial phenomena and dimensions, it is the proper place to remark that in this view the greater part of the wall-surrounded plains and annular mountains of the Moon may be most directly regarded as “ craters of elevation, without continuous phenomena of eruption,” in the sense of Leopold von Buch’s geological hypothesis. What, according to the European standard, is called large on the terrestrial surface—the craters of elevation of Rocca Monfina, Palma, Teneriffe, and Santorin—are indeed altogether inconsiderable as

compared with Ptolemy, Hipparchus, and many other lunar forms. In breadth, Palma is only 3800 toises (24300 Eng. feet); Santorin, according to Captain Graves's recent determination, 5200 toises (33250 Eng. feet); and Teneriffe, at the utmost, 7600 toises (48600 Eng. feet), or only $\frac{1}{3}$ th or $\frac{1}{4}$ th of the breadths of the two above-named lunar craters. The small craters of the Peak of Teneriffe and Vesuvius (little more than three or four hundred feet in diameter) would hardly be discernible through telescopes. In by far the greater number of cases the annular mountains are destitute of any central mount; and, where such exist, they are described as dome-shaped or flattened (as Hevelius and Macrobius), not as cones of eruption with openings (⁵⁹¹). I here mention, solely on account of the historical interest which may attach to them, the accounts given of the burning volcanoes supposed to have been seen on the dark side of the Moon on the 4th of May, 1783, and the luminous appearances in Plato observed by Bianchini (16th Aug. 1725) and by Short (22d April, 1751). The causes of the illusion have long since been ascertained. They belong to the more vivid earth-light reflected by particular portions of the surface of our planet upon the dark side of the Moon (⁵⁹²).

It has been remarked, and doubtless with much reason, that, from the absence of water on the moon—(the “rills,” which are very narrow, and in most cases rectilinear depressions (⁵⁹³), are not rivers)—we may imagine its surface to bear a general resemblance to that of the Earth in its primitive or more ancient condition, before the deposit of shelly sedimentary strata, or the formation, transportation, and distribution of alluvium by the continued action

of tides and currents. (The absence of seas in the Moon forbids the supposition of tides raised by the Sun and Earth.) The most that we can suppose would be small deposits of detritus resulting from friction. In our mountain-chains upheaved over fissures, we are also gradually beginning to recognise here and there partial groupings of elevations, forming, as it were, egg-shaped basins. How entirely different would the Earth's surface appear to us, if we saw it stripped of the sedimentary and tertiary formations, and of all alluvial deposits !

The Moon, far more than all the other planetary bodies, diversifies and enlivens the aspect of the firmament in every zone by its varying phases and more rapid change of position relatively to the fixed stars ; while man, and even the beasts of the forest (⁵⁹⁴) (especially in the primeval forests of the torrid zone), rejoice in its mild lustre. By the attracting force which it exerts in conjunction with the Sun it communicates motion to our seas, and, by the periodical raising of their surfaces and the eroding action of the tides, gradually modifies the outlines of our coasts, impedes or favours man's labours, and furnishes the greater part of the materials of which sandstones and conglomerates are composed, these last being again covered in their turn by the loose rounded particles which form alluvium (⁵⁹⁵). Thus the Moon, as one of the "sources of movement" on the terrestrial surface, influences continually the geognostic features of our planet.

The incontestible action (⁵⁹⁶) of our satellite on atmospheric pressure, aqueous precipitations, and the dispersion of clouds, will be treated of in the latter and purely telluric portion of the Cosmos.

Mars.

The diameter of this planet is 892 German, or 3568 English geographical miles, (being only 0·519 of the Earth's diameter, notwithstanding its considerably greater solar distance). The excentricity of its orbit is 0·0932168; being, next to that of Mercury, the greatest among the old planets. This circumstance, together with its proximity to the Earth, rendered it the best adapted to lead to Kepler's great discovery of the elliptic orbits of the planets. The rotation of Mars (⁵⁹⁷) is, according to Mädler and Wilhelm Beer, 24 hours, 37 minutes, and 23 seconds. The sidereal period of revolution round the Sun is 1 year, 321 days, 17 hours, 30 minutes, 41 seconds. The inclination of the orbit of Mars to the terrestrial Equator is 24° 44' 24"; the mass of the planet $\frac{1}{2680337}$; and its density, in comparison with that of the Earth, 0·958. As the great approximation of Encke's comet was made use of for investigating the mass of Mercury, so the mass of Mars will some day be ascertained with greater accuracy by the perturbations which it may cause in the movements of De Vico's comet.

The compression of the planet Mars at its poles, which, singularly enough, was always doubted by the great astronomer of Königsberg, was first recognised by William Herschel in 1784. In respect to the amount of the ellipticity, however, uncertainty long prevailed. William Herschel gave it as $\frac{1}{16}$; according to Arago's more exact measurement (⁵⁹⁸) with a prismatic telescope of Rochon, it would be much less: in 1824 he found it as 189 : 194, or $\frac{1}{38}$; and, by a later measurement in 1847, it was found $\frac{1}{32}$. Arago, however, is inclined to believe that the com-

pression is somewhat greater than either of the two last-named quantities.

If the study of the surface of the Moon reminds us of many geognostical relations in the surface of our own planet, the analogies with the Earth which Mars presents are, on the other hand, entirely of a meteorological kind. On the disk of Mars (besides the dark spots, of which some are blackish, others—very few in number, however—orange⁽⁵⁹⁹⁾, and surrounded by what are called “seas”⁽⁶⁰⁰⁾ of the contrasted colour, green) at the two poles of the axis of rotation, or it may be at the poles of cold in their vicinity, are two white snow-bright patches⁽⁶⁰¹⁾. These were noticed as early as 1716 by Philip Maraldi; but their connection with climatic variations in the planet was first described by the elder Herschel in 1784, in the 74th volume of the Philosophical Transactions. The white spots become alternately larger or smaller as the pole approaches its winter or its summer. Arago has measured with his polariscope the intensity of the light of these snowy zones, and has found it twice as great as that of the light of the remainder of the disk. The “Physico-astronomical Contributions” of Mädler and Beer contain some excellent graphical representations⁽⁶⁰³⁾ of the northern and southern hemispheres of Mars, in which this remarkable phenomenon, unique so far as our knowledge extends in the entire planetary system, is shown in its relations of measure, in all the variations through which it passes under the influence of the change of seasons and the powerful action of the polar summer in melting the snow. Careful observations continued for ten years have also taught us that the dark spots of Mars retain constantly both their forms and their relative positions on the planet. The periodical enlarge-

ment of the snowy districts,—being a meteorological phænomenon implying aqueous precipitations dependent, as respects their character, on changes of temperature,—and some optical phænomena presented by the dark spots when the rotation of the planet brings them to the margin of the disk, render the existence of an atmosphere of Mars more than probable.

The Small Planets.

In the general considerations (⁶⁰³) on planetary bodies, we have already designated the group of the small planets (Asteroids, Planetoids, Coplanets, or telescopic or ultra-zodiacal planets) intermediate between Mars and Jupiter as a *middle group*, forming in some degree a *dividing zone*, separating the solar domain into an inner and an outer portion—the one comprising the four interior planets, Mercury, Venus, Earth, and Mars; and the other the four exterior planets, Jupiter, Saturn, Uranus, and Neptune. This middle group has a highly distinct character of its own, in the intricate or intersecting, highly inclined, and very excentric orbits of the planets of which it consists; and also in their extraordinary smallness, as the diameter even of Vesta does not appear to equal the fourth part of that of Mercury. When the first volume of Kosmos appeared in Germany in 1845, only 4 of the small planets—Ceres, Pallas, Juno, and Vesta, discovered by Piazzi, Olbers, and Harding (1st Jan. 1801 to 29th March, 1807)—were known to us. At the present moment (July 1851) the number has increased to 14, being one-third of the number of all the known planetary bodies—*i. e.* 43 primary planets and satellites.

Within the solar domain, the attention of observers was long directed to the augmentation of the members of partial systems (the moons or satellites revolving around the primary planets), and to the discovery of new planets in the remote regions beyond Saturn and Uranus. Since the accidental discovery of Ceres by Piazzi, and more especially since the systematically-planned discovery of Astræa by Hencke, as well as since the great improvement in star-maps ⁽⁶⁰⁴⁾ (those of the Berlin Academy contain all stars of the 9th and many of the 10th magnitude), there is opened to astronomical activity in a nearer region of the Universe, a rich and perhaps almost inexhaustible field of research. It is a distinguishing merit of the *Astronomical Jahrbuch* or Almanac, published in my paternal city by Encke, Director of the Berlin Astronomical Observatory, with the co-operation of Dr. Wolfers, that the Ephemerides of the increasing host of the small planets are treated in it with peculiar fulness. Hitherto the region nearest to the orbit of Mars appears the most fully occupied; but already "the breadth of the entire zone, as given by the difference between the Radii Vectores of the nearest perihelion (Victoria), and of the farthest aphelion (Hygeia), considerably exceeds the distance of Mars from the Sun" ⁽⁶⁰⁵⁾.

I have already noticed ⁽⁶⁰⁶⁾ the large amount of the excentricity of the orbits of the small planets—of which the least are those of Ceres, Egeria, and Vesta, and the greatest those of Juno, Pallas, and Iris—as well as the inclinations of the orbits to the Ecliptic, ranging from Pallas $34^{\circ} 37'$, and Egeria $16^{\circ} 33'$, to Hygeia $3^{\circ} 47'$. I here subjoin a tabular view of the elements of the small planets, for which I am indebted to my friend Dr. Galle.

ELEMENTS OF THE 14 SMALL PLANETS FOR THEIR TIMES OF OPPOSITION IN OR NEAR THE YEAR 1851.

| | Flora. | Victoria | Vesta. | Iris. | Metis. | Hebe. | Parthenope. | Astrea. | Egeria. | Irene. | Juno. | Ceres. | Pallas. | Hygeia. |
|----------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| E | 1852. | 1850. | 1851. | 1851. | 1851. | 1851. | 1851. | 1851. | 1852. | 1851. | 1851. | 1851. | 1851. | 1851. |
| | March 24. | Oct. | June 9. | Oct. 1. | Feb. 8. | July 12. | Oct. 22. | April 29-5. | March 15. | July 1. | June 11-5. | Dec. 30. | Nov. 5. | Sept. 28-5. |
| L | 174° 45' | 342° 18' | 256° 38' | 18° 36' | 126° 28' | 311° 39' | 17° 51' | 197° 37' | 162° 29' | 234° 15' | 276° 0' | 105° 33' | 72° 35' | 356° 45' |
| π | 32 51 | 301 57 | 250 32 | 41 22 | 71 7 | 15 17 | 317 5 | 135 43 | 118 17 | 179 10 | 54 20 | 147 59 | 121 23 | 228 2 |
| Ω | 110 21 | 235 28 | 103 22 | 259 44 | 68 29 | 138 31 | 124 59 | 141 28 | 43 18 | 86 51 | 170 55 | 80 49 | 172 45 | 287 38 |
| i | 5 53 | 8 23 | 7 8 | 5 28 | 5 36 | 14 47 | 4 37 | 5 19 | 16 33 | 9 6 | 13 3 | 10 37 | 34 37 | 3 47 |
| μ | 1086''-04 | 994''-51 | 977''-90 | 963''-03 | 962''-58 | 939''-65 | 926''-22 | 857''-50 | 854''-96 | 853''-77 | 813''-88 | 770''-75 | 768''-43 | 634''-24 |
| a | 2-2018 | 2-3349 | 2-3612 | 2-3855 | 2-3862 | 2-4249 | 2-4483 | 2-5774 | 2-5825 | 2-5849 | 2-6687 | 2-7673 | 2-7729 | 3-1514 |
| e | 0-15679 | 0-21792 | 0-08892 | 0-23239 | 0-12229 | 0-20186 | 0-09789 | 0-18875 | 0-08627 | 0-16786 | 0-25586 | 0-07647 | 0-23956 | 0-10092 |
| U | 1193 ^d | 1303 ^d | 1325 ^d | 1346 ^d | 1346 ^d | 1379 ^d | 1399 ^d | 1511 ^d | 1516 ^d | 1518 ^d | 1592 ^d | 1681 ^d | 1687 ^d | 2043 ^d |

E signifies the Epoch of the mean longitude in mean Berlin time; L, the mean longitude in the orbit; π , the longitude of the perihelion; Ω , the longitude of the ascending node; i , the inclination of the orbit to the Ecliptic; μ , the mean daily sidereal motion; a , the semimajor axis; e , the eccentricity in parts of the semi-axis; U, the sidereal period of revolution in days. The longitudes refer to the equinox of the epoch.

The mutual relations of the orbits of the asteroids and the combinations of the orbits have formed the subject of ingenious investigations, first (1848) by Gould (⁶⁰⁷), and quite recently by D'Arrest. The latter says (⁶⁰⁸), "it appears to testify in favour of a real or inherent connection between all the members of the entire group of the small planets, that, if we figure to ourselves the natural dimensions of their orbits as forming actual material rings, these rings are all so interlinked, that, by taking hold of any one, all the others would be lifted by or found suspended on it. If Iris, discovered by Hind in August 1847, had accidentally remained unknown to us—as doubtless is still the case with many other planetary bodies in that region—the group would consist of two separate parts:—a circumstance which must appear the more unexpected, because the zone of the solar system occupied by these planets is a wide one."

We cannot take our leave of this wonderful and numerous planetary group, without alluding, even in this fragmentary description of the several members of the solar system, to the bold views of a highly-gifted and deeply investigating astronomer, respecting the origin of the asteroids and their mutually intersecting orbits. A result derived from Gauss's calculations—that Ceres, in her ascending passage through the plane of the orbit of Pallas, comes exceedingly near the latter planet—led Olbers to conjecture, that "possibly these two planets might be fragments of a single large planet formerly occupying the wide interval between Mars and Jupiter, but since destroyed by some natural force or catastrophe; and that we might expect to discover in the same region more such fragments describing an elliptic orbit round the Sun" (⁶⁰⁹).

The possibility of determining by calculation, even approximately, the probable epoch of such a cosmical event, which should also be that of the origin of the small planets, is more than doubtful, seeing the complications arising from the great number of the supposed "fragments" with which we are already acquainted, the secular retrogressions of the apsides, and the movement of the nodal lines (⁶¹⁰). Olbers marked the region of the nodal line of the orbits of Ceres and Pallas as corresponding to the northern wing of Virgo and to the constellation of Cetus. In the last-named constellation, scarcely two years later, Juno was discovered by Harding—accidentally, however—in the course of the construction of a star catalogue: in the former, after a long five years' search directed by the hypothesis, Olbers himself discovered Vesta. This is not the place for deciding whether these two results, standing by themselves, are sufficient to support the hypothesis. The cometary mists or nebulosities, in which the small planets were at first imagined to be enveloped, have disappeared before the examinations made with more perfect instruments. Olbers attributed the considerable alterations of light to which these planets were supposed to be subject, to their irregular figure as "fragments of a disrupted planet" (⁶¹¹).

Jupiter.

Jupiter's mean distance from the Sun is 5·202767 in parts of the Earth's mean solar distance. The true mean diameter of this largest of all the planets is 19294 German, or 77176 English geographical miles,—equal, therefore, to 11·255 diameters of the Earth, and about $\frac{1}{3}$ th more than

the diameter of the remoter Saturn. The sidereal revolution of Jupiter round the Sun is performed in 11 years, 314 days, 20 hours, 2 minutes, and 7 seconds. The ellipticity of its figure or compression at the poles, according to the prismatic micrometer measurements of Arago, the result of which was transferred in 1824 into the Exposition du Système du Monde (p. 38), is as 167 : 177, or $\frac{1}{17.7}$; which agrees very nearly with the later investigations (1839) of Beer and Mädler (⁶¹²), who found it between $\frac{1}{18.7}$ and $\frac{1}{21.8}$. Hansen and Sir John Herschel prefer $\frac{1}{14}$. The earliest observation of Jupiter's ellipticity by Dominique Cassini was prior to the year 1666, as I have already recalled elsewhere. This circumstance has a peculiar historical interest, from the influence which, as has been acutely remarked by Sir David Brewster, it may have exercised on Newton's ideas respecting the figure of the Earth. The *Principia Philosophiæ Naturalis* seems to afford indications favourable to such a supposition; but the dates at which the *Principia* and Cassini's observations of the equatorial and polar diameters of Jupiter were respectively published, might occasion some chronological doubts on the subject (⁶¹³).

As the mass of Jupiter is, next to the mass of the Sun, the most important element in the whole of our planetary system, its more exact determination in recent times by Airy (1834), by means of the perturbations of Juno and Vesta, as well as by the elongation of Jupiter's satellites, especially the 4th (⁶¹⁴), must be regarded as one of the advances in calculating astronomy most fruitful in consequences. The effect of the corrections obtained is to augment the mass of Jupiter, and to diminish that of Mercury. The mass of

Jupiter, including his four satellites, as now known to us, is $\frac{1}{1047.879}$; whilst in 1824 Laplace still considered it $\frac{1}{1066.09}$ (⁶¹⁵).

The rotation of Jupiter is performed, according to Airy, in $9^{\text{h}}, 55^{\text{m}}, 21^{\text{s}}.3$, mean solar time. Dominique Cassini, in 1665, had found it to be between $9^{\text{h}} 55^{\text{m}}$ and $9^{\text{h}} 56^{\text{m}}$, by means of a spot which continued to be visible on the disk of the planet for several years, and even as late as 1691, preserving always the same colour and outline (⁶¹⁶). The spots seen on Jupiter are, in most cases, darker than the streaks or bands called Jupiter's belts. They do not, however, appear to belong to the actual surface of the planet; for it has occasionally been found that some spots, near the poles more particularly, gave a different time of rotation from that given by others in the equatorial regions. According to a very experienced observer—Heinrich Schwabe, at Dessau—the dark, more definitely bounded, spots in the two grey belts bordering the Equator have been seen for several successive years exclusively in one of the belts only, at one time in the southern, and at another in the northern belt. The process of formation of these spots is therefore subject to change in respect of place. Occasionally (it was so, according to Schwabe's observations, in November 1834) the spots of Jupiter, viewed with a magnifying power of 280 in a Fraunhofer's telescope, resemble small spots on the Sun having nuclei surrounded by penumbras; but even then their degree of blackness is less than that of the shadows of the satellites. The nucleus is probably a part of the body of the planet itself; and when the atmospheric opening through which it is seen maintains its place above the same

point, the motion of the spots gives the true time of rotation. These spots sometimes divide into two or more, also resembling in this respect the spots of the Sun, as was already recognised by Dominique Cassini in 1665.

In the equatorial zone of Jupiter there are two broad principal bands or belts of a grey or greyish-brown colour, which become paler towards the edges, and gradually fade away altogether. Their boundaries are very unequal and variable, and they are separated from each other by an intermediate quite bright equatorial streak. Towards both poles, also, the entire surface is covered with many narrower, paler, often interrupted, and even delicately-branched streaks or bands, always parallel to the Equator. "These phænomena," says Arago, "are most easily explained by the hypothesis of an atmosphere partially obscured by strata of clouds, but which, in zones adjacent to the Equator, is freed from obscuring vapours, and rendered diaphanous—probably by the effect of trade-winds. Since (as was already assumed by William Herschel, in a memoir which appeared in 1793, in the 83d volume of the Philosophical Transactions) the surface of clouds reflects a more intense light than the surface of the planet itself, so the part of the surface which we see through the clear air must appear darker than the cloudy strata which reflect much light. Therefore, grey (or dark) and bright bands alternate with each other: when the visual ray from the eye of the observer is directed at small angles obliquely towards the margin of the planet, the grey bands are seen through a more considerable and thicker mass of atmospheric strata, reflecting a greater quantity of light, and appear less dark as they recede from the centre towards the margin" (617).

Satellites of Jupiter.

At the brilliant epoch of Galileo, the just view was already propounded, that the subordinate system of Jupiter presented, in regard to many relations of time and space, an image or picture, on a smaller scale, of the entire solar or planetary system. This view, which then spread rapidly, together with the discovery of the phases of Venus which followed soon afterwards (February 1610), contributed much to promote the more general reception of the Copernican system. The four satellites of Jupiter are the only group of satellites belonging to the outer planets which has not received any augmentation since the epoch of its first discovery (⁶¹⁸) (by Simon Marius, on the 29th of December, 1609), a period of nearly two centuries and a half.

The following Table contains, according to Hansen, the sidereal periods of revolution of Jupiter's satellites, their mean distances expressed in semi-diameters of the central planet, and the mass of each in parts of the mass of Jupiter :—

| Satel- lites. | Period of revo- lution. | | | Distance from Jupiter. | Diameter in German geographi- cal miles. | Mass. |
|------------------|----------------------------|----|----|------------------------------|---|--------------|
| | d. | h. | m. | | | |
| 1 | 1 | 18 | 28 | 6.049 | 529 | 0.0000173281 |
| 2 | 3 | 13 | 14 | 9.623 | 475 | 0.0000232355 |
| 3 | 7 | 3 | 43 | 15.350 | 776 | 0.0000884972 |
| 4 | 16 | 16 | 32 | 26.998 | 664 | 0.0000426591 |

If $\frac{1}{1047879}$ expresses the mass of Jupiter, together with

his satellites, the mass of the planet alone, without the satellites, is $\frac{1}{1048039}$, or only about $\frac{1}{6000}$ th less.

Comparisons of magnitude, distance, and excentricity, with the satellites of other planets or systems, have already been given in an earlier part of the present volume (p. 338 to 340). The intensity of the light of the four satellites of Jupiter is not proportional to their volume; for, generally speaking, the 3d and the 1st, the ratio of whose magnitudes according to their diameters is as 8 : 5, appear the brightest, and the 2d, which is the smallest and densest of the satellites, is usually brighter than the larger 4th, which is considered the faintest of all. Casual or temporary fluctuations in the intensity of light of the satellites, which have also been remarked, have been ascribed sometimes to alterations in their surfaces, and sometimes to obscurations in their atmospheres (⁶¹⁹). They, however, all appear to reflect a more intense light than the central planet. When the Earth is between Jupiter and the Sun, and the satellites, therefore, in their movement from east to west, appear to enter the eastern margin of Jupiter, and, passing in front of the planet's disk, successively cover, to our eyes, different portions of it, they can be recognised in their passage, even with not very high magnifying powers, as they detach themselves "in bright" from the disk. It becomes more difficult to distinguish the satellites as they approach the centre of the planet's disk. From this early-observed phænomenon, Pound, Newton's and Bradley's friend, had already inferred that the disk of Jupiter is less bright towards the margin than at the centre. Arago believes that this statement; which has been repeated by Messier, presents difficulties which require to be solved by new and more

delicate observations. Jupiter has been seen without any of his satellites by Molyneux, in November 1681; by Sir William Herschel on the 23d of May, 1802; and lastly by Griesbach, on the 27th of September, 1843. Such a non-visibility of the satellites refers, however, only to the space external to the planet's disk, and does not oppose the theorem that all the four satellites can never be eclipsed or occulted at the same time.

Saturn.

The sidereal or true period of revolution of Saturn is 29 years, 166 days, 23 hours, 16 minutes, and 32 seconds. Its mean diameter is 15507 German, or 62028 English geographical miles, equal to 9·022 diameters of the Earth. The time of rotation of Saturn, derived from observations of some dark spots (knot-like thickenings or condensations of the streaks) ⁽⁶²⁰⁾, is 10 hours, 29 minutes, 17 seconds. To this great velocity of rotation round the axis there corresponds a great compression at the poles; this compression was determined by William Herschel, in 1776, at $\frac{1}{10\cdot4}$. Bessel, from observations more accordant with each other and continued for three years, found, at the mean distance of the planet from the Earth, the polar diameter 15''·381, and the equatorial diameter 17''·053; giving an ellipticity or compression of $\frac{1}{10\cdot2}$ ⁽⁶²¹⁾. Saturn has also bands or belts, but less marked and somewhat broader than those of Jupiter. The most constant is a grey equatorial band: this is followed by several others, which, however, have varying forms, indicating an atmospheric origin. William Herschel found that they were not always parallel to the ring; and

they do not extend to the poles. The parts of the disk adjacent to the poles present a very remarkable phænomenon, consisting in a variation in the reflected light, dependent on the seasons of the year in Saturn. The polar regions shine more brightly in their respective winters,—a phænomenon which reminds us of the varying snowy regions of Mars,—and which did not escape the keen-sightedness of William Herschel. Whether this increased luminous intensity may arise from the temporary formation of snow and ice, or whether it may be attributed to an extraordinary accumulation of clouds, it would equally indicate effects produced by changes of temperature and the presence of an atmosphere (622).

We have already stated the mass of Saturn to be $\frac{1}{3501}$: from this amount, and from its great comparative volume (its diameter is $\frac{4}{5}$ of that of Jupiter), we infer a very small degree of density, diminishing towards the surface. If the density, (which is $\frac{76}{1000}$ of the density of water), were homogeneous throughout, the compression at the poles would be still greater than it is observed to be.

This planet is surrounded in the plane of its equator by at least two detached exceedingly thin rings, situated in one and the same plane: they have a greater intensity of light than the planet itself, and the outer ring is brighter than the inner one (623). The division of what had been recognised, in 1655, by Huygens, as a single ring (624), was seen, indeed, as early as 1675 by Dominique Cassini, but was first described with exactness by William Herschel (1789—1792). Since they were first remarked by Short, finer lines or divisions in the outer ring have been repeatedly observed; but these lines or streaks have never appeared very constant.

Very recently, in the latter months of 1850, Bond, at Cambridge, U.S., on the 11th of November, with the great refractor of Merz having a 14-inch object-glass, and Dawes, at Maidstone, in England, on the 25th of November,—therefore almost simultaneously,—discovered between the second, (hitherto called the inner) ring, and the planet itself, a third very faintly illuminated, darker ring. It is divided from the second ring by a black line, and fills up a third part of the space intervening between the second ring and the planet, which has hitherto been supposed to be vacant, and through which Derham thought he had seen small stars.

The dimensions of the divided ring of Saturn have been determined by Bessel and Struve. According to Struve, the angle subtended by the external diameter of the outermost ring, at Saturn's mean distance, is $40''\cdot09$,—equal to 38300 German, or 153200 English, geographical miles;—and the angle subtended by the internal diameter of the same ring is $35''\cdot29$,—equal to 33700 German, or 134800 English, geographical miles. The external diameter of the second ring has been determined at $34''\cdot47$; and its internal diameter at $26''\cdot67$. The interval which separates the last-named ring from the surface of the planet is given by Struve at $4''\cdot34$. The entire breadth of the first and second ring is 3700 German, or 14800 English, geographical miles; the distance of the ring from the surface of Saturn is about 5000 German, or 20000 English, geographical miles; the gap which separates the first and second rings, and which is indicated by the black line of division seen by Dominique Cassini, is only 390 German, or 1560 English, geographical miles. The thickness of these rings is believed not to exceed 20 German, or 80 English, geogra-

phical miles. The mass of the rings is, according to Bessel, $\frac{1}{118}$ of the mass of Saturn. They present some (⁶²⁵) inequalities, by means of which it has been possible to observe approximately their time of rotation, which is exactly equal to that of the planet. Irregularities of form shew themselves in the "disappearances of the ring," when one of the anses usually becomes invisible sooner than the other.

The excentric position of Saturn in respect to its ring, discovered by Schwabe, at Dessau, in September 1827, is a very remarkable phænomenon. The body of the planet is a little to the west of the place which it would occupy if it were truly concentric with the surrounding ring. This observation has been confirmed by Harding, Struve (⁶²⁶), John Herschel, and South (partly by micrometric measurements). Small, apparently periodical, differences in the amount of the excentricity, which have been found from series of corresponding observations by Schwabe, Harding, and de Vico at Rome, are perhaps due to oscillations of the centre of gravity of the ring round the centre of the planet. It is a curious and striking circumstance, that so early as the end of the 17th century, an ecclesiastic of Avignon, Gallet, attempted without success to call the attention of the astronomers of that period to the excentric position of Saturn (⁶²⁷). With a density diminishing towards the surface, and so exceedingly small,—perhaps scarcely $\frac{3}{8}$ of that of water,—it is difficult to make to ourselves any representation of the molecular state, or material quality or constitution of the body of the planet; or even to decide whether this constitution should actually suppose fluidity (*i. e.* mobility of the smallest particles *inter se*), or rigidity, (according to the often adduced analogies of deal, pumice, cork, or

a solidified fluid, as ice). The astronomer of Krusenstern's expedition, Horner, terms the ring of Saturn a series of clouds; and would make the mountains of Saturn to consist of masses and vesicles of vapour (628). Conjectural astronomy has here a wide and legitimate field in which to exercise itself freely. Of a wholly different kind are the severer speculations, based on observation and on analytical calculus, of two distinguished American astronomers, Bond and Pierce, respecting the possibility of the "stability" of Saturn's ring (629). They both agree in pronouncing in favour of a state of fluidity, and also in favour of a continual variability of form and of divisibility in the outer ring. The maintenance of the general configuration is regarded by Pierce as dependent on the influence and position of the satellites, as without this dependence, even admitting inequalities in the ring, the equilibrium could not be preserved.

Satellites of Saturn.

The five oldest, or longest known, satellites of Saturn, were discovered between the years 1655 and 1684 (Titan, the sixth in distance, by Huygens, and four by Cassini, viz. Japetus, the outermost of all, Rhea, Tethys, and Dione). These discoveries were followed, in 1789, by that of the two satellites nearest to the primary planet (Mimas and Enceladus), by William Herschel. Lastly, the 7th satellite, Hyperion, the last but one in point of distance, was discovered in September, 1848, almost simultaneously, by Bond, at Cambridge, U.S., and by Lassell, at Liverpool. I have before treated in this work (Kosmos, Bd. i. S. 102, and

Bd. iii. S. 463 ; English edit. Vol. i. p. 89, and Vol. iii. p. 340) of the relative magnitudes and distances in this system of satellites. The periods of revolution and mean distances, the latter expressed in parts of the equatorial semi-diameter of Saturn, according to the observations of Sir John Herschel at the Cape of Good Hope (⁶³⁰) between 1835 and 1837, are as follows:—

| Satellites according to the time of their discovery. | Satellites according to their distances from the planet. | Period of revolution. | | | | Mean distance. |
|--|--|-----------------------|----|----|------|----------------|
| | | d. | h. | m. | s. | |
| <i>f.</i> | 1. Mimas . . | 0 | 22 | 37 | 22·9 | 3·3607 |
| <i>g.</i> | 2. Enceladus . | 1 | 8 | 53 | 6·7 | 4·3125 |
| <i>e.</i> | 3. Tethys . . | 1 | 21 | 18 | 25·7 | 5·3396 |
| <i>d.</i> | 4. Dione . . | 2 | 17 | 41 | 8·9 | 6·8398 |
| <i>c.</i> | 5. Rhea . . | 4 | 12 | 25 | 10·8 | 9·5528 |
| <i>a.</i> | 6. Titan . . | 15 | 22 | 41 | 25·2 | 22·1450 |
| <i>h.</i> | 7. Hyperion . | 22 | 12 | | ? | 28·0000 ? |
| <i>b.</i> | 8. Japetus . | 79 | 7 | 53 | 40·4 | 64·3590 |

Between the four first or nearest satellites, we find a remarkable relation in the commensurability of their periods of revolution. The period of the 3d satellite (Tethys), is double that of the 1st (Mimas) ; and that of the 4th satellite (Dione), is double that of the 2d (Enceladus). The exactness of these proportions amounts to $\frac{1}{800}$ of the longer periods. This result, which has not been much attended to, was communicated to me as early as November 1845, in letters from Sir John Herschel. The four satellites of Jupiter shew also a certain degree of regularity in their distances, the intervals between them presenting with tolerable approximation the series 3, 6, 12. The 2d satellite is dis-

tant from the 1st 3·6 ; the 3d from the 2d 5·7 ; and the 4th from the 3d 11·6 semi-diameters of Jupiter. Fries and Challis have attempted to shew that the so-called law of Titius prevails in all the systems of satellites, even in that of Uranus (⁶³¹).

Uranus.

The recognition of the existence of this planet, the great discovery of William Herschel, not only augmented for the first time the number of those six planets which had for thousands of years been known to man, and more than doubled the diameter of the solar domain ; it also led, at the end of 65 years, by means of the perturbations sustained by Uranus proceeding from still more distant regions, to the discovery of Neptune. Uranus was discovered accidentally (March 13, 1781) during the examination of a small group of stars in Gemini, and was recognised by means of its minute disk, which, under the successive employment of magnifying powers of 460 and 932, increased much more than did other stars in its vicinity. The keen-sighted and sagacious discoverer, so familiar with all optical phænomena, also remarked, that with increased magnifying powers the intensity of light in the new body decreased considerably ; whilst in fixed stars of equal magnitude (between the 6th and 7th) it remained the same.

Herschel termed Uranus, when he first announced its existence (⁶³²), a comet ; and the united labours of Saxon, Lexell, Laplace, and Méchain, which were greatly facilitated by the discovery made by the meritorious Bode, in 1784, of older observations of that body by Tobias Mayer, in 1756,

and by Flamstead, in 1690, established with admirable promptitude the elliptical orbit and all the planetary elements of Uranus. Its mean distance from the Sun is, according to Hansen, 19.18239 distances of the Earth from the Sun, or $396\frac{1}{2}$ millions of geographical miles (1586 millions English geographical miles); its sidereal period of revolution is 84 years, 5 days, 19 hours, 41 minutes, and 36 seconds; its inclination to the ecliptic $0^{\circ}46'28''$; and its apparent diameter at its mean distance from the Earth $9''\cdot9$. Its mass, which the first observations of its satellites had given at $\frac{1}{17918}$, is derived, by Lamont's observations, as only $\frac{1}{24605}$: according to this, its density would be intermediate between those of Jupiter and Saturn (633). Ellipticity of figure, or compression at the poles, of Uranus, was suspected by William Herschel from observations in which he employed magnifying powers from 800 to 2400: according to Mädler's measurements, in the years 1842 and 1843, its amount would seem to fall between $\frac{1}{10\cdot7}$ and $\frac{1}{9\cdot9}$ (634). That the at first supposed two rings of Uranus were merely the effect of an optical illusion was acknowledged by the discoverer himself, ever so ready to apply due caution, and to continue perseveringly to test the reality of all newly acquired data.

Satellites of Uranus.

"Uranus," says the younger Herschel, "is surrounded by four, or probably by five or six, satellites." They present a remarkable peculiarity, in a feature to which nothing similar has yet been found in any part of the solar system: viz. that whereas all other satellites (those of the Earth, Jupiter, and Saturn), as well as all the primary planets,

move from west to east, and all, excepting some of the asteroids, have orbits but little inclined to the ecliptic, the almost perfectly circular path of the satellites of Uranus is inclined to the ecliptic at an angle of $78^{\circ} 58'$, being therefore nearly perpendicular to it; and the satellites themselves move from east to west. In the satellites of Uranus, as well as in those of Saturn, the sequence or arrangement of the nomenclature, 1st, 2d, 3d, &c., taken from their respective distances from the primary planet, is altogether distinct from the sequence of the epochs of their discovery. Of the satellites of Uranus, those first discovered were the 2d and the 4th, by William Herschel, in 1787; then, in 1790, the 1st and the 5th; and lastly, in 1794, the 6th and the 3d,—all by the same astronomer. In the course of the fifty-six years which have elapsed since the latest discovery (that of the 3d satellite), the existence of so many as six satellites has been often, but unduly doubted; the observations of the last twenty years have gradually shewn how much confidence may be placed in the great discoverer of Slough in this department of planetary astronomy also. Hitherto the satellites of Uranus which have been seen again are the 1st, 2d, 4th, and 6th; to which may perhaps be added the 3d, according to Lassell's observation of the 6th of November, 1848. On account of the large aperture of his reflector, and the abundance of light obtained thereby, the elder Herschel, with his acute vision, considered a magnifying power of 157 sufficient under favourable atmospheric circumstances; his son prescribes generally for these exceedingly small luminous disks a magnifying power of 300. The 2d and 4th satellites are those which have been seen again earliest, most certainly, and most frequently;—in Europe

and the Cape of Good Hope by Sir John Herschel, and subsequently by Lamont at Munich, and Lassell at Liverpool. The 1st satellite of Uranus was rediscovered and observed by Lassell from the 14th of September to the 9th of November, 1847, and by Otto Struve from the 8th of October to the 10th of December, of the same year; and the outermost, or 6th satellite, by Lamont, on the 1st of October, 1837. The 5th satellite does not appear to have been seen again at all; and the 3d not with sufficient certainty (⁶³⁵). These details are not without importance, as suggesting fresh motives for not giving too much weight to so-called negative evidence.*

Neptune.

The merit of the successful working out and earliest publication of an inverse problem of perturbation, (viz. the problem of deducing from given perturbations of a known planet the elements of the unknown perturbing one), and even of having occasioned, by a bold prediction, the great discovery of Neptune by Galle, on the 23d of September, 1846, belongs to the acute powers of combination, and to the persevering labours, of Le Verrier (⁶³⁶). It is, as Encke has expressed it, the most brilliant of all planetary discoveries, because purely theoretical investigations caused the antecedent prediction of the existence and the place of the new and yet unknown planet. The promptitude of the

* [See at the close of the present volume a note containing an account of the discovery, by Mr. Lassell, of two more satellites of Uranus, communicated to M. de Humboldt whilst the volume in the original was passing through the press, but after this section had been printed.—EDITOR.]

actual discovery was favoured by the excellent star-maps of the Berlin Academy, by Bremiker (⁶³⁷). If, among the distances of the outer planets from the Sun, the distance of Saturn (9·53) is approximately twice as great as that of Jupiter (5·20), and the distance of Uranus (19·18) approximately twice as great as that of Saturn,—the distance of Neptune (30·04) would require, in order to complete a similar proportion, to have a third part more, or fully ten Earth-distances, added to it. Our planetary boundary is at the present time 621 millions of German, or 2484 millions of English, geographical miles from the central body; by the discovery of Neptune, the terminal or border-stone, marking the limit of our planetary knowledge, has been made to recede more than 223 millions (892 English) such miles, or upwards of 10·8 distances of the Earth from the Sun. Step by step as the perturbations suffered by each last-known planet are recognised, fresh and fresh planets are discovered, until, by reason of their remoteness, they cease to be visible through our telescopes (⁶³⁸).

According to the latest determinations the period of revolution of Neptune is 60126·7 days, or 164 years and 226 days; and its semi-major axis 30·03628. The excentricity of its orbit is 0·00871946, the least next to that of Venus; its mass is $\frac{1}{4446}$: its apparent diameter is, according to Encke and Galle, 2''·70, and according to Challis even 3''·07; which would give its density as compared to that of the Earth 0·230, greater therefore than that of Uranus 0·178 (⁶³⁹).

Soon after the discovery of Neptune a ring was ascribed to it by Galle, Lassell, and Challis. The first-named of these astronomers had employed a magnifying power of 567,

and tried to determine the great inclination of the supposed ring to the ecliptic; but in the case of Neptune, as long before in that of Uranus, subsequent examination has dispelled the belief in the existence of a ring.

I think it right to forbear, in this work, from more than an allusion to the certainly earlier but unpublished labours,—not therefore crowned by recognised success,—of the highly distinguished and acute English geometrician, John Couch Adams, of St. John's College, Cambridge. The historical facts relating to these labours, and to Le Verrier's and Galle's happy discovery of the new planet, are related circumstantially, impartially, and from well-assured sources of authority, in two memoirs, by the Astronomer-Royal Airy, and by Bernhard von Lindenau (⁶⁴⁰). Intellectual labours directed almost at the same time to the same great object, offer, besides the spectacle of a competition honourable to both competitors, an interest the more vivid, because the selection of the processes employed testifies the brilliant state of the higher mathematical knowledge at the present epoch.

Satellites of Neptune.

If, in the outer planets, the existence of a ring has as yet presented itself to our view in one instance only, and if the rarity of this phænomenon causes us therefore to conjecture that the formation of a detached belt of matter is dependent on the concurrence of peculiar conditions difficult of fulfilment; on the other hand, the existence of satellites,—accompanying the outer planets, Jupiter, Saturn, and Uranus,—appears to be a far more general phænomenon. So early as the beginning of August, 1847, Lassell recog-

nised with certainty (⁶⁴¹) the first of Neptune's satellites, in his great 20-foot reflector, with an aperture of 24 inches. Otto Struve (⁶⁴²), at Pulkowa (11th Sept. to 20th Dec. 1847), and Bond (⁶⁴³), the Director of the Astronomical Observatory of Cambridge, U.S. (16th Sept. 1847), confirmed Lassell's discovery. The Pulkowa observations gave—the satellite's period of revolution, 5 days, 21 hours, 7 min.; the inclination of its orbit to the ecliptic, $34^{\circ} 7'$; its distance from the centre of the primary planet, 54000 German (216000 English) geographical miles; and its mass, $\frac{1}{4306}$. Three years later (14th August, 1850) Lassell discovered a second satellite of Neptune, to which he applied magnifying powers of 628 (⁶⁴⁴). This last discovery has not yet, I believe, been confirmed by any other observer.

III.

COMETS.

IN the solar domain, the comets—which Xenocrates and Theon of Alexandria termed “Clouds of Light,” and which, according to an ancient belief, handed down from the Chaldeans, were said by Apollonius the Myndian to “ascend periodically from remote distance on long (regulated) paths”—although subject to the attracting force of the central body of our system, form, nevertheless, a peculiar and distinct group. They are distinguished from planetary bodies properly so called, and meaning thereby both primary planets and satellites, not merely by the great excentricity of their orbits, but also by what is still more material—their cutting through or intersecting the orbits of the planets; and they present, moreover, a variability of form—a mutability of outline—which, in some individuals, (for example, in Klinkenberg’s comet of 1744 so accurately described by Hensius, and in Halley’s comet on its last appearance in 1835), becomes sensible even in the course of a few hours. Before Encke had enriched our knowledge of the solar system with comets of short period,—called interior comets because their orbits are included within some of the planetary orbits,—dogmatic

fancies, based on mistaken analogies respecting a supposed law of increasing excentricity, magnitude, and rarity of matter in planetary bodies with increasing solar distances, led to the view, that beyond Saturn there would be discovered excentric planetary cosmical forms of enormous volume, "constituting intermediate links or gradations between planets and comets; and that the last or outermost planet might even deserve to be called a comet, because it might perhaps be found to intersect the orbit of the preceding planet nearest to itself, *i. e.* Saturn" (645). Such a view of the graduated succession of forms in the structure of the Universe, analogous to the often misused doctrine of gradation or transition of form in organic existence, was shared by Kant, one of the greatest intellects of the eighteenth century. Respectively twenty-six and ninety-one years after the dedication to Frederick the Great of the *Naturgeschichte des Himmels* by the Königsberg philosopher, Uranus and Neptune were discovered by William Herschel and Galle; but both these planets have a less excentricity than Saturn; indeed, while the excentricity of Saturn is 0.056, that of the outermost of all the planets now known to us, Neptune, is 0.008, nearly the same as that of Venus, so near to the Sun (0.006). In other respects, also, neither Uranus nor Neptune show anything of the anticipated cometary qualities.

As within a recent period, (since 1819), the discovery of five interior comets have followed that of Encke's,—the whole six forming apparently a distinct group, whose semi-major axis does not differ much from that of the majority of the small planets,—the question has been suggested, whether the group of the interior comets may not have originally constituted a single cosmical body,—as in the case of the small

planets according to the hypothesis of Olbers ; and whether this original large comet may not have been separated into several parts by the influence of Mars ; such a separation, or bi-partition, having actually taken place almost before the eyes of observers, in the year 1846, on the last return of the interior comet of Biela. Certain resemblances between the elements have led Professor Stephen Alexander, of the College of New Jersey, to undertake investigations respecting the possibility of a common origin of the asteroids, (or small planets between Mars and Jupiter,) and some, or even all, of the comets (646). On grounds of analogy founded on the supposed nebulous envelopes of the small planets, all recent and more accurate observations show that the hypothesis is quite unsupported. Other circumstances are also unfavourable to it. Although it is true that the orbits of the small planets are not parallel to each other, and present, indeed, in the case of Pallas, the phænomenon of an excessive inclination, yet with all this want of parallelism in their own paths, they do not, like comets, intersect the orbits of the great, old, or longer known planets. This circumstance, which, in any hypothesis of a primitive impulse in direction and velocity is exceedingly material, taken in conjunction with the diversity in physical constitution between the interior comets and the small planets,—the planets appearing to be entirely without any nebulous or vaporous matter,—seems to render a similarity of origin between these two classes of cosmical bodies very improbable. Laplace, also, in his theory of “planetary genesis” from zones of vapour revolving around the sun and condensing round nuclei, thought that comets must be separated entirely from planets. “Dans l’hypothèse des zones de

vapeurs et d'un noyau s'accroissant par la condensation de l'atmosphère qui l'environne, les comètes sont étrangères au système planétaire" (647).

I have already called attention, in the first volume of my work (648), to the fact that comets combine the smallest mass with the occupation of the largest space within the solar domain; they also exceed all other planetary cosmical bodies in number of individuals; the calculus of probabilities, based on the assumption of an equable distribution of orbits, limits, nearness to the Sun, and possible continued invisibility, leads to our inferring the existence of many thousands. I purposely exclude from such comparative considerations "aerolites," or "meteoric asteroids," because much obscurity still prevails respecting their nature. We must distinguish among comets those whose orbits have been computed by astronomers from those of which we possess, in some cases, only incomplete observations, and in others, mere notices in chronicles. As, according to Galle's latest exact enumeration to the year 1847 inclusive, 178 comets had been calculated, we may very well continue to take as the number of comets which have been seen, including those of which we merely possess notices, a rough total of from six to seven hundred. When the comet of 1682, announced by Halley, reappeared in 1759, it was regarded as something very remarkable that three comets should be visible in the same year. Now, so animated is the examination of the celestial vault, and from so many points of the earth's surface at the same time, that in each of the years 1819, 1825, and 1840, four comets were seen and computed; in 1826, five; and in 1846, even as many as eight.

In comets seen with the unassisted eye, recent times have been more rich than was the latter part of the last century ; but still the appearance of a comet brilliant in both head and tail continues to be a rare and remarkable natural phænomenon. It may not be without interest to reckon up the number of comets which have been seen in Europe with the naked eye during the last few centuries (649). The richest period was the 16th century, when 23 such comets were seen. The 17th had 12, of which only 2 were in the first half. In the 18th century only 8 such comets appeared, whereas we have had 9 in the first fifty years of the 19th. Of these, the finest were those of 1807, 1811, 1819, 1835, and 1843. In earlier times it has happened more than once that from thirty to forty years have passed without the record of such a spectacle having been once enjoyed. The years which appear poor in comets may, however, for aught we know, have been actually rich in large comets having their perihelions situated beyond the orbits of Jupiter and Saturn. Of telescopic comets, there are now discovered, on an average, at least two or three a year. In three successive months, in 1840, Galle found 3 new comets ; from 1764 to 1798 Messier found 12 ; and Pons, from 1801 to 1827, found 27. Thus Kepler's expression respecting the multitude of comets in space (" ut pisces in oceano") almost appears to be justified.

The careful register of the comets seen in China, made known to us by Edouard Biot from the collection of Matuan-lin, is of no small importance. It extends back beyond the foundation of the Ionic school of Thales and the Lydian Alyattes, and comprises in two sections the places of comets from 613 years before, to 1222 after our era ; and from

1222 to 1644 during the period of the dynasty of Ming. I repeat here (Kosmos, Bd. i. S. 389, Anm. 12; Engl. ed. p. xvii. Note 42), that whilst from the middle of the 3d to the end of the 14th century, comets have to be computed exclusively from Chinese observations, the calculation of Halley's comet at its appearance in 1456 is the first which has been made exclusively from European observations: those of Regiomontanus were, however, followed, on the return of Halley's comet, by the very exact ones of Apianus, at Ingolstadt, in August of the year 1531. The appearance of a superb comet which acquired celebrity by means of African and Brazilian voyages of discovery, and which was called by Italians "Signor Astone," the great "Asta," belongs to the intermediate date of May 1500 (⁶⁵⁰). By the similarity of the elements, Laugier (⁶⁵¹) recognised in the Chinese observations a seventh appearance of Halley's comet (that of 1378): the third comet of 1840, discovered by Galle (⁶⁵²) on the 6th of March, appears in the same way to be identical with that of 1097. The Mexicans in their Year-books connected events with comets and other celestial observations. It is a curious fact that it is only in the Chinese Comet-Register that I have been able to recognise, (as having been observed in December of the same year), the comet of 1490, which I discovered in Le Tellier's Mexican Manuscript, and figured in my "Monumens des Peuples indigènes de l'Amérique" (⁶⁵³). This comet had been entered by the Mexicans in their register twenty-eight years before Cortes appeared for the first time on the coast of Vera Cruz (Chalchiuheucan).

I have spoken in detail in the first volume of my work (S. 106—112; English edit. p. 92—98), of the shape and appearance of comets, of their variations of form, brightness

and colour, and of the emanations from the head, which, bending back, form the tail (⁶⁵⁴), following in my description the observations of Heinsius (1744), Bessel, Struve, and Sir John Herschel. In recent times, besides the magnificent comet of 1843 (⁶⁵⁵), which was seen by Bowring at Chihuahua (N.W. America) as a small white cloud, from nine in the morning to sunset, and by Amici at Parma, in full noonday, at $1^{\circ} 23'$ east of the Sun (⁶⁵⁶), the 1st comet of 1847, discovered by Hind in the neighbourhood of Capella, was visible in London on the day of its perihelion, when very near the Sun.

For the further elucidation of what has been said above, respecting the remarks of the Chinese astronomers on the occasion of their observation of the comet of March 837, during the dynasty of Thang, I will here introduce a translation from the Ma-tuan-lin, of the statement of the law followed in the direction of the tails of comets:—"In general, in a comet east of the Sun, the tail, reckoning from the nucleus, is directed to the east; but if the comet appears to the west of the Sun, the tail is turned towards the west." (⁶⁵⁷). Fracastoro and Apianus say more definitely, and still more correctly, that "a line in the direction of the axis of the tail, prolonged through the head of the comet, strikes the centre of the Sun." The words used by Seneca (*Nat. Quæst.* vii. 20),—"the tails of comets flee from the Sun's rays,"—are also descriptive of their character in this respect. Among the planets and comets yet known to us, while the proportion of the shortest to the longest period of revolution, dependent on the length of the semi-major axis, is in planets as 1 : 683, in comets it is as 1 : 2670. These ratios are derived from comparing Mercury, having a period of revo-

lution of 87·97 days, with Neptune, whose period is 60126·7 days ; and Encke's comet, having 3·3 years, with the comet of 1680, observed by Gottfried Kirch at Coburg, by Newton and by Halley, whose computed period is 8814 years. I have already noticed (Kosmos, Bd. i. S. 116—118, and Bd. iii. S. 371—373 ; Engl. edit. Vol. i. p. 102—103, and Vol. iii. p. 260—261), the distance of the fixed star nearest to our solar system (α Centauri), from the aphelion (or greatest distance from the Sun) of the last-named comet, as determined by Encke in an excellent memoir on the subject,—the very small velocity, 10 feet in a second, of the same comet at the remotest part of its path,—and the greatest proximity attained by Lexell's and Burckhardt's comet of 1770 to the Earth, (being 6 distances of the Moon from the Earth),—and by the comet of 1680, and still more the comet of 1843, to the Sun. The 2d comet of 1819, which, as seen in Europe, emerged suddenly in considerable magnitude from the Sun's rays, must, according to its elements, have passed on the 26th of June (but, unfortunately, without being seen!) in front of the Sun's disk (⁶⁵⁸). This must also have been the case with the comet of 1823, which, besides the ordinary tail turned from the Sun, had another turned directly towards the Sun. If the tails of these two comets had a considerable length, vaporous particles belonging to them must have become mingled with our atmosphere, as doubtless has often happened. The question has been propounded, whether the extraordinary mists which, in 1783 and 1831, covered a large part of our continent, may have been the result of such an admixture (⁶⁵⁹).

While the quantity of radiant heat received by the comets of 1680 and 1843, when in such near proximity to the Sun,

has been compared to the temperature of the focus of a burning-glass of more than 32 inches diameter (⁶⁶⁰), another highly meritorious astronomer (⁶⁶¹) considers that "all comets without a solid nucleus, cannot, from their exceeding tenuity, receive or appropriate any solar heat whatsoever; and have therefore only the temperature of space" (⁶⁶²). If we consider attentively the many and striking analogies in the phænomena presented, according to Melloni and Forbes, by bright and by dark sources of heat, it seems, in the present state and connection of our physical ideas, difficult not to assume processes in the Sun itself which produce, by the vibrations of an ether (by waves of different length), at once radiant light and radiant heat. Mention was long made in many astronomical works of a supposed occultation of the Moon by a comet, in 1454, the statement of which the Jesuit Pontanus, the first translator of the Byzantine writer George Phranza, thought he had discovered in a Munich manuscript. This supposition of the passage of a comet between the Earth and the Moon, in 1454, is as erroneous as is a similar assertion by Lichtenberg in respect to the comet of 1770. Phranza's Chronicles were published in full for the first time, in Vienna, in 1796; and it is said in them expressly, that in the year of the world 6962, during the time that an eclipse of the Moon was taking place, quite in the ordinary manner, according to the order and circular path of the heavenly luminaries, a comet, similar to a mist, appeared, and came near to the Moon. The date, corresponding to 1450, is given incorrectly; for Phranza says positively that the lunar eclipse and the comet were seen *after* the taking of Constantinople (19th of May, 1453); and an eclipse of the Moon did really take place on the 12th

of May, 1454. (See Jacobs in Zach's *Monatl. Corresp.* Bd. xxiii. 1811, S. 196—202).

The facts relative to Lexell's comet and Jupiter's satellites, *i. e.* the disturbances which it sustained from them without sensibly influencing their periods of revolution (Kosmos, Bd. i. S. 117; English edit. Vol. i. p. 103), have undergone more accurate investigation by Le Verrier. Messier discovered this remarkable comet on the 14th of June, 1770, as a faint nebula in Sagittarius; but eight days later its nucleus shone already like a star of the 2d magnitude. Previous to the perihelion no tail was visible; but afterwards one developed itself, by slight emanations, to a length of barely 1° . Lexell found for his comet an elliptic path, and a period of revolution of 5.585 years, a result which was confirmed by Burekhardt in his excellent prize memoir of 1806. According to Clausen it approached the Earth, on the 1st of July, 1770, within 363 semi-diameters of the Earth (311000 German, or 1244000 English geographical miles, or six distances of the Moon from the Earth). That the comet should not have been seen earlier (March 1776), and later (October 1781), has, in accordance with Lexell's previous conjecture, been made out analytically by Laplace, in the 4th volume of the *Mécanique celeste*, as the effect of perturbations proceeding from the direction occupied by Jupiter's system at the time of the approximations, in the two years 1767 and 1779. Le Verrier finds that, according to one hypothesis respecting the comet's path, it should have passed, in 1779, through the orbits of the satellites of Jupiter; and that, according to another hypothesis, it should have passed far outside the 4th or outermost satellite⁽⁶⁶³⁾.

The molecular state of the head or nucleus, which presents so singular an outline, as well as of the tail of comets, is the more difficult to comprehend, since it does not cause any refraction of rays, and since, by Arago's important discovery (*Kosmos*, Bd. i. S. 111, 391 and 392, Anm. 19—21; English edit. p. 97, xviii. and xix., Notes, 49—51), the light of comets has been shewn to consist partly of polarised, and therefore of reflected solar light. While the smallest stars are seen to shine with undiminished brightness through the vaporous emanations which form the tail, and even through almost the centre of the nucleus itself, or at least exceedingly near to the centre (*per cometem non aliter quam per nubem ulteriora cernuntur*; Seneca, *Nat. Quæst.* vii. 18), the analysis of the light of comets in Arago's experiments which I witnessed shows, on the other hand, that the vaporous envelopes are capable, notwithstanding their tenuity, of reflecting or giving back light received from a foreign source (⁶⁶⁴); that these cosmical bodies have "an imperfect transparency (⁶⁶⁵); and that light does not pass through them unimpeded." In a group of nebulous bodies of such extreme tenuity, the particular instances of great luminous intensity, as in the comet of 1843, or the star-like brightness of a nucleus, excite the more astonishment, because the reflection of the Sun's light is assumed to be the exclusive cause. But may we not suppose in comets, in addition to this, a light-evolving process of their own?

The particles emanating or evaporating from brush-like or fan-shaped comets' tails of many millions of miles in length, disperse themselves in space, and may perhaps either form of themselves the resisting or impeding fluid or medium (⁶⁶⁶) which gradually contracts the path of Encke's

comet, or may mingle with the ancient cosmical matter which has not been condensed either into celestial bodies or into the ring which forms our Zodiacal Light. We see material particles disappear, as it were, before our eyes, and can hardly conjecture where they reassemble. Now, however probable may be the condensation in the neighbourhood of the central body of our system of a gaseous fluid filling space, yet in comets, whose nucleus, according to Valz, becomes small in the vicinity of the Sun, we cannot well imagine to ourselves that this effect is caused by the surrounding fluid being there more dense, and thus pressing upon and contracting a vesicular nebulous envelope (⁶⁶⁷). If, in the emanations of comets, the outlines of the light-reflecting nebulosity are usually very little defined, it is the more striking, and the more instructive in respect to the molecular state of the body, to remark that, in particular cases and individuals (for example, in Halley's comet, seen at the end of January 1836 at the Cape of Good Hope), there has been observed in the parabolic front part of the comet such a well-marked and definite outline, as we hardly ever see in the piled up clouds or cumuli of our atmosphere. The illustrious observer at the Cape compared the unusual appearance, indicative of the strength of the mutual attraction of the particles, to an alabaster vessel strongly illuminated from within (⁶⁶⁸).

Since the appearance of the first volume of my work, an occurrence has presented itself among the bodies of which we are treating, the mere possibility of which could scarcely have been anticipated. Biela's comet, (an interior comet of short period of revolution, $6\frac{2}{3}$ years), parted asunder and formed two comets, similar in form though unequal in

size, each exhibiting both a head or nucleus, and a tail. So long as they could be observed they did not reunite, but were moving onward separately and almost parallel to each other. As early as the 19th of December, 1845, Hind had remarked in the still undivided comet a kind of protuberance towards the north: on the 21st, when observed by Encke at Berlin, nothing resembling a division could yet be seen. On the 29th, the division which had then taken place, was first seen and recognised in North America; in Europe it was not perceived until the middle and end of January, 1846. The new smaller comet moved foremost towards the north. The distance between the two was at first 3, and afterwards (20th of February), according to Otto Struve's interesting drawing, 6 minutes (⁶⁶⁹). The strength of the light varied, so that the light of the gradually increasing second comet was for a time greater than that of the first or original comet. The nebulous envelopes surrounding each of the two nuclei had no definitely marked outlines: in the larger comet there was even, towards the S.S.W., a swelling of very faint light; but the space between the two comets was seen at Pulkowa to be entirely free from nebulosity (⁶⁷⁰). Some days later, Lieutenant Maury, at Washington, noticed with a 9-inch Munich refractor rays sent by the larger older comet to the smaller new one, so that there was for a time a sort of bridge-like connection between them. On the 24th of March, the smaller comet, from the increasing faintness of its light, could but just be recognised. Afterwards the larger comet was alone seen up to the 16th or 20th of April, when it also vanished. I have described the particulars of this wonderful phænomenon (⁶⁷¹) so far as it was possible to observe them: unhappily the act of separa-

tion, and the state of the older comet a short time previously, escaped observation. Did the separated comet become invisible solely from increasing distance and great faintness of light, or did it dissolve? Will it again appear and be recognised as a companion? and will Biela's comet on future reappearances present to us similar anomalous phænomena?

The production of a new planetary cosmical body by division, naturally suggests the question, whether, in the multitude of comets revolving round the Sun, several may not have originated, or may originate from time to time, by a similar process? and whether, by retardation, *i. e.* unequal velocity of revolution, and by unequal influence of perturbations, different orbits may not be produced? In a memoir by Stephen Alexander, to which I have already alluded, it is attempted to explain the origin of all the interior comets by the adoption of such an hypothesis, which cannot, indeed, be said to rest on any adequate foundation. It would seem as if similar cosmical events had been observed, but not sufficiently well described, by the ancients. Seneca relates,—but, indeed, as he himself states, not on trustworthy testimony,—that the comet, to which the downfall of the cities of Helice and Bura was attributed, divided asunder into two parts. He adds, mockingly—“Why is it that no one has yet seen two comets unite into one?”⁽⁶⁷²⁾ The Chinese astronomers speak of three “double,” or “couples of,” comets, which appeared in 896, and went through their course together⁽⁶⁷³⁾.

Among the great number of comets whose course has been computed, there are eight whose periods of revolution are of shorter duration than the period of revolution of Neptune. Of these eight, six are interior comets, *i. e.* comets

whose aphelia are less distant from the Sun than is a point in the orbit of Neptune: they are—Encke's comet (aphelion 4.09); de Vico's (5.02); Brorsen's (5.64); Faye's (5.93); Biela's (6.19); and d'Arrest's (6.44). The Earth's mean distance from the Sun being unity, the paths of all these six interior comets have aphelia situated between Hygeia (3.15) and a limit which is placed almost $1\frac{1}{4}$ distances of the Earth beyond Jupiter (5.20). The two other comets which have also shorter periods of revolution than Neptune, are Olbers's comet, having a period of 74, and Halley's, having a period of 76 years. Up to the year 1819, when the existence of an interior comet was first recognised by Encke, the above-named two comets were those which had the shortest known periods of revolution. The aphelia of Olbers's comet of 1815, and of Halley's comet, are situated only 4 and $5\frac{2}{5}$ distances of the Earth from the Sun beyond the limit at or within which, according to the discovery of Neptune, they would be considered interior comets. Although the application of the term "interior comet" may undergo alteration by the future discovery of trans-Neptunian planets, since the limit which renders comets "interior" is a variable one, yet the term is preferable to that of "comets of short period," inasmuch as it depends at every epoch of our knowledge on something definite at that epoch. The six interior comets which have now been securely computed, only vary indeed in their periods of revolution from 3.3 to 7.4 years; but if the expectation of the return at the end of 16 years of the comet discovered by Peters at Naples, on the 26th of June, 1846 (the 6th comet of the year 1846, with a semi-major axis of 6.32), should be confirmed (674), it may be anticipated that, as respects the

duration of the period of revolution, intermediate links will gradually be discovered between the comets of Olbers and of Faye, and that it will in future be difficult to determine any fixed limit defining "shortness of period." I subjoin the table in which Dr. Galle has collected the elements of the six interior comets (see p. 410).

It follows from this review, that from the recognition of Encke's (⁶⁷⁵) as an interior comet, in 1819, to the discovery of the last interior comet of d'Arrest, 32 years only have elapsed. Elliptic elements for the last-named comet have also been computed by Yvon Villarceau, in Schumacher's *Astr. Nachr.* No. 773, who, as well as Valz, has expressed some conjectures respecting its possible identity with the comet of 1678, observed by La Hire, and calculated by Douwes. Two other comets, apparently also having periods of revolution of five or six years, are—the 3d of 1819, discovered by Pons, and calculated by Encke; and the 4th of 1819, found by Blanpain, and considered by Clausen to be identical with the 1st of 1743. Neither of these comets, however, can yet be classed with those in regard to which long-continued and exact observations permit greater certainty and completeness in the assigned elements.

The inclination of the paths of the interior comets to the ecliptic is, generally speaking, small, *i. e.* between 3° and 13° : in Brorsen's comet only it is considerable, attaining 31° . All the interior comets which have yet been discovered, have, like all the planets and satellites of the solar system, a direct motion (advancing in their orbits from west to east). Sir John Herschel has called attention to the greater rarity of retrograde motion in those comets whose degree of inclination to the ecliptic is small (⁶⁷⁶). This opposite direction

MORE EXACTLY CALCULATED ELEMENTS OF THE 6 INNER COMETS.

| | Encke. | de Vico. | Brorsen. | d'Arrest. | Biela. | Faye. |
|--|---|--|---|---|--|---|
| Epoch of the passage through the perihelion in mean Paris time | 1848, Nov. 26 2 ^h 55 ^m 56 ^s | 1844, Sept. 2 11 ^h 33 ^m 57 ^s | 1846, Feb. 25 9 ^h 8 ^m 1 ^s | 1851, July 8 16 ^h 57 ^m 23 ^s | 1846, Feb. 10 23 ^h 51 ^m 36 ^s | 1843, Oct. 17 3 ^h 42 ^m 16 ^s |
| Longitude of the Perihelion | 157° 47' 8" | 342° 30' 55" | 116° 28' 15" | 322° 59' 46" | 109° 2' 20" | 49° 34' 19' |
| Longitude of the Ascending Node | 334 22 12 | 63 49 17 | 102 40 58 | 148 27 20 | 245 54 39 | 209 29 19 |
| Inclination to the Ecliptic | 13 8 36 | 2 54 50 | 30 55 53 | 13 56 12 | 12 34 53 | 11 22 31 |
| Semimajor axis | 2.214814 | 3.102800 | 3.146494 | 3.461846 | 3.524522 | 3.811790 |
| Perihelion distance | 0.337032 | 1.186401 | 0.650103 | 1.173976 | 0.8566448 | 1.692579 |
| Aphelion distance | 4.092595 | 5.019198 | 5.642884 | 5.749717 | 6.192596 | 5.931001 |
| Excentricity | 0.847828 | 0.617635 | 0.793388 | 0.660881 | 0.757003 | 0.555962 |
| Period of revolution in days | 1204 | 1996 | 2039 | 2353 | 2417 | 2718 |
| Period of revolution in years | 3.30 | 5.47 | 5.58 | 6.44 | 6.62 | 7.44 |
| Calculated by | Encke, Astr. Nachr. xxvii. p. 113. | Brünnow, Prize Memoir, Amst. 1849. | Brünnow, Astr. Nachr. xxix. p. 377. | d'Arrest, Astr. Nachr. xxxiii. p. 125. | Plantamour, Astr. Nachr. xxv. p. 117. | Le Verrier, Astr. Nachr. xxiii. p. 196. |

of motion, which exists only in a certain class of bodies belonging to the solar system, is of great importance in reference to a very generally prevailing opinion respecting the origin of celestial bodies belonging to one system, and respecting primitive impulse. It appears to shew us the comet-world, though placed in the remotest distance, subjected to the attraction of the central body, yet possessing greater individuality than the planets. Such a consideration has led, unduly, to the idea of comets being older than planets (⁶⁷⁷),—of their being, as it were, primeval forms of imperfectly condensed cosmical matter in space. Under this supposition it has been asked whether, notwithstanding the enormous distance of the nearest fixed star of which we know the parallax from the aphelion of the comet of 1680, some of the comets which come within our view may not be wanderers passing through our system, from the domain of one sun to that of another?

I propose to place next to the class of comets, as with great probability belonging to the solar domain, the Ring of the Zodiacal Light; and next to that, the multitude of meteoric asteroids which sometimes fall upon our Earth, and respecting the existence of which as bodies in cosmical space unanimity of opinion by no means prevails. As I myself, conformably to the examples of Chladni, Olbers, Laplace, Arago, John Herschel, and Bessel, decidedly regard aerolites as being of extra-terrestrial cosmical origin, I may naturally close the present section on those cometary bodies, which have been sometimes termed “wandering stars,” with the expression of a confident expectation, that by increasing care and accuracy in the observation of aerolites, fireballs, and falling stars, the oppo-

site opinion will disappear, as the opinion which generally prevailed up to the 16th century of the meteoric origin of comets has long since done. Although in ancient times the astrological corporation of the "Chaldeans in Babylon," a large part of the Pythagorean school, and Apollonius the Myndian, regarded comets as celestial bodies, returning at determinate periods in long planetary paths,—on the other hand, the powerful anti-Pythagorean school of Aristotle and Epigenes, combated by Seneca, declared them to be products of meteorological processes in our atmosphere (678). Analogous fluctuations of opinion between cosmical and telluric hypotheses, between external space and the atmosphere of our own planet, will in the end conduct us, in the case of aerolites also, to the reception of just views.

IV.

RING OF ZODIACAL LIGHT.

IN our richly varied Solar System, several of the distinct classes of bodies of which it consists have only been recognised by us in their existence, place, and form, at successive intervals of time, in the last two centuries and a half. There have thus been made known to us:—First, subordinate or particular systems, in which, in analogy with the chief or general system of the solar domain, smaller cosmical spheroidised bodies revolve around a larger one;—next, the existence of concentric rings surrounding one of the less dense exterior planets, being also the one amongst them which is most rich in satellites;—next, the existence and the probable material cause of the mild, pyramidally shaped, Zodiacal Light, very visible to the unassisted eye;—next, the mutually intersecting orbits of what are called the small planets or asteroids, situated beyond the zodiacal zone, and included between the domains of two primary planets;—and lastly, the remarkable group of inner comets, whose aphelia are less

remote than the aphelia of Saturn, of Uranus, or of Neptune. In a cosmical presentation or description of the Universe, it is right to recall this variety or diversity between different members of the solar system, which, however, by no means excludes uniformity of origin and permanent dependence on the same motive forces.

Great as is still the obscurity which surrounds the material or physical cause of the Zodiacal Light, yet, considering the mathematical certainty that the limits of the Sun's atmosphere cannot extend beyond $\frac{9}{10}$ of the distance of Mercury, the opinion contended for by Laplace, Schubert, Arago, Poisson, and Biot,—according to which the Zodiacal Light is supposed to proceed from a detached, vaporous, flattened ring, revolving freely in space between the orbits of Venus and Mars,—would seem the most satisfactory hypothesis which presents itself in the present very defective state of our knowledge. In the Sun, as well as in Saturn (a subordinate system), the outermost limit of the atmosphere can only extend to where the attraction of the central body (whether primary or secondary) exactly balances the centrifugal force: the portions of the atmosphere which may have passed beyond this limit become detached, and must pursue their course either condensed into spheroidal planets or satellites, or, if not in the form of spheres, in that of solid or of vaporous rings. According to this view, the “Ring of the Zodiacal Light” would take its place in the category of planetary forms, subject to the general laws of their formation.

From the small progress in respect to observation which has been made in this neglected part of our astronomical

knowledge, I have little to add to what I have already said concerning it, derived from my own experience and from that of others (Kosmos, Bd. i. S. 142—149, and 409—414, Anm. 61—78; Bd. iii. S. 323: English edit. Vol. i. p. 127—133, and xxxiii.—xxxvii. Notes 91—99; Vol. iii. p. 228). Twenty-two years before the Zodiacal Light was seen and noticed by Dominique Cassini, to whom its first observation is commonly ascribed, Childrey (Chaplain to Lord Henry Somerset), in his *Britannia Baconica*, published in 1661, recommended it to the attention of astronomers as a previously undescribed phænomenon, which he had seen for several years in the month of February and in the beginning of March. I think it also right to remind my readers of a letter from Rothmann to Tycho Brahe (noticed by Olbers), from which it appears that, as early as the end of the 16th century, Tycho had seen and remarked the shining of the Zodiacal Light, and had taken it for an abnormal vernal evening twilight. I was myself first stimulated to make this phænomenon the object of persevering observation, from being struck, as I was quitting Europe, with its increasing brightness in Spain, on the coast of Valencia, and in the plains of New Castille. I found that the strength of the light, I might almost say of the illumination, increased astonishingly as I approached the equator in South America and in the Pacific. In the ever-dry clear air of Cumana, in the grassy steppes (Llanos) of Caracas, on the high table-lands of Quito and the Mexican Lakes, and more particularly at elevations from eight to twelve or thirteen thousand feet, where I was able to remain for a longer time, I found its brightness sometimes surpass that of the finest parts of the Milky Way,

between the front part of the constellation of the Ship and Sagittarius; or, to name portions of the heavens visible in our own hemisphere, between Aquila and Cygnus.

On the whole, however, the brightness of the Zodiacal Light did not appear to me to increase sensibly with the elevation of the observer's station, but rather to depend principally on internal variations, *i. e.* on greater or less degrees of luminous intensity in the phænomenon itself. I even remarked, when in the Pacific, a counter-glow, like that of sunset. I have said, depending "*principally*" on internal variations, because I by no means deny the possibility of a concurrent influence from the greater or less transparency of the upper strata of the atmosphere, while in its lower strata my instruments indicated no hygrometric changes, or sometimes such as would have had an opposite tendency. Advances in our knowledge of the Zodiacal Light may be most hopefully looked for from the tropical regions, where meteorological processes attain the greatest degree either of uniformity or of regularity in their periodical variations. The phænomenon is there perpetual: and a careful comparison of observations at stations of different elevation, and under different local circumstances, would enable us to decide, by the aid of the calculus of probabilities, what we ought to ascribe to cosmical luminous processes, and what to mere meteorological influences.

It has been stated more than once, that for several successive years scarcely any Zodiacal Light, or only a very faint trace of it, has been seen in Europe. Does the light appear proportionally enfeebled in the equatorial zone in years when this is the case? Such an investigation, how-

ever, must not be limited to the configuration of the light, derived either from distances from known stars, or from direct measurements. The intensity of the light, its uniformity, or, on the other hand, its intermittence (quivering and flashing), and its analysis by the polariscope, ought to be the chief objects of examination. Arago (in the *Annuaire* for 1836, p. 298) has already pointed out that a comparison of the observations of Dominique Cassini is perhaps sufficient to show “*que la supposition des intermittences de la diaphanéité atmosphérique ne saurait suffire à l'explication des variations signalées par cet astronome.*”

Immediately after the first Paris observations of this great observer, and of his friend, Fatio de Duillier, the Zodiacal Light attracted the regard of the Indian voyagers, Pater Noel, de Bèze, and Duhalde; but detached notices (for the most part chiefly occupied with describing the gratification afforded by the unwonted spectacle) are not available for a thorough discussion of the causes on which the variability of the light depends. It is not on rapid journeys, or voyages called voyages of circumnavigation, as the endeavours of the active Horner have shewn in more recent times (*Zach, Monatl. Corresp. Bd. x. S. 337—340*), that the desired object can be attained in a thorough and satisfactory manner. A permanent residence of several years in some of the countries of the tropics is requisite for obtaining the solution of the problems, presented by the variations in form and intensity of the Zodiacal Light. For this object, as well as for meteorology generally, the greatest advantages may be expected, when scientific cultivation shall at length have extended over the equinoctial regions formerly called Spanish America,

where large populous cities—Cuzco, La Paz, and Potosi—are situated at 10700 and 12500 (about 11400 and 13320 English) feet above the level of the sea. The numerical results at which Houzeau has been able to arrive, and which, indeed, could only be based on a small number of accurate observations, render it probable that the major axis of the Ring of the Zodiacal Light does not coincide with the plane of the Sun's equator, and that the vaporous mass of the Ring, whose molecular condition is wholly unknown to us, does not pass beyond the Earth's orbit (Schum. Astr. Nachr. No. 492).

V.

FALLING STARS, BALLS OF FIRE, AND METEORIC STONES.

SINCE the spring of 1845, when I published the first volume of *Kosmos*, containing the Picture of Nature or General View of Cosmical Phænomena, the earlier results of observation of falls of Aerolites, and of periodical streams of falling stars which were then at my disposal, have been largely augmented, thus rendering our knowledge on the subject in many ways more extensive and more correct. Many questions have undergone stricter and more critical examination, more especially the very important one of what has been called "radiation," *i. e.* points of departure from whence the shooting stars appear to proceed, at the recurring epochs or periods at which they are seen to fall in unusual abundance. Recent observations, the results of which present a high degree of probability, have also augmented the number of such epochs, of which the August and November periods were for a long time the only ones which attracted attention. The meritorious exertions, first of Brandes, Benzenberg, Olbers, and Bessel; and subsequently of Erman, Boguslawski, Quetelet, Feldt, Saigey, Eduard Heis, and Julius Schmidt, have led

to the employment of more exact corresponding measurements; while at the same time a more widely prevailing mathematical training has rendered observers less liable to persuade themselves of the accord of uncertain observations with a previously conceived theory.

The progress of our knowledge respecting igneous meteors will be the more rapid the more impartially facts are separated from opinions, so that while carefully sifting or testing all alleged particular facts, on the one hand, we may not, on the other, fall into the error of rejecting as bad or as uncertain observations, whatever results we are not yet able to explain. It appears to me most important to separate physical relations, from those geometrical and numerical relations which admit, generally speaking, of more certain and assured investigation. To this latter class belong—altitude; velocity; unity or multiplicity of points of departure where “radiation” is recognised; mean number of igneous meteors, whether in sporadic or periodic phænomena, reduced, in order to determine their frequency, to the same standard of measure in time, magnitude, and form,—all being considered in connection with the seasons of the year, and with hours, or intervals before and after midnight. The investigation of both classes of circumstances or relations, viz. the physical and the geometrical, will gradually lead to one and the same object, *i. e.* to “genetic” considerations on the true nature and character of these phænomena.

I have before pointed out that, generally speaking, our communication with the regions of cosmical space is solely through light- and heat-exciting undulations, and through the mysterious forces of attraction, exerted by distant masses or celestial bodies according to the quantity of their material

particles, on our globe, its oceans, and its atmosphere. The luminous vibration which proceeds from the smallest telescopic fixed star in a resolvable nebula, to the impression of which our eye is susceptible, brings to us, (as is mathematically shewn by the sure knowledge we possess of the velocity and aberration of light), the evidence of the most ancient existence of matter of which we are cognisant (679). By a simple combination of ideas, a luminous impression received from the depths of star-filled space leads us back more than a myriad of ages into the depths of primeval time. The luminous impression given by streams or showers of falling stars, aerolite-discharging fire-balls, or similar igneous meteors, are of a wholly different nature, since they only kindle or become ignited on arriving at or entering the Earth's atmosphere; and, on the other hand, the falling aerolite affords the only instance of actual material contact with something foreign to our globe. "Accustomed to know non-telluric bodies solely by measurement, by calculation, and by the inferences of our reason, it is with a kind of astonishment that we touch, weigh, and submit to chemical analysis, metallic and earthy masses appertaining to the world without,"—to the celestial spaces external to our planet; and that we find in them our native minerals, rendering it probable, as was already conjectured by Newton, that substances belonging to one group of cosmical bodies, or to one planetary system, are for the most part the same (680).

We are indebted to the diligence of the Chinese, and to their habit of recording everything in registers, for the oldest chronologically determined falls of aerolites. Accounts of this kind go back to 644 years before our era; therefore to the time of Tyrtæus and of the second Messenian War of the

Spartans, 176 years before the fall of the enormous meteoric mass at *Ægos Potamoi*. Edouard Biot has discovered in the *Ma-tuan-lin*, which contains extracts from the astronomical section of the oldest imperial annals, 16 falls of aerolites for the interval between the middle of the 7th century B.C. and the 333d year of our era; whereas Greek and Roman writers mention only 4 such phænomena for the same interval.

It is worthy of remark, that the Ionic school, in early accordance with our present opinions, assumed the cosmical origin of meteoric stones. The impression made on all the Hellenic nations by so grand a phænomenon as that of *Ægos Potamoi* (at a spot which 62 years later was rendered still more celebrated by the victory of Lysander over the Athenians, which terminated the Peloponnesian War), must have exercised a decided and not sufficiently regarded influence on the direction and development of the Ionic Physical Philosophy⁽⁶⁸¹⁾. Anaxagoras of Clazomene was at the ripe age of 32 years when this remarkable event in nature took place. He viewed the heavenly bodies in general as stony masses torn off from the Earth by the violent action of the revolving force (*Plut. de plac. Philos. iii. p. 13*; and *Plato de legib. xii. p. 9667*), and deemed that these solid stony bodies were rendered glowing by the fiery æther, so that they radiate back the light imparted to them by the æther. According to Theophrastus (*Stob. Eclog. phys. lib. i. p. 560*), Anaxagoras said that, lower than the Moon, and between it and the Earth, there move yet other dark bodies, which may occasion eclipses of the Moon (*Diog. Laert. ii. 12*; *Origenes, Philosophum, cap. 8*). Diogenes of Apollonia, who, though not a scholar of Anaximenes⁽⁶⁸²⁾, probably belonged to a

period intermediate between Anaxagoras and Democritus, expresses himself still more clearly respecting the structure of the Universe. According to him, as I have already remarked elsewhere, "together with the visible stars there move other invisible ones, which are therefore without names. These sometimes fall upon the Earth and are extinguished, as took place with the star of stone which fell at Ægos Potamoi" (Stob. Eclog. p. 508) (683).

The "opinion of some natural philosophers" respecting igneous meteors (falling stars and aerolites), developed in detail by Plutarch in the Life of Lysander (cap. 12), is quite that of the Cretan Diogenes. It is there said, "falling stars are not emanations or rejected portions thrown off from the ethereal fire, which, when they come into our atmosphere, are extinguished after being kindled; they are rather celestial bodies, which, having once had an impetus of revolution, fall, or are cast down, to the Earth by its intermission" (684). We find nothing of this view of the structure of the Universe, or of the assumption of dark bodies which fall on our Earth from the celestial regions, in the teaching of the *ancient* Ionic school, from Thales and Hippo to Empedocles (685). The impression of the great natural event above alluded to, which took place in the 78th Olympiad, appears to have had a powerful effect in calling forth ideas connected with the fall of dark masses. In the late pseudo-Plutarch writings (Plac. ii. 13), we merely read that the Milesian Thales regarded "all the heavenly bodies as earthy and igneous bodies (*γεωδη και εμπυρα*)." The efforts and tendencies of the *early* Ionic physiology were directed to seeking out the primeval beginning of things; the origin of substances by mixture, and their gradual alteration and transi-

tion into one another; and to processes of formation by solidification or by rarefaction. The revolution of the celestial sphere, "which keeps the Earth steadfast in the centre," is, indeed, already mentioned by Empedocles as an active moving cosmical force. As in these first remote preludes, as it were, to physical theories of an æther, the fiery air, and even fire itself, represent the expansive force of heat, so there was connected with this upper æthereal region the idea of an impetus of revolution tearing away rocky fragments from the Earth. Hence Aristotle (*Meteorol.* i. 339, Bekker) terms the æther "the for-ever-moving body"—as it were, the immediate substratum of motion,—and seeks etymological reasons for this assertion (686). Therefore we find in the biography of Lysander, "that the intermission of the rotative force causes the fall of heavenly bodies;" as also in another place, where Plutarch is evidently alluding to the opinions of Anaxagoras, or of Diogenes of Apollonia (*de Facie in Orbe Lunæ*, p. 923), he puts forward the statement, "that the Moon, if its force of revolution ceased, would fall to the Earth, like the stone in the sling" (687). We see in this comparison of the sling, how the idea of a centrifugal force of rotation or revolution, which Empedocles recognised in the (apparent) revolution of the celestial sphere, gradually came to have associated with it the corresponding, or counterpart, idea of a centripetal force. This force was more clearly and specifically indicated by the most sagacious of all the elucidators of Aristotle, Simplicius (page 491, Bekker). He proposes to explain the "non-falling" of the heavenly bodies by the "force of revolution prevailing over the proper falling force, or downward traction." These are the first presentiments or anticipations respecting

active central forces ; and in a similar manner, recognising as it were the inertness or force of inertia in matter, John Philoponus, of Alexandria, a scholar of Ammonius Hermeæ, and probably also of the 6th century, ascribes “the motion of the revolving planets to a primitive impetus,” which he combines with the idea of “falling,” *i. e.* the idea of “a tendency in all matter, heavy or light, towards the Earth” (de Creatione Mundi, lib. i. cap. 12). We have thus attempted to shew how a grand natural phænomenon, and the earliest purely cosmical explanation of the fall of aerolites, contributed materially to promote, in Grecian antiquity, the gradual development, not indeed by mathematical combination, of the germs of that which, by the mental labour of succeeding centuries, led to the recognition of the laws of circular motion discovered by Huygens.

Commencing with the geometric relations of periodical (not sporadical) falling stars, we direct our attention by preference to that which more recent observations have shewn concerning the “radiation,” or “points of departure,” of the meteors, and their wholly “planetary velocity.” Both these features, of “radiation” and “velocity,” characterise them, with a high degree of probability, as luminous bodies independent of the Earth’s rotation, arriving in our atmosphere from “without,” or from the regions of space. The North American observations of the “November period,” on the occasions of the showers of falling stars in that month, in the years 1833, 1834, and 1837, had caused the direction of the star γ Leonis to be indicated as the point of departure ; and the observations of the “August phænomenon,” in 1839, indicated, in the same way, the star Algol in the constellation of Perseus, or a point between

Perseus and Taurus. Approximately, these points or "radiation-centres" were the constellations towards which the Earth was moving at the respective epochs (⁶⁸⁸). Saigey, who had submitted all the American observations of 1833 to a very exact investigation, remarked that the steady radiation from the constellation of Leo was observed, strictly speaking, only after midnight, in the last three or four hours before day-break; and he further notices, that out of 18 observers between the city of Mexico and Lake Huron, only 10 recognised the same general point of departure of the meteors as did Denison Olmsted, Professor of Mathematics at Newhaven, Massachusetts (⁶⁸⁹).

The excellent memoir of Eduard Heis, at Aix-la-Chapelle, which presents in a brief and condensed form very exact observations made by himself on periodical returns of falling stars at Aix during ten years, contains results respecting the "centres of radiation," which are the more important because the observer has submitted them to a rigid mathematical discussion. According to him (⁶⁹⁰), the falling stars of the November period are characterised by their paths being more dispersed than those of the August period. But in each of the two periods there were observed to be, simultaneously, more points of departure than one, these being by no means always situated within the same constellation, as since 1833 had been too hastily assumed. Heis found in the August periods of 1839, 1841, 1842, 1843, 1844, 1847, and 1848, in addition to the principal point of departure in Perseus, two others situated in Draco and in the North Pole (⁶⁹¹). "In order to obtain accurate results in respect to the points of departure of the paths of falling stars in the November period, in the years

1839, 1841, 1846, and 1847, the mean paths belonging respectively to each of the 4 points (in Perseus, Leo, Cassiopeia, and the head of Draco), were laid down separately on a 30-inch celestial globe, and the position of the point from which the greatest number of paths took their departure was on every occasion deduced. The result derived from the investigation was, that out of 407 falling stars of which the paths were marked, 171 proceeded from the constellation of Perseus, near the star η in the head of Medusa, 83 from Leo, 35 from the part of Cassiopeia near the variable star α , 40 from the head of Draco, and fully 78 from undetermined points. Thus the falling stars which radiated from Perseus were almost twice as numerous as those from Leo" (692).

The radiation from Perseus would appear a very remarkable fact, as having shewn itself in both periods. An acute observer, who has been occupied for eight or ten years with the phænomena of meteors, Julius Schmidt, Assistant at the Astronomical Observatory at Bonn, expresses himself very distinctly on this subject, in a letter to myself, written in July 1851:—"Abstracting the abundant falls of shooting stars of November 1833 and 1834, as well as some later ones, in which the point in Leo seemed to send forth swarms of meteors, I am at present inclined to regard the point of convergence in Perseus as that which furnishes the greatest number of meteors, not only in August, but throughout the year. Taking as my basis the values derived from 478 observations by Heis, I find that this point is situated in $50^{\circ} 3' \text{ R.A.}$, and $51^{\circ} 5' \text{ Decl.}$: this applies to the years 1844—1846. In November 1849 (7th to 14th), I saw two hundred more falling stars than, since 1841, I had ever observed in the month of November. Of these, generally

speaking, only a few came from the constellation of Leo; by far the greater number from that of Perseus. Hence it appears to me to follow, that the *great* November phænomenon of 1799 and 1833 did not reappear at that time (1841). Olbers also believed the maximum effect in the November phænomenon to have a period of 34 years (Kosmos, Bd. i. S. 132; English edit. p. 117). If we consider the directions of the paths of the meteors in all their complication, and have regard to their periodical return, we find that there are certain points or centres of radiation which always recur, and others which appear only sporadically and in a variable manner."

Whether the different points of departure vary from year to year,—which, if we assume the existence of "closed rings," would indicate an alteration in the situation of the rings in which the meteors move,—cannot as yet be certainly determined from the observations. A fine series of such observations, by Houzeau (in the years 1839—1842), appears to testify against a progressive variation (⁶⁹³). Eduard Heis has shewn very justly (⁶⁹⁴) that in Greek and Roman antiquity, attention had already been drawn to a certain temporary uniformity in the direction in which the falling stars shot across the celestial vault: this direction was then regarded as the effect of a wind already beginning to blow in the higher parts of the atmosphere, and was thus believed to announce to navigators an approaching gale from the same quarter, which might be expected to descend from the upper to the lower regions.

If the periodical streams of shooting stars are distinguished from sporadical ones by the general parallelism of the paths, or by their radiating from one or more determinate points of departure, a second criterion is also afforded by the num-

bers in a given interval of time. This brings us to the much contested problem of the distinction between an extraordinary and an ordinary fall of shooting stars. Two excellent observers, Olbers and Quetelet, have respectively assigned, the one 5 or 6, and the other 8, as the mean or average hourly number of meteors visible within one person's sphere of vision (⁶⁹⁵) on days not extraordinary. The discussion of a very large number of observations is required for the elucidation of this question, which is as important as the determination of the laws in respect to their direction. I therefore addressed myself with confidence to the already mentioned observer, Julius Schmidt, at Bonn, who, long accustomed to astronomical accuracy, has also comprehended in his labours, with the animated zeal which belongs to him, the whole of the phænomenon of meteors, of which the formation of aerolites and their precipitation or fall upon the surface of the Earth are regarded by him as only one of the phases,—the rarest, and therefore not the most important. The following are the principal results contained in the communications with which, in compliance with my request, he has favoured me (⁶⁹⁶).

“Between three and eight years of observation have given for the phænomenon of sporadic shooting stars the mean number of from 4 to 5 per hour: this is the ordinary state, as distinguished from a periodical phænomenon. The mean numbers of *sporadically* shooting or falling stars per hour, in the several months, are as follows:—

January, 3·4; February, —; March, 4·9; April, 2·4;
May, 3·9; June, 5·3; July, 4·5; August, 5·3; Sep-

tember, 4·7 ; October, 4·5 ; November, 5·3 ; December, 4·0.

In *periodical* falls of meteors we may expect, on the average, from 13 to 15 in each hour. For a single period, that of August,—the stream of St. Lawrence,—we find on the mean of from 3 to 8 years of observation, the following gradual increase of numbers from the ordinary sporadical, to the extraordinary periodical, phænomenon :—

| Time. | Number of Meteors per Hour. | Number of Years of Observation. |
|----------------------|--------------------------------|------------------------------------|
| 6th August | 6 | 1 |
| 7th „ | 11 | 3 |
| 8th „ | 15 | 4 |
| 9th „ | 29 | 8 |
| 10th „ | 31 | 6 |
| 11th „ | 19 | 5 |
| 12th „ | 7 | 3 |

August of the last year, 1851, (a single year therefore) gave per hour, notwithstanding the bright moonlight,—

| | |
|----------------------|------------|
| 7th August | 3 meteors. |
| 8th „ | 8 „ |
| 9th „ | 16 „ |
| 10th „ | 18 „ |
| 11th „ | 3 „ |
| 12th „ | 1 meteor. |

According to Heis, there were observed, on the 10th of August—

| | | |
|------------------------------|-----|----------|
| In 1839, in 1 hour | 160 | meteors. |
| In 1841 „ | 43 | „ |
| In 1848 „ | 50 | „ |

In 1842 there fell, in the August stream of meteors, at the time of the maximum of the phænomenon, 34 shooting stars in 10 minutes. All these numbers refer to the sphere of vision of one observer. Since 1838, the November falls have been less remarkable. (However, on the 12th of November, 1839, Heis still counted from 22 to 35 meteors per hour; and on the 13th November, 1846, from 27 to 33.) So much do the streams of meteors differ in abundance in particular years. The number of falling meteors is, however, always considerably greater at those periods than in ordinary nights, which shew only 4 or 5 sporadically shooting stars in an hour. It is in January (reckoning from the 4th), in February, and in March, that meteors appear to be most rare” (697).

“Although the August and November periods are, with reason, the most remarked, yet, since falling stars have been observed with greater watchfulness and exactness, both in regard to number and parallelism, five other periods have also been recognised :—

January : the two or three first days, from the 1st to the 3d; still somewhat doubtful.

April : 18th or 20th? previously conjectured by Arago. Great streams occurred on the 25th of April, 1095; 22d April, 1800; 20th April, 1803 (Kosmos, Bd. i. S. 404; Engl. ed. p. xxix. Note 74; Annuaire pour 1836, p. 297).

May : 26th?

July: 26th to 30th; Quetelet. Maximum more particularly between the 27th and 29th July. The lamented Edouard Biot found from the oldest Chinese observations a general maximum between the 18th and 27th of July.

August: but prior to the stream of St. Lawrence, and particularly between the 2d and 5th of the month. For the most part no regular increase is observed from the 26th of July to the 10th of August.

—— The “August period,” or “stream of St. Lawrence” itself; Muschenbroeck and Brandes (Kosmos, Bd. i. S. 130 and 403; English edit. pp. 114 and xxviii. Notes 71 and 73). A decided maximum on the 10th of August observed for many years. (An ancient tradition prevails in Thessaly, in the mountainous districts around Mount Pelion, that during the night of the Feast of the Transfiguration, on the 6th of August, the heavens open, and lights, or candles, *κανδήλια*, appear in the midst of the opening. Herrick, in Silliman’s Amer. Jour. Vol. xxxvii. 1839, p. 337; and Quetelet, in the Nouv. Mém. de l’Acad. de Bruxelles, T. xv. p. 9.)

October: the 19th and about the 26th. Quetelet; Boguslawski in the “Arbeiten der schles. Gesellschaft für vaterl. Cultur,” 1843, S. 178; and Heis, S. 33. Heis brings together observations of the 21st Oct. 1766, 18th Oct. 1838, 17th Oct. 1841, 24th Oct. 1845, 11th—12th Oct. 1847, and 20th—26th Oct. 1848. (On the three October phænomena in the years 902, 1202, and 1366, see Kosmos, Bd. i. S. 133 and 398; English edit. p. 118 and p. xxiv.) The conjecture of Boguslawski, that the Chinese meteor-swarms of 18th—27th July, and the great fall of shooting stars of 1366,

on the 21st October (Old Style), were the August and November periods which have now moved forward, loses much of its weight by the considerable amount of new experience gained from 1838 to 1848 (⁶⁹⁸).

November: 12th to 14th day; very rarely the 8th or 10th. The great fall of meteors at Cumana, 11th—12th November, 1799, which was described by Bonpland and myself, so far gave occasion to the belief in periodically returning phænomena on determinate days, that when the similarly great meteor-fall of 1833 (Nov. 12th—13th) took place, the phænomenon of 1799 was remembered (⁶⁹⁹).

December: 9th—12th; but, according to Brandes' observation, Dec. 6th—7th, in 1798; Herrick, in New-haven, 1838, Dec. 7th—8th; Heis, 1847, Dec. 8th and 10th.

These eight or nine epochs of periodical streams of meteors, of which the last five are the best assured, are here recommended to the diligence of observers. Not only do the streams differ from each other in different months, but also the abundance and brightness of the same stream differ strikingly in different years.

“The upper limit of the height above the Earth of falling stars cannot be accurately made out, and Olbers already regarded all heights of above 30 German, or 120 English geographical miles, as very uncertainly determined. The lower limit, formerly assigned as usually about 16 miles (or upwards of 95000 feet), must be considerably diminished. Some are found by measurement to descend almost as low as the summits of Chimborazo and Aconcagua, or to within

4 geographical miles of the level of the sea. On the other hand, Heis remarks that, by exact calculation, a shooting star seen on the 10th of July, 1837, simultaneously at Berlin and at Breslau, shone out first at an elevation of 62 German, or 248 English miles, and disappeared at the height of 42 German, or 168 English miles: other shooting stars, on the same night, vanished at the height of 56 English geographical miles. From the older investigation of Brandes (1823), it followed that out of 100 shooting stars seen and well measured from two stations, 4 had an elevation of only from 4 to 12 English geographical miles, 15 between 12 and 24; 22 between 24 and 40; 35 (about one-third of the whole number) between 40 and 60; 13 between 60 and 80; and only 11 (about one in ten of the whole) above 80, these being, indeed, mostly between 180 and 240 English geographical miles. The inferences in respect to the colour of shooting stars, derived from a collection of 4000 observations, extending over 9 years, were: that $\frac{2}{3}$ are white, $\frac{1}{7}$ yellow, $\frac{1}{17}$ orange, and only $\frac{1}{37}$ green."

Olbers remarked that, at Bremen, during the fall of meteors in the night of the 12th—13th November, 1838, there was a fine Aurora Borealis, which covered a large portion of the heavens with a vivid blood-red light; and that the falling stars which shot across this region preserved their whiteness unimpaired. Hence it may be inferred that the beams of the Aurora were further from the Earth than the shooting stars, when these last became invisible in their fall (Schum. Astr. Nachr. No. 372, S. 178).

The relative velocity of motion of shooting stars has hitherto been estimated at from $4\frac{1}{2}$ to 9 German, or 18 to 36 English geographical miles in a second; while the Earth

has only a velocity of translation of 4.1 German, or 16.4 English geographical miles (Kosmos, Bd. i. S. 127 and 400; English edit. p. 112 and xxv. Note 68). Corresponding observations by Julius Schmidt, at Bonn, and Heis, at Aix-la-Chapelle, in 1849, gave, indeed, as the minimum velocity of a shooting star, which was seen at a perpendicular height of 48 miles above St. Goar, and moved in the direction of the Lake of Laach, only 14 English geographical miles. According to other observations of the same observers, and of Houzeau at Mons, however, the velocity of four shooting stars was found between 46 and 95 English geographical miles in a second, therefore twice and five times as great as the planetary velocity of the Earth. The strongest evidence of a cosmical origin is afforded by this result, taken in connection with the circumstance that periodical shooting stars continue for several hours to proceed, independently of the Earth's rotation, from one and the same star, although the direction of the star may not be that towards which the Earth is then moving.

According to existing measurements, balls of fire appear on the whole to move more slowly than shooting stars. When meteoric stones drop from fire-balls, it is deserving of remark to how small a depth they sink into the ground. The mass, weighing 276 pounds, which fell on the 7th of November, 1492, at Ensisheim, in Alsace, only penetrated to a depth of about 3 feet; and the same was the case with the aerolite of Braunau, on the 14th of July, 1847. I only know of two meteoric stones which tore up the loose soil to a depth respectively of 6 and 18 feet; the aerolite of Castro Villari, in the Abruzzi, of the 9th of February, 1583, and

that of Hradschina, in the Agram district, 26th of May, 1751.

The question whether, in shooting stars, any substance falls to the earth, has been much discussed, and opposite opinions have been entertained. The straw-thatched roofs of the Commune of Belmont (Departement de l'Air, Arrondissement Belley), which were set on fire by a meteor on the night of the 13th of November (the epoch, therefore, of the November phænomenon), were ignited, it would appear, not by the fall of a shooting star, but by a bursting fire-ball, which, from the account given by Millet d'Aubenton, is supposed, (though this is uncertain,) to have let fall aerolites. A similar conflagration, occasioned by a ball of fire, happened on the 22d of March, 1846, at 3 in the afternoon, in the Commune de St.-Paul, near Bagnère de Luchon. The fall of stones which took place at Angers on the 9th of June, 1822, was, on the other hand, attributed to a fine shooting star seen near Poitiers. This phænomenon, which has not been described with sufficient fulness, deserves the greatest consideration. The falling star in question resembled much what are called Roman Candles in fireworks. It left behind a straight train or streak, very narrow in the upper, and very broad in the lower part; of great brightness, and lasting ten or twelve minutes. Sixty-eight miles north of Poitiers an aerolite fell, accompanied by loud detonations.

Do the substances of which the shooting stars consist always burn or consume in the outermost strata of the atmosphere, whose refracting power is shewn by the phænomena of twilight? The different colours exhibited, as mentioned above, during the process of combustion, appear to

indicate chemical diversity of substance. The form of these igneous meteors is also extremely variable: some appear only as phosphoric lines, and these so slender and numerous, that Forster, in the winter of 1832, saw the sky appear illuminated by them, as if covered by a faintly shining veil (700). Many shooting stars move merely as shining points, and leave no tail or train behind. The continued burning shewn in the more rapid or slower disappearance of the trains, which are usually many miles in length, is the more remarkable, because the burning train sometimes bends into a curve, and makes but little progressive movement. The circumstance observed by Admiral Krusenstern and his companions during their voyage of circumnavigation, of the luminosity continuing for some hours of the train of a fire-ball which had itself long disappeared, recalls vividly to our remembrance the "long shining" of the cloud from which, according to the not indeed altogether trustworthy narration of Damachos, the aerolite of *Ægos Potamoi* is supposed to have fallen (*Kosmos*, Bd. i. S. 395 and 407; English edit. pp. xxi. and xxxii. Notes 60 and 87).

There are shooting stars of very different magnitudes, their apparent diameters sometimes increasing until they are equal to that of Jupiter or Venus. In the fall of shooting stars at Toulouse, 10th April, 1812, and on the occasion of a ball of fire observed at Utrecht on the 23d of August of the same year, a body of large dimensions was seen to accrue, as it were, from a luminous point, first shooting upwards with the appearance of a star, and then expanding into a globe equal to the apparent magnitude of the Moon. In very abundant falls of meteors, as in those of 1799 and 1833, many fire-balls were undoubtedly inter-

dispersed among thousands of shooting stars; but the identity of these two kinds of igneous meteors is nevertheless, as yet, by no means proved. Affinity is not identity. There still remains much to be investigated in the physical relations of both these classes;—as also respecting the effect, remarked by Admiral Wrangel on the shores of the Icy Sea⁽⁷⁰¹⁾, produced by shooting stars on the development of the Aurora Borealis;—and the many vaguely described, indeed, but not therefore to be hastily denied, luminous processes which appear to have preceded the formation of some fire-balls. In the greater number of cases, balls of fire have appeared unaccompanied by falling stars; and there has been nothing periodical in the phænomenon. What we know of shooting stars, in respect to their radiation from particular points, can for the present only be applied with great caution to fire-balls.

Meteoric stones fall, in very rare cases, with a perfectly clear sky without the previous formation of a black meteor-cloud, and without any luminous phænomena being seen, but with a loud and terrible crashing sound, as at Klein Wenden, not far from Mühlhausen, on the 16th of September, 1843;—or, which is a less rare case, they are hurled from a suddenly formed dark cloud, accompanied with phænomena of sound, but without light;—and lastly, and this is the most frequent case, the fall of meteoric stones takes place in close connection with bright fire-balls. Well-described and indubitable examples of this connection are afforded by the falls of stones at Barbotan (Dep. des Landes), on the 24th of July, 1790, accompanied by the appearance, at the same time, of a red ball of fire and a small *white* meteoric cloud⁽⁷⁰²⁾, from which the aerolites fell; the

fall of a stone at Benares, in Hindostan, on the 13th of December, 1798; and that which took place at Aigle, in the Departement de l'Orne, on April 26th, 1803. This last-named phænomenon — which, of all those that have been enumerated, is the one which has been most carefully examined and described (by Biot), and which occurred twenty-three centuries after the fall of the great stone in Thrace, and three centuries after a friar had been killed by an aerolite at Crema (⁷⁰³),—finally prevailed over the scepticism which appears to be indigenious in academical bodies. The following is the description of the phænomenon of 1803:—At Alençon, Falaise, and Caen, at 1 P.M., a large ball of fire was seen moving from S.E. to N.W., with an everywhere perfectly clear sky. A few moments later, at Aigle, an explosion lasting five or six minutes was heard, taking place in a dark, almost motionless, very small cloud: it was followed by three or four detonations like cannon-shots, and by a noise resembling the fire of small arms and the roll of many drums. At each explosion some of the vapours forming the small dark cloud were seen to detach themselves and float away. At this place no luminous phænomena were perceived. At the same time there fell, on an elliptically shaped piece of ground, of which the major axis, running from S.E. to N.W., was nearly five English miles in length (1·2 German geographical mile), many meteoric stones, of which the largest weighed $17\frac{1}{2}$ pounds. The stones were hot, but not red hot (⁷⁰⁴), smoked sensibly, and, which is a very striking circumstance, were more easily broken in the few first days after their fall than subsequently. I have purposely dwelt the longer on this phænomenon, because I wish to compare it with one

which took place on the 13th of September, 1768. On that day, at half-past four in the afternoon, near the village of Luce (Departement de l'Eure et Loire), four miles west of Chartres, a dark cloud was seen, and there was heard to come from it a noise like a cannon-shot, followed immediately afterwards by a hissing in the air, occasioned by the fall of a black stone moving in a curve. The fallen stone, which was half sunk in the earth, weighed $7\frac{1}{2}$ pounds, and was so hot that it could not be touched. It was analysed, but only in a very imperfect manner, by Lavoisier, Fougereux, and Cadet. So far as was perceived the whole occurrence was unaccompanied by any luminous phænomena.

As soon as periodical falls of shooting stars became an object of observation, so that on particular nights their appearance was watched and waited for, it was remarked that the frequency of meteors increased with increasing time from midnight, and that the greatest number fell between 2 and 5, A.M. Even in the great fall of meteors at Cumana in the night of the 11th to 12th of November, 1799, my travelling companion had seen the greatest abundance of shooting stars between the hours of $2\frac{1}{2}$ and 4 A.M. A very meritorious observer of these phænomena, Coulvier-Gravier, presented an important memoir "Sur la variation horaire des étoiles filantes," to the Institut of Paris, in May 1845. It is very difficult to divine the reason of such an "horary variation," or why the distance from midnight should influence these phænomena. If it should be established that, under different meridians, shooting stars are not seen in their greatest abundance until a certain determinate period between midnight and day-break, we should have to assume, together with a cosmical origin, the not very probable

hypothesis that these hours of the night, or rather of the early morning, are peculiarly favourable to the "ignition," or luminousness, of falling stars; those which shoot in the hours before midnight remaining more often invisible. We must long continue to persevere in collecting observations. The principal characteristics of the solid masses which fall from the atmosphere, both as respects their chemical relations, and their granular texture which has been examined more particularly by Gustav Rose, have been treated by me in my first volume (*Kozmos*, Bd. i. S. 133—137; English edit. p. 119—122) with I believe tolerable completeness, according to the state of our knowledge at that time (1845). The successive labours of Howard, Klaproth, Thénard, Vauquelin, Proust, Berzelius, Stromeyer, Laugier, Dufresnoy, Gustav and Heinrich Rose, Boussingault, Rammelsberg, and Shepard, have supplied a rich harvest⁽⁷⁰⁵⁾; but it may not be inappropriate to remember, that probably two-thirds of the meteoric stones which have fallen are hidden from us in the depths of the sea. Although aerolites from all zones, and from the most widely dispersed places,—in Greenland, Mexico, and South America, Europe, Siberia, and Hindostan,—exhibit an obvious physiognomic similarity, when examined more closely they are also found to present great diversities. Some contain 96 per cent. of iron, others (Siena) scarcely 2 per cent. Almost all have a thin, black, shining, and at the same time somewhat veined, crust or coating; but in one (that of Chantonay), this crust was entirely wanting. The specific weight of some meteoric stones is as great as 4.28, while in the carbonaceous stone of Alais, consisting of friable lamellæ, it was found to be only 1.94. Some (Juvenas) have a texture resembling that

of dolerite, in which crystallised olivine, augite, and anorthite, can be severally recognised; others (as the mass of Pallas) shew merely iron, containing nickel and olivine; while others again (judging by the relative proportions of the ingredients) are aggregates of hornblende and albite (Chateau-Renard), or of hornblende and labradorite (Blansko and Chantonay).

According to a general review of the results which have been derived by Professor Rammelsberg,—an acute chemist, who has recently occupied himself uninterruptedly, with equal activity and success, with the analysis of aerolites, and with their composition from simple minerals,—“the distinction of masses which have fallen from the atmosphere into two classes—viz. meteoric iron and meteoric stones—is not to be taken rigidly and absolutely. We find, although rarely, meteoric iron with intermingled silicates, (in the Siberian mass of 1270 Russian pounds, which has been reweighed by Hess, there are interspersed grains of olivine);—and, on the other hand, many meteoric stones contain metallic iron.

“*A.* Meteoric iron,—the fall of which has only in a few cases been actually observed by eye-witnesses (Hradschina, Agram, 26th of May, 1751; and Braunau, 14th of July, 1847), while the greater number of analogous masses have remained long on the surface of the ground,—has in general very similar physical and chemical qualities. It almost always contains, in finer or coarser particles, a sulphuret of iron, which does not, however, appear to be either iron pyrites or magnetic pyrites, but proto-sulphuret of iron (⁷⁰⁶). The principal mass in such cases does not consist of a pure metallic iron; it is formed rather of an alloy

of iron and nickel: so that the presence of the nickel, which is a constant ingredient (on an average 10 per cent., sometimes rather more, and sometimes rather less), is justly regarded as an excellent criterion of the meteoric character of the entire mass. It is simply an alloy of two isomorphous metals, not a combination in definite proportions. We also find intermixed in smaller quantities cobalt, manganese, magnesium, tin, copper, and carbon. The last-named substance is partly mechanically interspersed in the form of graphite difficult of combustion, and partly chemically combined or united with iron; analogous, therefore, to much bar-iron. A mass of meteoric iron also always contains a peculiar combination of phosphorus with iron and nickel, which substances, on dissolving the iron in hydrochloric acid, remain behind in the form of microscopic crystalline needles and lamellæ of a silvery whiteness."

"*B.* Meteoric stones, more strictly so called,—are usually divided, according to their external appearance, into two classes. In one of these, the apparently homogeneous and principal portion of the mass shews interspersed grains and spangles of meteoric iron, which are attracted by a magnet, and are quite similar in their nature to meteoric iron, found by itself in larger masses. To this class belong, for example, the stones of Blansko, Lissa, Aigle, Ensisheim, Chantonnay, Klein Wenden near Nordhausen, Erxleben, Chateau-Renard, and Utrecht. The other class is free from metallic intermixtures, and presents rather a crystalline assemblage or mixture of different mineral substances; as, for example, in the stones of Juvenas, Lontalax, and Stannern."

After the first chemical examinations of meteoric stones made by Howard, Klaproth, and Vauquelin, the possibility

of their consisting of an assemblage of distinct combinations was for a long time not adverted to ; their component parts were examined only generally, and it was thought sufficient to remove by means of a magnet any metallic iron which might be contained in them. After Mohs had drawn attention to the analogy of some aerolites with certain telluric kinds of rock, Nordenskjöld attempted to shew that olivine, leucite, and magnetic iron, were the constituent parts of the aerolite of Lontalax, in Finland ; but the fine observations of Gustav Rose have shewn beyond a doubt that the meteoric stone of Juvenas consists of magnetic pyrites, augite, and a feldspar which has much resemblance to labradorite. Berzelius was thus led to examine by chemical methods the mineral nature of the several combinations in the aerolites of Blansko, Chantonay, and Alais (Kongl. Vetenskaps Academiens Handlingar för 1834). The path thus happily indicated by Berzelius has been since extensively pursued.

“*a.* The first and more numerous class of meteoric stones, viz. those with metallic iron, contain this substance, sometimes in minute interspersed particles, and sometimes in larger masses, which occasionally even form, as it were, a connected iron skeleton, thus constituting a transitional link with those masses of meteoric iron in which, as in the Siberian mass of Pallas, other substances are not found. The olivine which they always contain causes them to be rich in magnesia, and is itself the ingredient which is decomposed when these meteoric stones are treated with acids. Like the telluric olivine it is a silicate of magnesia and protoxide of iron. The part of the stones which is not attacked by acids is a mixture of feldspatic and augitic substances, the nature of which can only be determined by calculation from

the whole of the mixture (as labradorite, hornblende, augite, or oligoklas).

“*β*. The second, much rarer, class of meteoric stones has been less examined. These stones sometimes contain magnetic iron, olivine, and some feldspatic and augitic substances; and sometimes they consist merely of the two last mentioned simple minerals, and the feldspar is then represented by anorthite (707). Chromate of iron (protoxide of iron, oxide of chromium) is found in small quantities in almost all meteoric stones: phosphoric acid and titanitic acid, discovered by Rammelsberg in the remarkable stone of Juvenas, may perhaps indicate the presence of apatite and titanite.

“The simple substances which have as yet been shewn to exist in meteoric stones are the following:—Oxygen, sulphur, phosphorus, carbon, silicon, aluminum, magnesium, calcium, potassium, sodium, iron, nickel, cobalt, chrome, manganese, copper, tin, and titanium; being in all 18 substances (708). The more immediate components are—*a*, metallic: an alloy of nickel and iron, a compound of phosphorus with iron and nickel, sulphide of iron, and magnetic pyrites;—*b*, oxydised: magnetic iron and chromate of iron;—*c*, silicates: olivine, anorthite, labradorite, and augite.”

It would still remain for me, with the view of concentrating in this place the greatest possible number of important facts, taken apart from hypothetical anticipations, to point out the many analogies which some meteoric stones present, if regarded as rocks, with the older trap rocks (dolerites, diorites, and melaphyres), and to basalts and more recent

lavas. These analogies are the more striking, because the "metallic alloy of nickel and iron, which is constantly contained in certain meteoric masses," has not hitherto been discovered in telluric minerals. The same distinguished chemist of whose friendly communications I have availed myself in the last few pages, has enlarged upon this subject in a separate treatise (709), the results of which will be more appropriately noticed in the geological portion of the *Cosmos*.

CONCLUSION.

IN concluding the Uranological portion of the physical description of the Universe, and casting a retrospective glance on what has been attempted,—I will not say accomplished,—I feel it necessary, after the execution of so difficult an undertaking, to remind my readers afresh, that its accomplishment was only possible under the conditions which were indicated in the introduction to the third volume. The attempted cosmical treatment of Uranology is limited in its design to the presentation or description of what we know of the celestial spaces and the matter by which they are occupied, whether agglomerated into spheres, or existing in an uncondensed or unagglomerated form. The work undertaken is, therefore, in its nature essentially distinct from the more comprehensive meritorious works on astronomy in the different literatures of the present time. Astronomy itself, regarded as a science, and as the triumph of mathematical combination, based on the secure foundation of the doctrine of gravitation, and on the degree of perfection attained by the higher analysis as the intellectual instrument of investigation, treats of the phænomena of motion, as measured by time and space; of the locality or position of the celestial bodies in their continually varying

relations to each other; of changes of form, as in tailed comets; and changes of light, amounting even to new apparition and entire extinction of light in distant suns. The quantity of existing matter in the Universe remains, it is believed, always the same; but, according to what has been already investigated of the physical laws of nature in the *terrestrial* sphere, we there see ever recurring, as if ever unsatisfied, *change* ceaselessly prevailing in countless and indescribable combinations, in the perpetual circle of the permutation of substances. This manifestation of force or power in matter is called forth by its, at least apparent, elementary heterogeneity. Exciting motion in portions of space immeasurably small, the heterogeneity of substances complicates all problems relating to terrestrial processes of nature.

Astronomical problems are more simple in their character. Celestial mechanics, as yet free from the complications alluded to, and directed to considerations relative to the quantity of ponderable matter, *i. e.* to mass, and to light- and heat-exciting undulations, have, by reason of this simplicity, in which everything can be reduced to motion, remained amenable throughout to mathematical treatment. It is this advantage which gives to treatises on theoretical astronomy a great and peculiar charm. There is reflected in them what the mental labour of the last few centuries has achieved by analytical methods: we see in them how forms and orbits have been determined; how, in the phænomena of the motions of the planets, small fluctuations take place round a mean state of equilibrium; and how the preservation and permanence of the planetary system are provided for by its internal structure, and by the equilibrium of mutually compensating perturbations.

The examination of the means, or methods, by which we have thus arrived at the comprehension of the Universe, and the explanation of the intricate phænomena of the heavens, do not belong to the plan of the present work. The "Physical Description of the Universe" tells of the contents of space, and of the organic life which animates it, in the two spheres of uranologic and telluric relations. It dwells on the discovered laws of nature, and treats them as facts achieved and ascertained,—as the direct results of empirical induction. In order that a work on the Cosmos might be executed within its appropriate limits, and without acquiring an immoderate extension, it was necessary that it should not attempt to propound theoretically the bases of the connection of phænomena. In the view of this limitation of the proposed plan, I have devoted the more diligent care, in this astronomical volume of the Cosmos, to the several facts and to the order of their arrangement. From the consideration of cosmical space, *i. e.* its temperature, its degree of transparency, and the resisting medium which fills it, I have proceeded to the subjects of natural and telescopic vision; the limits of visibility; the velocity of light according to its different sources; our imperfect measurements of the intensity of light; and the new optical means of discriminating between direct and reflected light. Then follow,—the heaven of the fixed stars; the numbers of its self-luminous suns, so far as their positions are known to us, and their probable distribution; the variable stars which have well-measured periods; the proper motions of the fixed stars; the hypothesis of the existence of dark bodies, and their influence on the motions of double stars; and

lastly nebulæ, so far as these are not remote and very dense clusters of stars.

The transition from the sidereal portion of Uranology,—from the heaven of the fixed stars,—to our solar system, is only the transition from the universal to the particular. In the class of double stars, self-luminous cosmical bodies move round a common centre of gravity: in our solar system, which is composed of very heterogeneous elements, dark cosmical bodies revolve around a self-luminous one, or rather round a common centre of gravity which is sometimes within and sometimes without the circumference of the central body. The several members of the solar domain are more dissimilar in their nature than for many centuries there had been reason to suppose. They divide themselves into primary planets, and secondary ones or satellites, the primary planets having among them a group in which the orbits intersect each other;—an unascertained number of comets;—the ring of the zodiacal light;—and, with great probability, the periodic meteor-asteroids.

It still remains to state expressly the three great laws discovered by Kepler, in their actual application to the motions of the planets. First law: Every path of a planetary body is an ellipse, having the Sun in one of its foci. Second law: Every planetary body describes round the Sun equal areas in equal times. Third law: the squares of the periodic times of revolution of two planets are to each other as the cubes of their mean distances. The second of these laws is sometimes called the first, because it was discovered earlier than the others. (Kepler, *Astronomia nova, seu Physica cœlestis, tradita commentariis de motibus stellæ Martis, ex*

observ. *Tychonis Brahi elaborata*, 1609: compare cap. xl. with cap. lix.) The two first laws would be applicable if there were only one single planetary body in existence; the third and most important of the three, which was discovered nineteen years later than the other two, determines the law of the motions of two planets. (The manuscript of the *Harmonice Mundi*, which was published in 1619, was completed on the 27th of May, 1618.)

If the laws of the planetary motions were empirically discovered in the beginning of the 17th century, and if Newton first unveiled the force from whose action Kepler's laws must be regarded as necessary consequences, the end of the 18th century, through the new paths opened to the investigation of astronomical truths by the improvement of the infinitesimal calculus, has the merit of having demonstrated the "stability of the planetary system." The principal elements of this stability are, the invariability of the major axes of the planetary orbits demonstrated by Laplace (1773 and 1784), Lagrange, and Poisson; the long periodical variation, restricted within narrow limits, of the eccentricities of two large and remote planets, Jupiter and Saturn; the distribution of the masses, since the mass of Jupiter itself, the greatest of all the planetary bodies, is only $\frac{1}{1048}$ of that of the all-controlling central body; and lastly, the arrangement, that by the primordial plan of creation, and by the mode of their origination, all the planets of the solar system move in one direction both in regard to translation and to rotation, in orbits of small and little-varying ellipticity, and in planes having only moderate differences of inclination; and that the periods of revolution of the different planets have no common measure.

These elements of stability, elements as it were of the preservation and continuance of the "life" of the planets, are attached to the condition of mutual action within the interior of a circumscribed circle. If by the arrival from the regions of exterior space of a cosmical body not previously belonging to the system, this condition cease (Laplace, *Expos. du Syst. du Monde*, p. 309 and 391), then, indeed, there might ensue, as the result either of new forces of attraction or of a shock, consequences injurious or destructive to that which now exists, until at last, after a long conflict, a new equilibrium should be produced. The consideration of the possible arrival of a comet in a hyperbolic path from remote regions, even though the smallness of its mass should be compensated by an enormous velocity, could only occasion uneasiness to an imagination which should be inaccessible to the reassuring deductions of the calculus of probabilities. Those travelling clouds, the interior comets of our system, are as far from being dangerous to the stability of the system, as are the great inclinations of the orbits of some of the small planets situated between Mars and Jupiter. That which must be designated as a mere *possibility* lies beyond the domain of a Physical Description of the Universe. Science ought not to pass from its true domain into the misty land of cosmological dreams.

RECTIFICATIONS AND ADDITIONS TO THIS VOLUME.

Pages 35—36.

See Editor's Note at the foot of p. 36.

Pages 55—56.

The singular phenomenon of the apparently fluctuating motion of a star has been recently observed again. It was seen by very trustworthy witnesses at Trèves, on the 20th of January, 1851, between 7 and 8 in the evening. The star was Sirius, and was near the horizon at the time. See the letter of the Head Master of Mathematics, Herr Flesch, in Jahn's *Unterhaltungen für Freunde der Astronomie*.

Pages 112 and lix., Note (216).

The lively wish which I had expressed, to be enabled to trace with more certainty the historical epoch within which the disappearance of the red colour of Sirius falls, has been in part fulfilled by the honourable diligence of a young savant, Dr. Wöpeke, who combines great acquaintance with the Oriental languages with distinguished mathematical knowledge. This gentleman, the translator of, and commentator on, the important "Algebra" of Omar

Alkhayyami, writes to me from Paris, in 1851, as follows:—“The wish expressed by you in the astronomical volume of Kosmos, has led me to examine four manuscripts of the Uranography of Abdurrahman Al-Ssufi, which are here; and I have found that α Bootis, α Tauri, α Scorpii, and α Orionis, are all expressly termed ‘red:’ Sirius, on the contrary, has no such epithet applied to it. The passage relating to Sirius is in all the four manuscripts to the same effect, viz. that ‘the first of these stars’ (in Canis Major) ‘is the large bright star in the mouth, which is marked on the Astrolabe, and is called Al-je-maanijah.’” Does it not appear probable from this examination, and from what I cited from Alfragani (Note ²¹⁶) that the change of colour of Sirius took place intermediately between the epoch of Ptolemy and that of the Arabian astronomers?

Pages 191—192.

In the brief exposition of the method of finding the parallax of double stars by the velocity of light, it should have been said, that the interval of time which elapses between the moments when the planetary or secondary star is nearest to, and farthest from, the Earth, is always longer when the change is from the greatest proximity to the greatest distance, than in the inverse case, when the change is from the greatest distance to the greatest proximity.

Page 214.

In the French translation of the astronomical volume of Kosmos (Part I.), which I have rejoiced to see undertaken by Monsieur Faye, that highly-informed astronomer has greatly

enriched the section on double stars. I had unduly omitted to make use of the important labours of Monsieur Yvon Villarceau, which had been read to the French Institut in 1849 (*Connaissance des temps pour l'an 1852*, p. 3—128). I borrow here, from a table given by M. Faye of the elements of the orbits of eight double stars, the four first stars, which he believes to be the most securely calculated.

ELEMENTS OF THE ORBITS OF DOUBLE STARS.

| Names and Magnitudes of the Double Stars. | Semi-major Axis. | Excentricity. | Periods of revolution in years. | Names of the Computers. |
|--|------------------|---------------|---------------------------------|-------------------------|
| ξ Ursæ majoris (4 and 5, Groom- bridge.) | " | | | |
| | 3·857 | 0·4164 | 58·262 | Savary 1830 |
| | 3·278 | 0·3777 | 60·720 | J. Herschel... 1849 |
| | 2·295 | 0·4037 | 61·300 | Mädler 1847 |
| | 2·439 | 0·4315 | 61·576 | Y. Villarceau. 1848 |
| ρ Ophiuchi (4 and 6, Gr.) | 4·328 | 0·4300 | 73·862 | Encke..... 1832 |
| | 4·966 | 0·4445 | 92·338 | Y. Villarceau. 1849 |
| | 4·8... | 0·4781 | 92·... . | Mädler 1849 |
| ζ Herculis (3 and 6·5, Gr.) | 1·208 | 0·4320 | 30·22 | Mädler 1847 |
| | 1·254 | 0·4482 | 36·357 | Y. Villarceau. 1847 |
| η Coronæ (5·5 and 6, Gr.) | 0·902 | 0·2891 | 42·50 | Mädler 1847 |
| | 1·012 | 0·4744 | 42·501 | Y. Villarceau. 1847 |
| | 1·111 | 0·4695 | 66·257 | The same, 2d solution. |

The problem of the period of revolution of η Coronæ has two solutions: one being 42·5, and the other 66·3 years; but the latest observations of Otto Struve assign the preference to the second result. Mons. Yvon Villarceau finds for the semi-major axis, excentricity, and period of revolution expressed in years, of three other double stars, as follows:—

| | | | |
|-------------------------|----------|--------|---------|
| γ Virginis . . . | 3''·446 | 0·8699 | 153·787 |
| ζ Cancrī . . . | 0''·934 | 0·3662 | 58·590 |
| α Centauri . . . | 12''·128 | 0·7187 | 78·486 |

I have termed the occultation of one fixed star by another, (in the case of ζ Herculis), "apparent" (p. 212). Mons. Faye shows that it is a consequence of the factitious diameter of stars as seen in our telescopes (Kosmos, Bd. iii. S. 67 und 167; Engl. ed. p. 50 and 110).—The parallax of 1830 Groombridge, which I have given in S. 275 (Engl. ed. p. 190) at 0''·226, has been found by Schlüter and Wichmann at 0''·182, and by Otto Struve at 0''·034.

Page 371.

It was not until the section upon the small planets had been printed off that we received in the North of Germany the information of the discovery of a fifteenth small planet, Eunomia, by De Gasparis, on the 19th of July, 1851. The elements of Eunomia, computed by G. Rümker, are:—

| | |
|---------------------------------------|-------------------------------------|
| Epoch of mean longitude | { 1851, Oct. 10, M. Green. Time. |
| Mean longitude | 321° 25' 29'' |
| Longitude of perihelion | 27 35 38 |
| Longitude of ascending node | 293 52 55 |
| Inclination | 11 43 43 |
| Excentricity | 0·188402 |
| Semi-major axis | 2·64758 |
| Mean diurnal motion | 823''·630 |
| Period of revolution | 1574 days. |

Pages 388—390.

By a kind communication from Sir John Herschel, dated 8th Nov. 1851, I learn that Mr. Lassell observed distinctly on the 24th, 28th, and 30th of October, and on the 2d of November, 1851, two satellites of Uranus, which appear to be still nearer to the planet than the first satellite of Sir William Herschel, to which that astronomer ascribed a period of revolution of about 5 days 21 hours, but which has not been subsequently recognised. The periods of revolution of the two satellites now seen by Lassell were about 4 days and $2\frac{1}{2}$ days.

(³⁴⁷) p. 208.—Two glasses, presenting complementary colours, being placed over each other, give a white image of the Sun. During my long stay at the Paris Observatory, my friend Arago employed this arrangement with great advantage, in the place of the ordinary shade-glasses, for observations of solar eclipses, and of the Sun's spots. The colours to be taken are—red and green, yellow and blue, or green and violet. “Lorsqu'une lumière forte se trouve auprès d'une lumière faible, la dernière prend la teinte *complémentaire* de la première. C'est là le *contraste*: mais comme le rouge n'est presque jamais pur, on peut tout aussi bien dire que le rouge est complémentaire du bleu. Les couleurs voisines du Spectre solaire se substituent.” (Arago, MS. of 1847).

(³⁴⁸) p. 209.—Arago in the *Connaissance des Temps* pour l'an 1828, p. 299—300, and pour 1834, p. 246—250, and pour 1842, p. 347—350. “Les exceptions que je cite, prouvent que j'avais bien raison en 1825 de n'introduire la notion physique du *contraste* dans la question des étoiles doubles qu'avec la plus grande réserve. Le bleu est la couleur réelle de certaines étoiles. Il résulte des observations recueillies jusqu'ici que le firmament est non seulement parsemé de soleils *rouges* et *jaunes*, comme le savaient les Anciens, mais encore de soleils *bleus* et *verts*. C'est au tems et à des observations futures à nous apprendre si les étoiles vertes et bleues ne sont pas des soleils déjà en voie de décroissance; si les différentes nuances de ces astres n'indiquent pas que le combustion s'y opère à différens degrés; si la teinte, avec excès de rayons les plus réfrangibles, que présente souvent la petite étoile, ne tiendrait pas à la force absorbante d'une atmosphère que développerait l'action de l'étoile, ordinairement beaucoup plus brillante, qu'elle accompagne.—(Arago in the *Annuaire* for 1834, p. 295—301.

(³⁴⁹) p. 209.—Struve über Doppelsterne nach Dorpater Beobachtungen, 1837, S. 33—36, and *Mensuræ microm.* p. lxxxiii., enumerates sixty-three pairs of stars, in which both stars are blue or bluish, and in which, therefore, the colour cannot be the result of contrast. When it is necessary to compare together the colours of the same double stars, as given by different observers, it is particularly striking to remark how often the companion of a red or yellowish red star is called *blue* by one observer, and *green* by another.

(³⁵⁰) p. 209.—Arago in the *Annuaire* for 1834, p. 302.

(³⁵¹) p. 209.—*Kosmos*, Bd. iii. S. 168—172; Eng. ed. p. 110—114.

(³⁵²) p. 210.—“This superb double star (α Centauri) is beyond all comparison the most striking object of the kind in the heavens, and consists of

two individuals, both of a high ruddy or orange colour, though that of the smaller is of a somewhat more sombre and brownish cast." Sir John Herschel, *Cape Observations*, p. 300. According to the valuable observations of Captain Jacob, of the Bombay Engineers, in 1846—1848, the principal star is estimated at the 1st magnitude, and the companion from the 2.5 to the 3rd magnitude.

(³⁵²) p. 210.—*Kosmos*, Bd. iii. S. 235, 249 and 259, Eng. ed. pp. 155, 249, and note 274.

(³⁵⁴) p. 211.—Struve über Doppelst. nach Dorpat. Beob. S. 33.

(³⁵⁵) p. 211.—Same work, S. 36.

(³⁵⁶) p. 211.—Mädler, *Astr. S.* 517; John Herschel, *Outlines*, p. 568.

(³⁵⁷) p. 211.—Compare Mädler, *Untersuch. über die Fixstern-Systeme*, Th. i. S. 225—275, Th. ii. S. 235—240; the same Author, in *hi Astr. S.* 541; and John Herschel, *Outlines*, p. 573.

(³⁵⁸) p. 215.—*Kosmos*, Bd. i. S. 86—91 and 158 (English edition, p. 74—79 and 142); Bd. ii. S. 369 (English edit. p. 328); Bd. iii. S. 47—51, 178, 219, and 231 (English edit. p. 37—41, 120, 136, and 150).

(³⁵⁹) p. 215.—*Kosmos*, Bd. iii. S. 267—269 (Engl. edit. p. 182—183).

(³⁶⁰) p. 217.—*Kosmos*, Bd. i. S. 87 (Engl. edit. p. 75).

(³⁶¹) p. 218.—*Kosmos*, Bd. iii. S. 99, 131, Anm. 62; 178 and 210, Aum. 71; Engl. edit. p. 80, Note 151; p. 119, Note 237.

(³⁶²) p. 219.—Before the expedition of Alvaro Becerra. The Portuguese advanced in 1471 to the South of the Equator. See Humboldt, *Examen critique de l'Hist. de la Géogr. du Nouveau Continent*, T. i. p. 290—292. On the Eastern side of Africa, the commercial route through the Indian Ocean from Ocelis on the Straits of Bab-el-Mandeb to the Entrepot of Muzeris on the Malabar coast and to Ceylon, being favoured by the south-west monsoon (Hippalus), was frequented under the Ptolemies (*Kosmos*, Bd. ii. S. 203 and 433, Note 21; Engl. edit. p. 169, Note 261). On all these routes the Magellanic clouds must have been seen, although they have not been described.

(³⁶³) p. 219.—Sir John Herschel, *Cape Observations*, § 132.

(³⁶⁴) p. 219.—*Kosmos*, Bd. ii. S. 357 and 509, Note 43. Galileo, who sought to attribute the difference between the days of discovery (29 Dec. 1609, and 7 Jan. 1610) to the difference of calendars, in his wrath at what he terms the "bugia del impostore eretico Guntzenhusano," goes so far as to declare "che molto probabilmente il Eretico Simon Mario non ha osservato giammai i Pianeti Medicei" (see *Opere di Galileo Galilei*, Padova, 1744, T. ii. p. 235

—237; and Nelli, *Vita e Commercio Letterario di Galilei*, 1793, Vol. i. p. 240—246). Yet the “Eretico” had expressed himself in a very modest and peaceable manner respecting the measure of his own merit in the discovery. “I merely maintain,” said Simon Marius in the Preface to the *Mundus Jovialis*, “that, hæc sidera (Brandenburgica) a nullo mortalium mihi ulla ratione commonstrata, sed propria indagine sub ipsissimum fere tempus, vel aliquanto citius quo Galilæus in Italia ea primum vidit, a me in Germania adinventata et observata fuisse. Merito igitur Galilæo tribuitur et manet laus primæ inventionis horum siderum apud Italos. An autem inter meos Germanos quispiam ante me ea invenerit et viderit, hactenus intelligere non potui.”

(³⁶⁵) p. 219.—“*Mundus Jovialis* anno 1609 detectus ope perspicilli Belgici,” Noribergæ, 1614.

(³⁶⁶) p. 220.—*Kosmos*, Bd. ii. S. 368 (Engl. edit. p. 327).

(³⁶⁷) p. 220.—*Kosmos*, Bd. iii. S. 180 (Engl. edit. p. 122).

(³⁶⁸) p. 221.—“Galilei notò che le Nebulose di Orione null’ altro erano che mucchi e coacervazioni d’ innumerabili Stelle” (Nelli, *Vita di Galilei*, Vol. i. p. 208).

(³⁶⁹) p. 221.—“In primo integram Orionis constellationem pingere decreveram; vero, ab ingenti stellarum copia, temporis vero inopia obrutus, aggressionem hanc in aliam occasionem distuli.—Cum non tantum in Galaxia iactens ille candor veluti albicantis nubis spectetur, sed *complures consimilis coloris areolæ sparsim per æthera subfulgeant*, si in illarum quamlibet specillum convertas, Stellarum constipatarum coetum offendes. Amplius (quod magis mirabile) Stellæ, ab Astronomis singulis in hanc usque diem *Nebulosæ* appellatæ, Stellarum mirum in modum consitarum greges sunt: ex quarum radorum commixtione, dum unaquaque ob exilitatem seu maximam a nobis remotionem, oculorum aciem fugit, candor ille consurgit, qui densior pars cœli, Stellarum aut Solis radios retorquere valens, hucusque creditus est.”—*Opere di Galileo Galilei*, Padova, 1744, T. ii. p. 14—15; *Sidereus Nuncius*, pp. 13, 15 (No. 19—21), and 35 (No. 56).

(³⁷⁰) p. 221.—Compare *Kosmos*, Bd. iii. S. 106. I would also recall the vignette at the conclusion of the Introduction of Hevelii *Firmamentum Sobesianum*, 1687, in which three genii are seen, two of whom are observing with the sextant of Hevelius; while to the third genius, who carries a telescope and appears to offer it, the observers answer: *Præstat nudo oculo!*

(³⁷¹) p. 221.—Huygens, *Systema Saturnium*, in his *Opera varia*, Lugd. Bat. 1724, T. ii. p. 523 and 593.

(372) p. 222.—“ Dans les deux nébuleuses d'Andromède et d'Orion,” says Dominique Cassini, “ j'ai vu des étoiles qu'on n'aperçoit pas avec des lunettes communes. Nous ne savons pas si l'on ne pourroit pas avoir des lunettes assez grandes pour que toute la nébulosité pût se résoudre en de plus petites étoiles, comme il arrive à celles du Cancer et du Sagittaire” (Delambre, *Hist. de l'Astr. moderne*, T. ii. p. 700 and 744).

(373) p. 222.—Kosmos, Bd. i. S. 412, Anm. 66 (Engl. edit. Note 96).

(374) p. 223.—On the ideas of Lambert and Kant viewed in connection with each other,—what they had in common, and wherein they differed,—as well as on the dates of their publications, see Struve, *Etudes d'Astr. stellaire*, p. 11, 13, and 21; Notes 7, 15, and 33. Kant's “ *Allgemeine Naturgeschichte und Theorie des Himmels*” (General History of Nature and Theory of the Heavens) appeared anonymously, and with a dedication to the King of Prussia, in 1755; Lambert's “ *Photometria*,” as has been already remarked, appeared in 1760, and his “ *Sammlung kosmologischer Briefe über die Einrichtung des Weltbaues*” (Collection of Cosmological Letters on the Structure of the Universe) in 1761.

(375) p. 223.—“ Those nebulae,” said John Michell, 1767 (*Phil. Trans.* Vol. lviii. for 1767, p. 251), “ in which we can discover either none or only a few stars even with the assistance of the best telescopes, are probably systems, that are still more distant than the rest.”

(376) p. 224.—Messier, in the *Mém. de l'Académie des Sciences*, 1771, p. 435; and in the *Connaissance des Temps pour 1783 and 1784*. The whole list contains 103 objects.

(377) p. 224.—*Phil. Trans.* Vol. lxxvi., lxxix., and xcii.

(378) p. 224.—“ The nebular hypothesis, as it has been termed, and the theory of sidereal aggregation, stand in fact quite independent of each other” (Sir John Herschel, *Outlines of Astronomy*, § 872, p. 599).

(379) p. 225.—The numbers in the text are those of the objects enumerated from No. 1 to 2307 in the European or Northern Catalogue of 1833, and from No. 2308 to 4015 in the African or Southern Catalogue (*Cape Observations*, p. 51—128).

(380) p. 225.—James Dunlop, in the *Phil. Trans.* for 1828, p. 113—151.

(381) p. 225.—Compare Kosmos, Bd. iii. S. 81 and 117, Anm. 34 (English edit. p. 63, Note 123).

(382) p. 225.—“ An Account of the Earl of Rosse's Great Telescope,” p. 14—17, in which the list of the nebulae resolved in March 1845 by Dr. Robinson and Sir James South, is given. “ Dr. Robinson could not leave

this part of his subject without calling attention to the fact, that no real nebula seemed to exist among so many of these objects, chosen without any bias: all *appeared* to be clusters of stars, and every additional one which shall be resolved will be an additional argument against the existence of any such" (Schumacher, Astr. Nachr. No. 536). In the "Notice sur les grands Télescopes de Lord Oxmantown, aujourd'hui Earl of Rosse" (Bibliothèque universelle de Genève, T. lyii. 1845, p. 342—357), it is said: "Sir James South rappelle que jamais il n'a vu de représentations sidérales aussi magnifiques que celles que lui offrait l'instrument de Parsonstown; qu'une bonne partie des nébuleuses se présentaient comme des amas ou groupes d'étoiles, tandis que quelques autres, à ses yeux du moins, n'offraient aucune apparence de résolution en étoiles."

(³⁸³) p. 226.—Report of the Fifteenth Meeting of the British Association held at Cambridge in June 1845, p. xxxvi.; and Outlines of Astronomy, p. 597 and 598. "By far the major part," says Sir John Herschel, "probably at least nine-tenths of the nebulous contents of the heavens, consist of nebulae of spherical or elliptical forms, presenting every variety of elongation and central condensation. Of these, a *great number* have been resolved into distant stars (by the Reflector of the Earl of Rosse), and a vast number more have been found to possess that mottled appearance which renders it almost a matter of certainty that an increase of optical power would show them to be similarly composed. A not unnatural or unfair induction would therefore seem to be, that those which resist such resolution do so only in consequence of the smallness and closeness of the stars of which they consist; that in short they are only optically and not physically nebulous.—Although nebulae do exist which even in this powerful telescope (of Lord Rosse) appear as nebulae without any sign of resolution, it may very reasonably be doubted whether there be really any essential physical distinction between nebulae and clusters of stars."

(³⁸⁴) p. 226.—Dr. Nichol, Professor of Astronomy at Glasgow, has published in his "Thoughts on some Important Points relating to the System of the World," 1846, p. 55, this letter, dated Castle, Parsonstown: "In accordance with my promise of communicating to you the result of our examination of Orion, I think I may safely say, that there can be little, if any, doubt as to the resolvability of the nebula. Since you left us, there was not a single night when, in the absence of the moon, the air was fine enough to admit of our using more than half the magnifying power the speculum bears: still we could plainly see that all about the trapezium is a mass of stars; the rest of

the nebula also abounding with stars, and exhibiting the characteristics of resolvability strongly marked."

(³⁸⁵) p. 227.—Compare Edinburgh Review, Vol. lxxxvii. 1848, p. 186.

(³⁸⁶) p. 227.—Kosmos, Bd. iii. S. 183 and 212, Ann. 84 (English edit. p. 125, Note 250).

(³⁸⁷) p. 227.—Kosmos, Bd. iii. S. 44 (English edit. p. 35).

(³⁸⁸) p. 228.—Newton, Philos. Nat., Principia mathematica, 1760, T. iii. p. 671.

(³⁸⁹) p. 228.—Kosmos, Bd. i. S. 146 (Engl. edit. p. 131).

(³⁹⁰) p. 228.—Kosmos, Bd. i. S. 412, Ann. 66 (Engl. edit. Note 96).

(³⁹¹) p. 228.—Sir John Herschel, Cape Observations, § 109—111.

(³⁹²) p. 229.—It may be proper to explain here the grounds on which this enumeration is based. The three Catalogues of Sir William Herschel contain 2500 objects; viz. 2303 nebulae, and 197 star-clusters (Mädler, Astr. S. 448). These numbers underwent alteration in a later and much more exact review of the heavens by Sir John Herschel (Observations of Nebulae and Clusters of Stars made at Slough with a Twenty-foot Reflector, between the years 1825 and 1833: Phil. Trans. 1833, p. 365—481). About 1800 objects were identical with those of the three earlier catalogues; but from three to four hundred were provisionally excluded, and more than five hundred newly discovered ones had their Right Ascension and Declination determined (Struve, Astr. stellaire, p. 48). The Northern catalogue contains 152 clusters of stars, consequently $2307 - 152 = 2155$ nebulae; but in the Southern catalogue (Cape Observ. p. 3, § 6 and 7) we have to deduct from $4015 - 2307 = 1708$ objects (among which there are 236 star-clusters) 233 (viz. $89 + 135 + 9$: see Cape Observ. p. 3, § 6 and 7, and p. 128) as belonging to the Northern catalogue, observed by Sir William and Sir John Herschel at Slough, and by Messier at Paris. There thus remain for the Cape Observations, $1708 - 233 = 1475$ nebulae and clusters, or 1239 nebulae only. To the 2307 objects of the Northern catalogue of Slough we have to add, on the other hand, $135 + 9 = 144$. Thus this Northern list becomes increased to 2451 objects, containing, after deducting 152 clusters, 2299 nebulae; which numbers, however, do not apply to a very strict limit of the horizon according to the height of the Pole at Slough. If in the topography of the firmament it is deemed proper to assign numerical ratios to the two hemispheres, the author thinks that it is right to do so carefully, although the numbers in question must always be expected to vary at different epochs, and according to the progress of observation. It belongs to the general design of

the present work to attempt to depict the state of knowledge at a determinate epoch.

(³⁹⁸) p. 229.—Sir John Herschel says, in p. 134 of his *Cape Observations*, “There are between 300 and 400 nebulae of Sir William Herschel’s Catalogue still unobserved by me,—for the most part very faint objects.” . . .

(³⁹⁴) p. 229.—*Cape Observ.* § 7. (Compare Dunlop’s *Catalogue of Nebulae and Clusters of the Southern Hemisphere*, in the *Phil. Trans.* for 1828, p. 114—146.)

(³⁹⁵) p. 230.—*Kosmos*, Bd. iii. S. 297 (Engl. edit. p. 206—207.)

(³⁹⁶) p. 230.—*Cape Observ.* § 105—107.

(³⁹⁷) p. 231.—In *Kosmos*, Bd. iii. S. 181, line 6 from below, by an error of the press, the words South Pole and North Pole have been interchanged [this was rectified in the English edition, p. 124, line 8 from top].

(³⁹⁸) p. 231.—“In this *region* of ‘*Virgo*,’ occupying about one-eighth of the whole surface of the sphere, one-third of the entire nebulous contents of the heavens are congregated” (*Outlines*, p. 596).

(³⁹⁹) p. 231.—On this “barren region” see *Cape Observ.* § 101, p. 135.

(⁴⁰⁰) p. 232.—I found these numerical data on the summing up of the numbers furnished by the projection of the northern heavens, in the *Cape Observ.* Pl. xi.

(⁴⁰¹) p. 233.—Humboldt, *Examen crit. de l’Hist. de la Géographie*, T. iv. p. 319. In the long series of voyages undertaken under the influence of the Infante Don Henrique by the Portuguese along the West coast of Africa towards the Equator, the Venetian Cadamosto (whose proper name was Alvise da Ca da Mosto), after joining Antoniotto Usodimare at the mouth of the Senegal in 1454, was the first who occupied his attention with the search after a southern Pole-star. “As,” said he, “I still see the northern Pole-star” (he was in about 13° North latitude), I cannot see the south one itself; but the constellation which I see farthest towards the South is the Carro del Ostro (the Southern Wain or Car).” (*Aloysii Cadam. Navig. cap. 43*, p. 32; *Ramusio, Delle Navigazioni et Viaggi*, Vol. i. p. 107). May he have formed for himself a car or wain from some large stars of the constellation of the Ship? The idea that each of the two Poles had its car, appears to have been so prevalent at that time, that in the *Itinerarium Portugallense*, 1508, fol. 23, *b*, and in *Grynäns, Novus Orbis*, 1532, p. 58, there is a constellation, quite similar to the Little Bear, figured as having been seen by Cadamosto; while *Ramusio* (*Navigazioni*, Vol. i. p. 107) and the new *Collecção de Noticias para a hist. e geogr. das Nacoes Ultramarinas* (T. ii. Lisboa, 1812, p. 57, cap. 39)

figure instead, but in an equally arbitrary manner, the Southern Cross (Humboldt, *Examen crit. de l'Hist. de la Géogr.* T. v. p. 236). As it was usual in the Middle Ages to seek to replace the two dancers (*χορευται*) of Hyginus (Poet. astron. iii. 1), *i. e.* the Ludentes of the scholiast, to Germanicus, or Custodes of Vegetius, in the Little Bear,—the stars β and γ of that constellation were made into the Guards (le due Guardie) of the North Pole, near to which they are situated, and round which they revolve; and as this name of the “two Guards,” as well as the use made of them for determining the height of the Pole (Pedro de Medina, *Arte de Navegar*, 1545, libro v. cap. 4—7, p. 183—195), had become general among the navigators of all European nations in the Northern Seas—so, erroneous inferences of analogy led men to think they discovered on the southern horizon what they had long before sought for there. When Amerigo Vespucci, on his second voyage from May 1499 to Sept. 1500, and Vicente Yañez Pinzon (both whose voyages are perhaps the same), arrived as far south in the Southern Hemisphere as Cape San Augustin, they first began to occupy themselves diligently, but vainly, in seeking for a star visible in the immediate vicinity of the Southern Pole (Bandini, *Vita e Lettere di Amerigo Vespucci*, 1745, p. 70; Anghiera, *Oceanica*, 1510, Dec. I. lib. ix. p. 96; Humboldt, *Examen crit.* T. iv. p. 205, 319, and 325). The South Pole of the heavens was then in the constellation of the Octant, so that β Hydræ minoris, if we make the reduction according to Brisbane's Catalogue, had still fully $80^{\circ} 5'$ South Declination. Vespucci, in a letter addressed to Pietro Francesco de' Medici, said: “Whilst I was occupied with the wonders of the southern heavens, and seeking amongst them in vain for a southern Pole-star, I remembered a few words of our Dante, where, in the first chapter of the Purgatorio, supposing himself passing from one hemisphere to the other, and intending, I believe, to describe the Antarctic Pole, he sings—

“Io mi volsi a man destra”

I feel the more certain that the poet meant to indicate by his four stars (non viste mai fuor ch' alla prima gente) the Pole of the other firmament, because I saw in reality four stars which, together, formed a ‘mandorla,’ and had a small (?) motion.” Vespucci meant the Southern Cross, the Croce maravigliosa of Andrea Corsali (Letter from Cochin of the 6th of January, 1515, in Ramusio, Vol. i. p. 177), with the name of which he was not yet acquainted, and which subsequently was made use of by all navigators (like β and γ of

the Little Bear, in the case of the North Pole) for finding the Southern Pole (Mém. de l'Acad. des Sciences, 1666—1699, T. vii. Part 2, Paris, 1729, p. 58), and for determinations of latitude (Pedro de Medina, *Arte de Navegar*, 1545, libro v. cap. xi. p. 204). Compare what I have said on the subject of Dante's famous passage in my *Examen crit. de l'Hist. de la Géogr.* T. iv. p. 319—334. I also remarked there that α Crucis, with which in modern times Dunlop in 1826, and Rumker in 1836, occupied themselves at Paramatta, is one of the stars earliest recognised, in 1681 and 1687, by the Jesuit Fontaney, and by Noel and Richaud, as multiple stars (*Hist. de l'Acad. dep.* 1686—1699, T. ii. Par. 1733, p. 19; *Mem. de l'Acad. dep.* 1666—1699, T. vii. 2, Par. 1729, p. 206; *Lettres édifiantes*, Recueil vii. 1703, p. 79). Such early recognition of binary systems, long before the double star ζ Ursæ maj. was recognised as such (Part I. of present volume, p. 201), is the more remarkable, because seventy years afterwards Lacaille did not describe α Crucis as a double star,—possibly, as conjectured by Rumker, because the principal star and its companion were at that time at too small a distance apart. (Compare Sir John Herschel, *Cape Observations*, § 183—185.) Almost at the same time that the double character of α Crucis was discovered, that of α Centauri was also recognised by Richaud nineteen years before the voyage of Fenillée, to whom this discovery has been erroneously ascribed by Henderson. Richaud remarked that, “at the time of the comet of 1689, the two stars which form the double star α Crucis were at a considerable distance apart; but that the two components of α Centauri, although, when viewed through a twelve-feet refractor, they might indeed be clearly recognised as distinct, yet appeared almost to touch each other.”

(⁴⁰²) p. 234.—*Cape Observations*, § 44 and 104.

(⁴⁰³) p. 234.—*Kosmos*, Bd. iii. S. 179 and 211 (Engl. edit. p. 120, and Note 240). Yet, as has been already remarked in treating, in the first part of the present volume (p. 122), of star-clusters, Mr. Bond, of the United States of North America, has succeeded, by the extraordinary space-penetrating power of his refractor, in entirely resolving the long drawn out elliptical nebula in Andromeda, which, according to Bouillaud, had been described before Simon Marius, in 985 and in 1428, and which has a reddish light. In the vicinity of this celebrated nebula there is another, still unresolved, but very closely resembling it in form, discovered on the 27th of August, 1783, by my friend the late Miss Caroline Herschel, who died at a highly advanced age, honoured by all. (See *Phil. Trans.* 1833, No. 61 of the list of nebulae, fig. 52).

(⁴⁰⁴) p. 235.—Annular nebula : (Cape Observ. p. 53 ; Outlines of Astr. p. 602) ; Nébuleuse perforée : (Arago, in the *Annuaire* for 1842, p. 423) ; Bond, in *Schum. Astr. Nachr.* No. 611.

(⁴⁰⁵) p. 235.—Cape Observations, p. 114, Pl. vi. fig. 3 and 4 ; compare also No. 2072, in the *Phil. Trans.* for 1833, p. 466. See Lord Rosse's drawings of the ring-nebula in *Lyra*, and of the singular crab-nebula in Nichol's "Thoughts on the System of the World," p. 21, Pl. iv. ; and p. 22, Pl. i. fig. 5.

(⁴⁰⁶) p. 236.—Regarding the planetary nebula in *Ursa major* as a sphere, and supposing it placed at a distance from us not more than that of 61 *Cygni*, its apparent diameter of 2' 40" would imply an actual diameter seven times greater than that of the orbit of *Neptune* (Outlines, § 876).

(⁴⁰⁷) p. 236.—Outlines, p. 603 ; Cape Observations, § 47. An orange-red star of the 8th magnitude is near No. 3365, but the planetary nebula still appears of a deep indigo-blue when the red star is not in the field of the telescope : the colour is therefore not the effect of contrast.

(⁴⁰⁸) p. 236.—*Kosmos*, Bd. iii. S. 173, 299, and 309 (Engl. edit. p. 115, 208—209, Note 348). In more than 63 double stars the companion and the principal star are both blue or bluish. Small indigo-blue stars are intermingled in the superb many-coloured star-cluster No. 3435 of the Cape Catalogue (*Dunlop's Cat.* No. 301). There is an entirely uniform blue cluster of stars in the southern heavens (No. 573 of *Dunlop*, No. 3770 of *John Herschel*). It has $3\frac{1}{2}'$ diameter, with projections which run out to 8' of length : the stars are from the 16th to the 14th magnitude (Cape Observ. p. 119).

(⁴⁰⁹) p. 236.—*Kosmos*, Bd. i. S. 88 and 387 (Engl. edit. p. 76, Note 31). Compare Outlines, § 877.

(⁴¹⁰) p. 236.—On the complexity of the dynamic relations in the partial attractions in the interior of a spherically round star-cluster, which in weak telescopes appears as a round nebula denser towards the centre, see *Sir John Herschel*, in *Outlines of Astronomy*, § 866 and 872 ; Cape Observ. § 44 and 111—113 ; *Phil. Trans.* for 1833, p. 501 ; and Address of the President in the Report of the Fifteenth Meeting of the British Association, 1845, p. xxxvii.

(⁴¹¹) p. 237.—*Mairan*, *Traité de l'Aurore boréale*, p. 263 (Arago, in the *Annuaire* for 1842, p. 403—413).

(⁴¹²) p. 238.—Other instances of nebulous stars are only from the 9th to the 8th magnitude ; as, for example, No. 311 and No. 450 of the Catalogue of 1833, fig. 31, with photospheres of 1' 30" (Outlines, § 879).

(⁴¹³) p. 238.—Cape Observations, p. 117, No. 3727, Pl. vi. fig. 16.

(⁴¹⁴) p. 238.—The following may be cited as remarkable forms of irregular nebulæ:—the one resembling the letter Omega (see Cape Observ. Pl. ii. fig. 1, No. 2008, and which was also examined and described by Lamont and by a highly promising too early deceased North American astronomer, Mr. Mason, in the Memoirs of the American Philosophical Society, Vol. vii. p. 177); a nebula with six or eight nuclei (Cape Obs. p. 19, Pl. iii. fig. 4); a comet-like tuft-shaped nebula in which the nebulous rays sometimes appear as if proceeding from a star of the 9th magnitude (Pl. vi. fig. 18, No. 2534 and 3688); a nebula resembling the shade profile of a bust (Pl. iv. fig. 4, No. 3075); a creviced opening inclosing a thread-like nebula (No. 3501, Pl. iv. fig. 2).—Outlines, § 883; Cape Obs. § 121.

(⁴¹⁵) p. 239.—Kosmos, Bd. iii. S. 185 (English edit. p. 127); Outlines, § 785.

(⁴¹⁶) p. 239.—Kosmos, Bd. i. S. 157 and 415, Note 83 (Engl. edit. p. 141, Note 113. Sir John Herschel, first edition of Treatise on Astronomy, 1833, in Lardner's Cabinet Cyclopædia, § 616; Littrow, Theoretische Astronomie, 1834, Th. ii. § 234.

(⁴¹⁷) p. 239.—See Edinburgh Review, Jan. 1848, p. 187; and Cape Obs. § 96 and 107. "A zone of nebulæ," says Sir John Herschel, "encircling the heavens, has so many interruptions, and is so faintly marked out through by far the greater part of the circumference, that its existence as such can be hardly more than suspected."

(⁴¹⁸) p. 240.—"There is, I think, no doubt," wrote Dr. Galle, "that the drawing which you have sent me (Opere di Galilei, Padova, 1744, T. ii. p. 14, No. 20) includes Orion's belt and sword, and therefore the star θ ; but from the obvious inaccuracy of the drawing, the three small stars in the sword, the middle one of which is θ , and which to the unassisted eye appear to form a straight line, are difficult to find. I should think that you have pointed out the star α correctly, and that the bright star to the right of it, or the star immediately above, is θ ." Galileo says expressly: "In primo integram Orionis constellationem pingere decreveram; verum, ab ingenti stellarum copia, temporis vero inopia obrutus, aggressionem hanc in aliam occasionem distuli." The attention given by Galileo to the constellation of Orion is the more remarkable, because the number of 400 stars which he thought he counted in about ten square degrees between the belt and the sword (Nelli, Vita di Galilei, Vol. i. p. 208) misled Lambert (Cosmolog. Briefe, 1760, S. 155) so long afterwards into the erroneous estimate of 1650000 stars in the whole firmament (Struve, Astr. stellaire, p. 14, and Note 16).

(⁴¹⁹) p. 240.—Kosmos, Bd. ii. S. 369 (Eng. ed. p. 328).

(⁴²⁰) p. 241.—“Ex his autem tres illæ pene inter se contiguæ stellæ, cumque his aliæ quatuor, velut trans nebulam lucebant: ita ut spatium circa psas, qua forma hic conspicitur, multo illustrius appareret reliquo omni cælo; quod cum apprime serenum esset ac cerneretur nigerrimum, velut hiatus quodam interruptum videbatur, per quem in plagam magis lucidam esset prospectus. Idem vero in hanc usque diem nihil immutata facie sæpius atque eodem loco conspexi; adeo ut perpetuam illic sedem habere credibile sit hoc quidquid est portenti: cui certe simile aliud nusquam apud reliquas fixas potui animadvertere. Nam cæteræ nebulosæ olim existimatæ, atque ipsa via lactea, perspicillo inspectæ, nullas nebulas habere comperiuntur, neque aliud esse quam plurium stellarum congeries et frequentia” (Christiani Hugenii Opera varia, Lugd. Bat. 1724, p. 540-541). The magnifying power employed by Huygens in his 23-foot refractor was estimated by himself at only one hundred times (p. 538). Are the “quatuor stellæ trans nebulam lucentes” the stars of the trapezium? The small and very rough drawing (Tab. xlvii. fig. 4, phenomenon in Orione novum) represents only a group of three stars; and indeed near an indentation which might be taken for the Sinus magnus. Perhaps only the three stars of the trapezium which are between the 4th and 7th magnitudes are indicated. Dominique Cassini boasted that he was the first person who had seen the fourth star.

(⁴²¹) p. 241.—William Cranch Bond, in the Transactions of the American Academy of Arts and Sciences, new series, Vol. iii. p. 87-96.

(⁴²²) p. 242.—Cape Observations, § 54-69, Pl. viii.; Outlines, § 837 and 885, Pl. iv. fig. 1.

(⁴²³) p. 242.—Sir John Herschel, in the Memoirs of the Astron. Soc. Vol. ii. 1824, p. 487-495, Pl. vii. and viii. This latter drawing gives the nomenclature of the different regions of the nebula in Orion which has been examined by so many astronomers.

(⁴²⁴) p. 242.—Delambre, Hist. de l’Astr. moderne, T. ii. p. 700. Cassini reckoned the appearance of this fourth star (“aggiunta della quarta stella alle tre contigue”) among the alterations which he considered the nebula in Orion had undergone in his time.

(⁴²⁵) p. 242.—“It is remarkable that within the area of the trapezium no nebula exists. The brighter portion of the nebula immediately adjacent to the trapezium, forming the square front of the head, is shown with the 18-inch reflector broken up into masses, whose mottled and curdling light evidently indicates, by a sort of granular texture, its consisting of stars; and

when examined under the great light of Lord Rosse's reflector, or the exquisite defining power of the great achromatic at Cambridge, U.S., is evidently perceived to consist of clustering stars. There can, therefore, be very little doubt as to the whole consisting of stars, too minute to be discerned individually, even with these powerful aids, but which become visible as points of light when closely adjacent in the more crowded parts" (Outlines, p. 609). W. C. Bond, who employed a 23-foot refractor, furnished with a 14-inch object glass, says: "There is a great diminution of light in the interior of the trapezium, but no suspicion of a star (Mem. of the Amer. Acad., new series, Vol. iii. p. 93).

(⁴²⁶) p. 243.—Phil. Trans. for the year 1811, Vol. ci. p. 324.

(⁴²⁷) p. 243.—Transact. of the Royal Soc. of Edinburgh, Vol. xvi. 1849, Part 4, p. 445.

(⁴²⁸) p. 243.—Kosmos, Bd. iii. S. 251-254; Eng. ed. p. 171-174.

(⁴²⁹) p. 243.—Cape Observations, § 70-90, Pl. ix.; Outlines, § 887, Pl. iv. fig. 2.

(⁴³⁰) p. 244.—Kosmos, Bd. ii. S. 146; Eng. ed. p. 112.

(⁴³¹) p. 244.—Cape Observations, § 24, Pl. i. fig. 1, No. 3721 of the Cat.; Outlines, § 888.

(⁴³²) p. 244.—Nebula in Cygnus; partially in R. A. 20^h 49^m, N.P. D. 58° 27' (Outlines, § 891). Compare Cat. of 1833, No. 2092, Pl. xi. fig. 34.

(⁴³³) p. 245.—Compare the drawings in Pl. ii. fig. 2, with Pl. v. in the "Thoughts on some Important Points relating to the System of the World," 1846 (by Dr. Nichol, Professor of Astronomy at Glasgow), p. 22. Sir John Herschel, in his Outlines of Astronomy, p. 607, says—"Lord Rosse describes and figures this nebula as resolved into numerous stars *with intermixed nebula.*"

(⁴³⁴) p. 245.—Kosmos, Bd. i. S. 157 and 415, Anm. 81 (Eng. ed. p. 141 and xxxviii.), where the nebula No. 1622 is called a "brother-system."

(⁴³⁵) p. 245.—Report of the 15th Meeting of the British Association for the Advancement of Science, Notices, p. 4; Nichol, Thoughts, p. 23 (compare Pl. ii. fig. 1 with Pl. vi.) In the Outlines, § 882, it is said, "the whole, if not clearly resolved into stars, has a *resolvable* character which evidently indicates its composition."

(⁴³⁶) p. 246.—Kosmos, Bd. i. S. 88 and 387 (Anm. 2); Eng. ed. p. 76 and Note 32.

(⁴³⁷) p. 246.—Lacaille, in the Mém. de l'Acad. année 1755, p. 195. It is objectionable to apply, as Horner and Littrow have done, the name of "Magellanic Spots or Cape-clouds" to the coal-sacks.

(⁴²⁸) p. 246.—Kosmos, Bd. ii. S. 329 and 485 (Anm. 6); Eng. ed. p. 289, xcv. Note 446.

(⁴³⁹) p. 247.—Ideler, Untersuchungen über den Ursprung und die Bedeutung der Sternnamen (Investigations respecting the Origin and Signification of the Names of Stars), 1809, S. xlix. and 262. The name Abdurrahman Sufi is abbreviated by Ulugh Beg from Abdurrahman Ebn-Omar Ebn-Mohammed Ebn-Sahl Abu'l-Hassan el-Sufi el-Razi. Ulugh Beg, who, like Nassir-eddin, corrected the star-positions of Ptolemy by his own observations (1437), owns to having borrowed the positions of 27 more southern stars, not visible at Samarcand, from Abdurrahman Sufi.

(⁴⁴⁰) p. 248.—Compare my geographical inquiries respecting the discovery of the south point of Africa, and the statements of Cardinal Zurla and Count Baldelli, in the Examen. crit. de l'hist. de la Géogr. aux 15ème et 16ème Siècles, T. i. p. 229-348. It is a curious fact that the discovery of the Cape of Good Hope, which Martin Behaim calls Terra Fragosa, not Cabo Tormentoso, was made by Diaz in coming from the *eastward* (from Algoa Bay, in 33° 47' S. lat., more than 7° 18' east of Table Bay). Lichtenstein im Vaterlandischen Museum, Hamburg, 1810, S. 372-389.

(⁴⁴¹) p. 249.—The important, and not sufficiently noticed, discovery of the South point of the New Continent, in S. lat. 55° (very characteristically indicated in Urdaneta's journal by the words "acabamiento de tierra," the ceasing or terminating of the land), belongs to Francisco de Hoces, who commanded one of the ships of Loaysa's Expedition in 1525. He probably saw a part of Tierra del Fuego west of Staaten Island; for Cape Horn is, according to Fitz-Roy, in 55° 58' 41". Compare Navarrete, Viages y descubrim. de los Españoles, T. v. p. 28 and 404.

(⁴⁴²) p. 250.—Humboldt, Examen crit. T. iv. p. 205, 295-316; T. v. p. 225-229 and 235 (Ideler, Sternnamen, S. 346).

(⁴⁴³) p. 250.—Petrus Martyr Angl., Oceanica, Dec. III. lib. i. p. 217. I can show, from the numerical data in Dec. II. lib. x. p. 204, and Dec. III. lib. x. p. 232, that the part of the "Oceanica" in which the Magellanic Clouds are mentioned was written between 1514 and 1516; therefore, immediately after the Expedition of Juan Diaz de Solis to the Rio de la Plata (then called "Rio de Solis, una mar dulce"). The latitude assigned is much too high.

(⁴⁴⁴) p. 251.—Kosmos, Bd. ii. S. 329, Bd. iii. S. 151 and 175; Eng. ed. Vol. ii. p. 290, Vol. iii. p. 94 and 117.

(⁴⁴⁵) p. 252.—Kosmos, Bd. i. S. 88 and 387, Anm. 2; Eng. ed. p. 76 and xv. Note 32. Compare, in Cape Observations, 143-164, the Magellanic Clouds as they appear to the naked eye, Pl. vii.; telescopic analysis of the

Nubecula major, Pl. x.; and the Nebula of the Dorado represented separately, Pl. ii. fig 4 (§ 20-23): Outlines, § 892-896, Pl. v. fig. 1; and James Dunlop, in the Phil. Trans. for 1828, Part i. p. 147-151. So erroneous were the views of early observers, that the Jesuit Fontaney, an observer highly esteemed by Dominique Cassini, and to whom many valuable astronomical observations from India and China are owing, wrote, as late as 1685—"Le grand et le petit Nuages sont deux choses singulières. Ils ne paroissent aucunement un amas d'étoiles comme Præsepe Cancri, ni même une lueur sombre comme la nébuleuse d'Andromède. On n'y voit presque rien avec de très grandes lunettes, quoique sans ce secours on les voye fort blancs, particulièrement le grand Nuage" (Lettre du Père de Fontaney au Père de la Chaise, Confesseur du Roi, in the Lettres édifiantes, Recueil vii. 1703, p. 78; and Hist. de l'Acad. des Sciences dep. 1686-1699, T. ii. Paris, 1733, p. 19).—I have followed Sir John Herschel exclusively in the description of the Magellanic Clouds given in the text.

(⁴⁴⁶) p. 252.—Kosmos, Bd. iii. S. 183 and 212 (Anm. 85); Eng. ed. p. 125 and lxiv. Note 251.

(⁴⁴⁷) p. 252.—The same, S. 180 and 211 (Anm. 75); Eng. ed. p. 122 and lxiii. Note 241.

(⁴⁴⁸) p. 254.—Compare, in Cape Observations, § 20-23 and 133, the fine drawing, Pl. ii. fig. 4, and a small special map in the graphical analysis, Pl. x.; as well as Outlines, § 896, Pl. v. fig. 1.^o

(⁴⁴⁹) p. 255.—Kosmos, Bd. ii. S. 328 and 485 (Anm. 5); Eng. ed. p. 289 and xcv. Note 445.

(⁴⁵⁰) p. 255.—Mem. de l'Acad. des Sciences, dep. 1666 jusqu'à 1699, T. vii. Partie 2 (Paris, 1729), p. 206.

(⁴⁵¹) p. 255.—Letter to Olbers from St. Catherine's (Jan. 1804), in Zach's Monatl. Correspondenz zur Beförd. der Erd- und Himmelskunde, Bd. x. S. 240. (Respecting Feuillée's observation, and the rough drawing of the black patch in the Southern Cross, compare, also, Zach's Correspondenz, Bd. xv. 1807, S. 388-391).

(⁴⁵²) p. 256.—Cape Observations, Pl. xiii.

(⁴⁵³) p. 256.—Outlines of Astronomy, p. 531.

(⁴⁵⁴) p. 256.—Cape Observations, p. 384, No. 3407 of the catalogue of nebulae and star-clusters. (Compare Dunlop, in the Phil. Trans. for 1828, p. 149, and No. 272 of his catalogue).

(⁴⁵⁶) p. 257.—"Cette apparence d'un noir foncé dans la partie orientale de la Croix du Sud, qui frappe la vue de tous ceux qui regardent le ciel austral,

est causée par la vivacité de la blancheur de la voie lactée qui renferme l'espace noir et l'entoure de tous cotés."—Lacaille, in the Mém. de l'Acad. des Sciences, année 1755 (Paris, 1761), p. 199.

(⁴⁵⁷) p. 257.—Bd. i. S. 159 and 415 (Anm. 87); Eng. ed. p. 143 and xxxviii. Note 117.

(⁴⁵⁸) p. 257.—“When we see,” says Sir John Herschel, “in the Coal sack (near α Crucis) a sharply-defined oval space free from stars, it would seem much less probable that a conical or *tubular* hollow traverses the whole of a starry stratum, continuously extended from the eye outwards, than that a *distant* mass of comparatively moderate thickness should be simply perforated from side to side. . . .” (Outlines, § 792, p. 532; Lettre de Mr. Hooke à Mr. Auzout, in the Mém. de l'Académie, 1666-1699, T. viii. Partie 2, p. 30 and 73).

(⁴⁵⁹) p. 258.—Kosmos, Bd. i. S. 161; Eng. ed. p. 145.

(⁴⁶⁰) p. 261.—Compare what was said in an earlier volume, where distances of Uranus were employed as units of measure, that planet being the outermost member of the planetary system as then known to us (Kosmos Bd. i. S. 116, 153, and 415, Anm. 76; Eng. ed. p. 102, 103, 137, 138, and Note 106). Taking the distance of Neptune from the Sun at 30.04 distances of the Earth from the Sun, the distance of α Centauri from the Sun will be 7523 distances of Neptune, the parallax of the star being assumed to be 0".9128 (Kosmos, Bd. iii. S. 274, Eng. ed. p. 189); and yet the distance of β Cygni is almost twice and a half, and that of Sirius (taking its parallax at 0".230) four times as great as that of α Centauri. A “distance of Neptune” is about 621 German, (2484 English) millions of geographical miles; and the distance of Uranus from the Sun, according to Hansen, is 396½ (Eng. 1586) millions of such miles. According to Galle, the distance of Sirius, taking Henderson's parallax, is 896800 semi-diameters of the Earth's orbit = 18547000 (74188000 Eng.) millions of geographical miles—a distance which light requires 14 years to traverse. The aphelion of the comet of 1680 is 44 distances of Uranus, or 28 distances of Neptune, from the Sun. According to the above assumptions, the solar distance of the star α Centauri is almost 270 times greater than this cometary aphelion, which is here regarded as the minimum of the necessarily very uncertain estimation of the radius of the solar domain (Kosmos, Bd. iii. S. 294, Eng. ed. p. 204). In

this class of numerical data, the advantage gained by employing very great distances in space as our units of measure is, that we are thus enabled to express the results with a less enormous array of figures.

(⁴⁶¹) p. 262.—On the appearance and disappearance of new stars, see *Kosmos*, Bd. iii. S. 215-233; Eng. ed. p. 132-152.

(⁴⁶²) p. 267.—I have printed, in an earlier volume (*Kosmos*, Bd. ii. S. 347 and 499, Anm. 25; Eng. ed. p. 307 and cvi. Note 465), the passage in the 10th chapter of the first book “de Revolut.,” imitated from the *Somnium Scipionis*.

(⁴⁶³) p. 267.—Theonis Smyrnæi Platonici Liber de Astronomia, ed. H. Martin, 1849, p. 182 and 298: τῆς ἐμψυχίας μέσον τὸ περι τὸν ἥλιον, οἰοῦναι καρδιαν ὄντα του παντὸς, ὅθεν φέρουσιν αὐτοῦ καὶ τὴν ψυχὴν ἀρξαμένην διὰ παντὸς ἤκειν τοῦ σώματος τεταμένην ἀπὸ τῶν περάτων. (This new edition is worthy of notice, in reference to the peripatetic opinions of Adrastus, and many platonic opinions of Dercyllides.)

(⁴⁶⁴) p. 269.—Hansen, in Schumacher's *Jahrbuch für 1837*, S. 65-141.

(⁴⁶⁵) p. 271.—“D'après l'état actuel de nos connaissances astronomiques le Soleil se compose: 1° d'un globe central à peu près obscur; 2° d'une immense couche de nuages qui est suspendue à une certaine distance de ce globe et l'enveloppe de toutes parts; 3° d'une *photosphère*; en d'autres termes, d'une sphère resplendissante qui enveloppe la couche nuageuse, comme celle-ci, à son tour, enveloppe le noyau obscur. L'éclipse totale du 8 Juillet 1842 nous a mis sur la trace d'une troisième enveloppe, située au-dessus de la *photosphère*, et formée de nuages obscurs ou faiblement lumineux.—Ce sont les *nuages* de la troisième enveloppe solaire, situés en apparence pendant l'éclipse totale, sur le contour de l'astre ou un peu en dehors, qui ont donné lieu à ces singulières proéminences rougeâtres qui en 1842 ont si vivement excité l'attention du monde savant” (Arago, in the *Annuaire du Bureau des Longitudes pour l'an 1846*, p. 464 and 471). Sir John Herschel, in his *Outlines of Astronomy*, published in 1849 (p. 234, § 395), also assumes—“above the luminous surface of the Sun, and the region in which the spots reside, the existence of a gaseous atmosphere having a somewhat imperfect transparency.”

(⁴⁶⁶) p. 272.—It is proper to give first in the original the passages which are alluded to in the text, and to which my own attention was called by an instructive memoir by Dr. Clemens (“Giordano Bruno und Nicolaus von Cusa,” 1847, S. 101). The Cardinal Nicolaus of Cusa (the family name was Khrypffs—i. e. *écrevisse*, *craw-fish*), a native of Cues, on the Moselle,

says, in the 12th chapter of the second book of a treatise which enjoyed great celebrity at the time, “de docta Ignorantia” (Nicolai de Cusa, Opera, ed. Basil. 1565, p. 39) : “neque color nigredinis est argumentum vilitatis Terræ ; nam in Sole, si quis esset, non appareret illa claritas quæ nobis : considerato enim corpore Solis, tunc habet quandam quasi terram centraliorem, et quandam luciditatem quasi ignilem circumferentialem, et in medio quasi aqueam nubem et ærem clariorem, quem admodum terra ista sua elementa.” On the margin is written “Paradoxa” and “Hypni :” the latter word must, therefore, doubtless signify here also “dreams” (ἐνύπνια)—some hazardous speculation. Again, in a figurative comparison occurring in a long writing—Exercitationes ex Sermonibus Cardinalis (Opera, p. 579)—I find “Sicut in Sole considerari potest natura corporalis, et illa de se non est magnæ virtutis” (notwithstanding mass-attraction or gravitation!) “et non potest virtutem suam aliis corporibus communicare, quia non est radiosa. Et alia natura lucida illi unita, ita quod Sol ex unione utriusque naturæ habet virtutem, quæ sufficit huic sensibili mundo, ad vitam innovandam in vegetabilibus et animalibus, in elementis et mineralibus, per suam influentiam radiosam. Sic de Christo, qui est Sol justitiæ . . .” Dr. Clemens thinks that all this be something more than a happy conjectural anticipation. It appears to him “simply impossible that in the parts of the passage quoted (*considerato corpore Solis ; in Sole considerari potest . . .*) Cusa could have appealed to experience, unless there had been some tolerably accurate observation of the solar spots, both of their darker parts and of the penumbra.” He conjectures “that the philosophers of modern science had been anticipated in some of the results obtained by them, and that the Cardinal’s views may have been influenced by discoveries which are generally, but erroneously, supposed to have been first made at a later period.” It is certainly not only possible, but even very probable, that in districts where the sun is partially veiled for several months—as during the continuance of the “garua” on the coast of Peru—solar spots may have been seen even by uncivilised men with the naked eye ; but we have no accounts from any travellers of such a circumstance having attracted attention, or of the spots of the sun having ever been interwoven in the mythology of worshippers of that luminary. The mere, and very rare, sight with the naked eye of a solar spot on the sun’s disk, when either low down near the horizon, or covered with a thin veil of mist, and appearing white, red, or perhaps even of a greenish hue, would, I think, never have led even men exercised in intellectual thought to conjecture the existence of several successive coverings enveloping the dark body of the sun.

If Cardinal Cusa had known anything about solar spots, he would surely not have failed to introduce the "maculæ Solis" in some of the numerous comparisons which he so much delighted in drawing between physical and spiritual things. Let us only remember the vehement debates excited in the beginning of the 17th century, immediately after the invention of the telescope, by the discoveries of Fabricius and of Galileo. I have recalled in an earlier volume (Kosmos, Bd. ii. S. 503, Anm. 33; Eng. ed. p. cix. Note 473) the obscurely expressed astronomical representations of the Cardinal, who died in 1464, nine years, therefore, before the birth of Copernicus. The remarkable passage, "jam nobis manifestum est Terram in veritate moveri," is in lib. ii. cap. 12, de docta Ignorantia. According to Cusa, all things are in movement in every part of celestial space; we find no star which does not describe a circle. "Terra non potest esse fixa, sed movetur ut aliæ stellæ." He does not, however, suppose the Earth to revolve round the Sun, but the Earth and Sun to revolve "round the ever-changing poles of the Universe." Cusa, therefore, was not a Copernican, as is shown by this fragment, written by him with his own hand in 1444, and discovered by Dr. Clemens in the hospital at Cues.

(⁴⁶⁷) p. 272.—Kosmos, Bd. ii. S. 360-362 and 511-512, Anm. 49-53; Eng. ed. p. 319-321 and cxvi.-cxvii. Notes 489-493.

(⁴⁶⁸) p. 272.—"*Borbonia Sidera*, id est planetæ qui Solis lumina circumvolitant motu proprio et regulari, falso hactenus ab helioscopis Maculæ Solis nuncupati, ex novis observationibus Joannis Tarde, 1620.—*Austriaca Sidera heliocyclica* astronomicis hypothesibus illigata opera Caroli Malapertii Belgæ Montensis e Societate Jesu, 1633." The last-mentioned memoir has at least the merit of furnishing observations of a series of solar spots between 1618 and 1626. These are, however, the same years as those for which Scheiner published his own observations at Rome in his "*Rosa Ursina*." The Canon Tarde believed in the transit of small planets, because he deemed it impossible to ascribe such imperfections to the "eye of the World"—l'œil du Monde ne peut avoir des ophthalmies!" It is indeed surprising that, twenty years after Tarde's account of his *Borbonia Sidera*, Gascoigne, to whom the art of observation is so much indebted (Kosmos, Bd. iii. S. 76; Eng. ed. p. 59), should still have attributed the solar spots to the conjunction of numerous planetary, almost transparent, bodies revolving round the sun in great proximity to it. He supposed several of these, superposed upon each other, to be the cause of the dark shaded places. (Phil Trans., Vol. xxvii. 1710-1712, p. 282-290, letter from William Crabtree, August 1640.)

(⁴⁶⁹) p. 272.—Arago “sur les moyens d’observer les taches solaires,” in the *Annuaire* for 1842, p. 476-479. (Delambre, *Hist. de l’Astronomie du Moyen Age*, p. 394, as well as *Hist. de l’Astr. moderne*, T. i. p. 681.)

(⁴⁷⁰) p. 273.—*Mémoires pour servir à l’Histoire des Sciences*, par Mr. le Comte de Cassini, 1810, p. 242; Delambre, *Hist. de l’Astr. mod.* T. ii. p. 694. Although Cassini, as early as 1671, and La Hire in 1700, declared the body of the Sun to be dark, yet estimable elementary works on astronomy still continue to ascribe the first idea of this hypothesis to the meritorious astronomer Lalande. Lalande himself, in the edition of his *Astronomy* published in 1792, T. iii. § 3240, as well as in the first edition of 1764, T. i. § 2515, merely remains true to La Hire’s earlier expressed opinion—viz “que les taches sont les éminences de la masse solide et opaque du Soleil recouverte communément (en entier) par le fluide igné.” Between 1766 and 1774, Alexander Wilson formed the first just view of a funnel-shaped opening in the photosphere.

(⁴⁷¹) p. 273.—Alexander Wilson, *Observations on the Solar Spots*, in the *Phil. Trans.* Vol. lxiv. 1774, Part 1, p. 6-13, Tab. i.—“I found that the umbra, which before was equally broad all round the nucleus, appeared much contracted *on that part which lay towards the centre of the disk*, whilst the other parts of it remained nearly of the former dimensions. I perceived that the shady zone or umbra which surrounded the nucleus might be nothing else but the shelving sides of the luminous matter of the sun.” Compare, also, Arago, in the *Annuaire* for 1842, p. 506.

(⁴⁷²) p. 274.—Bode, in the *Beschäftigungen der Berlinischen Gesellschaft Naturforschender Freunde*, Bd. ii. 1776, S. 237-241 and 249.

(⁴⁷³) p. 277.—William Herschel, in the *Philosophical Transactions of the Royal Society* for 1801, Part 2. p. 310-316.

(⁴⁷⁴) p. 278.—An official notice of a high price of corn occurring in connection with obscuration of the sun for several months, is referred to in the historic fragments of the elder Cato. “*Luminis caligo*” and “*defectus Solis*” are expressions which, when employed by Roman writers, do not by any means signify on all occasions an eclipse of the sun; they have, for instance, no such meaning in the accounts of the long-continued dimness of the sun which is said to have followed the death of Cæsar. Thus we find in Aulus Gellius, in *Noct. Att.* ii. 28—“*Verba Catonis in originum quarto hæc sunt: non libet scribere, quod in tabula apud Pontificem maximum est, quotiens anona cara, quotiens lunæ an solis lumini caligo, aut quid obstiterit.*”

(⁴) p. 278.—Gautier, *Recherches relatives à l’influence que le nombre des*

taches solaires exerce sur les températures terrestres, in the Bibliothèque Universelle de Genève, Nouv. Série, T. li. 1844, p. 327-335.

(⁴⁷⁶) p. 278.—Arago, in the *Annuaire pour 1846*, p. 271-438.

(⁴⁷⁷) p. 278.—The same, p. 440-447.

(⁴⁷⁸) p. 279.—This is the whitish shining appearance which was also seen in the solar eclipse of the 15th of May, 1836, and of which even then the great Königsberg astronomer said very correctly, that “when the moon’s disk completely covered the sun there still remained visible a luminous ring of the solar atmosphere” (Bessel, in *Schum. Astr. Nachr.* No. 320).

(⁴⁷⁹) p. 279.—“Si nous examinons de plus près l’explication d’après laquelle les protubérances rougeâtres seraient assimilées à des nuages (de la troisième enveloppe), nous ne trouverions aucun principe de physique qui nous empêchât d’admettre que des masses nuageuses de 25 à 30000 lieues de long flottent dans l’atmosphère du Soleil ; que ces masses, comme certains nuages de l’atmosphère terrestre, ont des contours arrêtés, qu’elles affectent, çà et là, des formes très tourmentées, même des formes en surplomb ; que la lumière solaire (la photosphère) les colore en rouge.—Si cette troisième enveloppe existe, elle donnera peut-être la clef de quelques unes des grandes et déplorable anomalies que l’on remarque dans le cours des saisons” (Arago, in the *Annuaire for 1846*, p. 460 and 467).

(⁴⁸⁰) p. 280.—“Tout ce qui affaiblira sensiblement l’intensité éclairante de la portion de l’atmosphère terrestre qui paraît entourer et toucher le contour circulaire du Soleil, pourra contribuer à rendre les proéminences rougeâtres visibles. Il est donc permis d’espérer qu’un astronome exercé, établi au sommet d’une très haute montagne, pourrait y observer régulièrement les *nuages de la troisième enveloppe solaire*, situés en apparence sur le contour de l’astre *ou un peu en dehors* ; déterminer ce qu’ils ont de permanent et de variable, noter les périodes de disparition et de réapparition . . .” (Arago, *Annuaire for 1846*, p. 471).

(⁴⁸¹) p. 282.—Although it is undeniably possible that particular individuals among the Greeks and Romans may have seen large solar spots with the naked eye, yet it appears certain that such isolated observations, supposing them to have taken place, never led Greek or Roman writers to allude to those phenomena in any work which has come down to us. The passages in Theophrast. de Signis, iv. 1, p. 797,—Aratus Diosem, v. 90-92,—and Proclus, Paraphr. ii. 14, in which the younger Ideler (*Meteorol. Veterum*, p. 201, and *Commentary on Aristot. Meteor. T. i. p. 374*) thinks he perceives a men-

tion of solar spots—merely say that the sun's disk, which indicates good weather, shows no diversity of surface, nothing that marks it (*μηδέ τι σῆμα φεροι*), but rather perfect uniformity. The *σῆμα*, or chequered surface, is, moreover, expressly attributed to light cloud, belonging to the vapours of our atmosphere (the Scholiast to Aratus says, the "thickness of the air"): hence it is always the morning or the evening sun which is referred to, and which, quite independently of true solar spots, may certainly serve as *diaphanometers*, and are still regarded, both by sailors and agriculturists, according to an opinion by no means worthy of being despised, as affording useful indications of approaching changes of weather. The sun's disk, when near or on the horizon, is seen through the lowest atmospheric strata. Of the large solar spots which were seen by the naked eye in the years 807 and 840, and erroneously supposed to be transits of Mercury and Venus, the first was recorded in the great historic collection of Justus Reuberus, *Veteres Scriptores* (1726), in the part entitled *Annales Regum Francorum Pipini Karoli Magni et Ludovici a quodam ejus ætatis Astronomo, Ludovici regis domestico, conscripti*, p. 58. The authorship of these Annals was first attributed to a Benedictine monk (p. 28), and afterwards, and more correctly, to the celebrated Eginhard (Einhard, Charlemagne's private secretary): see *Annales Einhardi*, in Pertz's *Monumenta Germaniæ historica*, *Script. T. i. p. 194*. The passage referred to is the following:—"DCCCVII. stella Mercurii xvi. Kal. April. visa est in Sole qualis parva macula nigra, paululum superius medio centro ejusdem sideris, quæ a nobis octo dies conspicata est; sed quando primum intravit vel exivit, nubibus impredientibus, minime notare potuimus." The passage respecting the supposed transit of Venus mentioned by Arabian astronomers, is given by Simon Assemanus in the Introduction to the "*Globus cœlestis Cufico-Arabicus Veliæterni Musei Borgiani*," 1790, p. xxxviii., and is as follows:—"Anno Hegyræ 225, regnante Almootasemo Chalifa, visa est in Sole prope medium nigra quædam macula, idque feria tertia die decima nona Mensis Regebi . . ." It was believed to be the planet, and that *the same* macula nigra (therefore with interruptions of 12 or 13 days) was seen for 91 days. Soon afterwards Motassem died.—I subjoin 17 instances, taken from a larger number collected by me, of historical or traditional accounts of suddenly-occurring diminutions or obscurations of the light of day:—

Anno 45 B.C., at the time of the death of Julius Cæsar, after which the sun was for a whole year paler, and gave less heat than usual. so

that the air was thick; cold, and misty, and the fruits of the earth failed (Plutarch, in Jul. Cæs. cap. 87, Dio Cass. xliv. Virg. Georg. i. 466).

A.D. 33, at the time of our Saviour's crucifixion. "From the sixth hour there was darkness over all the land unto the ninth hour" (Matth. xxvii. 45); and in the parallel passage in St. Luke, "the sun was darkened" (Luke, xxiii. 45). Eusebius adduces, in explanation and confirmation, an eclipse of the Sun in the 202d Olympiad, mentioned by Phlegon, of Tralles, a writer of chronicles (Ideler, Handbuch der mathem. der Chronologie, Bd. ii. S. 147). But Wurm has shown that the eclipse belonging to this Olympiad, and which was visible over all Asia Minor, took place on the 24th of November, 29 years after the birth of Christ, or between three or four years earlier. The Crucifixion was at the time of the Passover, 14 Nisan (Ideler, Bd. i. S. 515-520), which was always celebrated at the time of the full moon. The sun cannot, therefore, have been eclipsed by the moon for three hours. The Jesuit Scheiner was inclined to attribute the diminution of light to a group of large solar spots.

358.—On the 22d of August, an obscuration of two hours in length, *previous* to the terrible earthquake of Nicomedia, which also destroyed many other towns in Macedonia and Pontus. The darkness lasted between two and three hours: "nec contigua vel adposita cernebantur." Ammian. Marcell. xvii. 7.

360.—In all the Eastern provinces of the Roman Empire (per Eoostractus) there was "caligo a primo auroræ exortu adusque meridiem" (Ammian. Marcell. xx. 3), but stars were seen; therefore it could not have been caused by showers of ashes; nor, from the long duration of the phenomenon, could it have been the effect of a total solar eclipse, to which the historian attributes it: "Cum lux cœlestis operiretur, e mundi conspectu penitus luce abrepta, defecisse diutius solem pavidæ mentes hominum æstimabant: primo attenuatum in lunæ corniculantis effigiem, deinde in speciem anctum semenstrem, posteaque in integrum restitutum. Quod alias non evenit ita perspicue, nisi cum post inæquales cursus intermenstruum lunæ ad idem revocatur." The description is quite that of a true solar eclipse; but what is to be done with the length of time and "caligo" in all the Eastern provinces?

409.—When Alaric appeared before Rome: the darkness such that

- stars were seen in the day-time. Schnurrer, *Chronik der Seuchen*, Th. i. S. 113.
- 536.—“Justinianus I. Cæsar imperavit annos triginta octo (527 to 565). Anno imperii nono deliquium lucis passus est Sol, quod annum integrum et duos amplius menses duravit, adeo ut parum admodum de luce ipsius appareret; dixeruntque homines Soli aliquid accidisse, quod nunquam ab eo recederet.” Gregorius Abu'l-Faragius, *Supplementum Historiæ Dynastiarum*, ed. Edw. Pocock, 1663, p. 94. This seems to have been a phenomenon very similar to that of 1783, to which the name of “Hohenrauch” has been given, but for such phenomena no general satisfactory explanation has been assigned.
- 567.—Justinus II. annos 13 imperavit (565-578). Anno imperii ipsius secundo apparuit in cælo ignis flammans juxta polum arcticum qui annum integrum permansit; obtexeruntque tenebræ mundum ab hora diei nona noctem usque, adeo ut nemo quicquam videret; deciditque ex ære quoddam pulveri minuto et cineri simile. Abu'l-Farag. l. c. p. 95. For a year continual Aurora, afterwards darkness, and showers of what we call “trade-wind dust” (?).
- 626.—According to Abu'l-Farag. (*Hist. Dynast.* p. 94 and 99), half the sun's disk continued obscured for eight months.
- 733.—A year after the Arabs had been driven back beyond the Pyrenees, as the result of the battle of Tours, the sun was darkened on the 19th of August in a terrifying manner. Schnurrer, *Chron.* Th. i. S. 164.
- 807.—A spot on the sun which was taken for Mercury. Reuber, *Vet. Script.* p. 58 (see above, p. xcvi.)
- 840.—From the 28th of May to the 26th of August (Assemani reckons May 839), the so-called transit of Venus over the sun's disk. See above, p. xviii. (The Caliph Al-Motassem reigned from 834 to 841, when he was succeeded by Haroun-el-Vatek, the ninth Caliph.)
- 934.—In the valuable *History of Portugal* by Faria y Sousa, 1730, p. 147, I find—“En Portugal se vió sin luz la tierra por dos meses. Avia el Sol perdido su splendor.” An opening in the sky then seemed to take place “por fractura,” with many flashes of lightning, and the full blaze of sunshine was then suddenly restored.
- 1091.—On the 21st of September a darkening of the sun took place

which lasted three hours, and after the obscuration had passed away the solar disk remained of a peculiar colour. "Fuit eclipsis Solis 11 Kal. Octob. fere tres horas: Sol circa meridiem dire nigrescebat." Martin Crusius, *Annales Svevici, Francof.* 1595, T. i. p. 279; Schnurrer, Th. i. S. 219.

1096.—On the 3d of May solar spots were seen with the naked eye: Signum in Sole apparuit V. Non Marci feria secunda incipientis quadragesimæ. Joh. Staindelii, presbyteri Pataviensis, *Chronicon generale, in Cefelii Rerum Boicarum Scriptoris*, T. i. 1763, p. 485.

1206.—On the last day of February, according to Joaquin de Villaba (*Epidemiologia Española Madr.* 1803, T. i. p. 30), there was complete darkness for 6 hours: "el día ultimo del mes de Febrero hubo un eclipse de sol que duró seis horas con tanta obscuridad como si fuera media noche. Siguiéron á este fenomeno abundantes y continuas lluvias." Schnurrer, Th. i. S. 258 and 265, speaks of an almost similar phenomenon in June 1191.

1241.—Five months after the Mongol battle of Leignitz: "obscuratus est Sol (in quibusdam locis?), et factæ sunt tenebræ, ita ut stellæ viderentur in cælo, circa festum S. Michaelis hora nona." *Chronicon Claustro-Neoburgense* (of the Neuburg Convent near Vienna, containing the years 218 to 1348 A.D.), in Pez, *Scriptores rerum Austriacarum*," Lips. 1721, T. i. p. 458.

1547.—The 23d, 24th, and 25th of April,—therefore a day before and a day after, as well as the actual day, of the battle of Mühlbach, in which the Prince Elector John Frederic was taken. Kepler says, (in *Paralipom. ad Vitellium, quibus Astronomiæ pars optica traditur*, 1604, p. 259)—"refert Gemma, pater et filius, anno 1547 ante conflictum Caroli V. cum Saxonix Duce Solem per tres dies ceu sanguine perfusum comparuisse, ut etiam stellæ pleræque in meridie conspicerentur." (So, also, Kepler, *de Stella nova in Serpentario*, p. 13). Great doubt exists as to the cause: "Solis lumen ob causas quasdam sublimes hebetari....." perhaps there may have been materia cometica latius sparsa. The cause cannot have been in our atmosphere, because stars were seen at noon." Schnurrer (*Chronik der Seuchen*, Th. ii. S. 93) is inclined to believe, notwithstanding the visibility of stars, that it was an "Hohenrauch," or a foreign admixture in the atmosphere, because the Emperor Charles V. complained before the battle

that "semper se nebulae densitate infestari, quoties sibi cum hoste pugnandum sit" (Lambert, Hortens. de bello german. lib. vi. p. 182).

(⁴⁸²) p. 283.—Horrebow (Basis Astronomiae, 1735, § 226) already uses the same expression. The solar light is, according to him, "An *Aurora borealis*, produced by active *magnetic forces continually* in operation in the *Sun's atmosphere*." (See Hanow, in Joh. Dan. Titius, gemeinnützige Abhandlungen über natürliche Dinge, 1768, S. 102.)

(⁴⁸³) p. 286.—Arago, in the Mémoires des Sciences mathém. et phys. d l'Institut de France, Année 1811, Partie i. p. 118; Mathieu, in Delambre Hist. de l'Astr. au 18ème Siècle, p. 351 and 652; Fourier, Eloge de William Herschel, in the Mém. de l'Institut, T. vi. Année 1823 (Par. 1827), p. lxxii. The result of an ingenious experiment of Forbes during a solar eclipse in 1836 is also remarkable, and evidences great homogeneity in the nature of the light which emanates from the centre and from the margin of the Sun's disc: a spectrum formed exclusively by rays either from the margin or limb was found perfectly identical, in respect to the number and position of the dark lines traversing it, with the spectrum which is formed by the whole of the rays. If rays of a certain refrangibility are wanting in the solar light, it is not, as Sir David Brewster conjectures, because they are lost in the Sun's atmosphere; since the marginal rays which traverse a much thicker stratum produce the same dark lines. (Forbes, in the Comptes rendus, T. ii. 1836, p. 576.) I conclude this note by subjoining all that I collected on this subject, in 1847, from Arago's manuscripts:—

"Des phénomènes de la polarisation colorée donnent la certitude que le bord du Soleil a la même intensité de lumière que le centre; car en plaçant dans la polariscope un segment du bord sur un segment du centre, j'obtiens (comme effet complémentaire du rouge et du bleu) un blanc pur. Dans un corps solide (dans une boule de fer chauffée au rouge) le même angle de vision embrasse une plus grande étendue au bord qu'au centre, selon la proportion du Cosinus de l'angle; mais dans la même proportion aussi le plus grand nombre de points matériels émettent une lumière plus faible *en raison de leur obliquité*. Le rapport de l'angle est naturellement le même pour une sphère gazeuse; mais l'obliquité ne produisant pas dans les gaz le même effet de diminution que dans les corps solides, le bord de la sphère gazeuse serait plus lumineux que le centre. Ce que nous appelons le disque lumineux du Soleil, est la photosphère gazeuse, comme je l'ai prouvé par le manque absolu de traces de polarisation sur le bord du disque. Pour expliquer donc *l'égalité d'intensité* du bord et du centre indiquée par le polariscope, il faut admettre

une enveloppe extérieure qui diminue (éteint) moins la lumière qui vient du centre que les rayons qui viennent sur le long trajet du bord à l'œil. Cette enveloppe extérieure forme la couronne blanchâtre dans les éclipses totales du Soleil. — La lumière qui émane des corps solides et liquides incandescens, est partiellement polarisée quand les rayons observés forment avec la surface de sortie, un angle d'un petit nombre de degrés ; mais il n'y a aucune trace sensible de polarisation lorsqu'on regarde de la même manière dans le polariscope des gaz enflammés. Cette expérience démontre que la lumière solaire ne sort pas d'une masse solide ou liquide incandescente. La lumière ne s'engendre pas uniquement à la surface des corps ; une portion naît dans leur substance même, cette substance fût-elle du platine. Ce n'est donc pas la décomposition de l'oxygène ambiant qui donne la lumière. L'émission de lumière polarisée par le fer liquide est un effet de réfraction au passage vers un moyen d'une moindre densité. Partout où il y a réfraction, il y a production d'un peu de lumière polarisée. Les gaz n'en donnent pas, parceque leur couches n'ont pas assez de densité. La lune suivie pendant le cours d'une lunaison entière offre des effets de polarisation, excepté à l'époque de la pleine lune et des jours qui en approchent beaucoup. La lumière solaire trouve, surtout dans les premiers et derniers quartiers, à la surface inégale (montagneuse) de notre satellite, des inclinaisons de plans convenables pour produire la polarisation par réflexion."

(⁴⁸⁴) p. 286.—Sir John Herschel, *Astron. Observ. made at the Cape of Good Hope*, § 425, p. 434 ; *Outlines of Astr.* § 395, p. 234. Compare Fizeau and Foucault, in the *Comptes rendus de l'Acad. des Sciences*, T. xviii. 1844, p. 860. It is sufficiently remarkable that Giordano Bruno, who ascended the scaffold eight years before the invention of the telescope, and eleven years before the discovery of the solar spots, believed already in the rotation of the Sun around its axis. On the other hand, he considered the light of the centre of the Sun's disk to be inferior in intensity to that of the margin. He imagined, by some effect of optical illusion, that he saw the Sun's disk turn, and its whirling edges expand and contract. (Jordano Bruno, par Christian Bartholmèss, T. ii. 1847, p. 367.)

(⁴⁸⁵) p. 287.—Fizeau and Foucault, *Recherches sur l'intensité de la lumière émise par le charbon dans l'expérience de Davy*, in the *Comptes rendus*, T. xviii. 1844, p. 753.—“The most intensely ignited solids (ignited quicklime in Drummond's oxy-hydrogen lamp) appear only as *black spots* on the disk of the Sun when held between it and the eye.” (*Outlines*, p. 326 ; *Kosmos*, Bd. ii. S. 361 ; English Ed. p. 321.)

(⁴⁸⁶) p. 287.—Compare Arago's comments on Galileo's letters to Marcus Welser, and his optical explanations and remarks on the influence of the diffused solar light reflected from the strata of the atmosphere, which covers as it were with a veil of light objects seen on the face of the heavens in the field of a telescope. (*Annuaire du Bureau des Longitudes* for 1842, p. 482—487.)

(⁴⁸⁷) p. 288.—Mädler, *Astr. S.* 81.

(⁴⁸⁸) p. 288.—*Philos. Magazine*, Ser. iii. Vol. 28, p. 230; and *Poggend. Annalen*, Bd. lxxviii. S. 101.

(⁴⁸⁹) p. 290.—Faraday on Atmospheric Magnetism, in "Exper. Researches on Electricity," 25th and 26th Series (*Phil. Trans.* for 1851, Part 1), § 2774, 2780, 2881, 2892—2968; and for the historical part of the research, § 2847.

(⁴⁹⁰) p. 291.—Compare Nervander, of Helsingfors, in the *Bulletin de la Classe physico-mathém. de l'Acad. de St.-Pétersbourg*, T. iii. 1845, p. 30—32; and Buys-Ballot, of Utrecht, in *Poggend. Annalen der Physik*, Bd. lxxviii. 1846, S. 205—213.

(⁴⁹¹) p. 291.—I have distinguished by marks of quotation what I have taken in p. 291 to p. 294 from Schwabe's manuscript communications. The observations of the years 1826 to 1843 were previously published in Schumacher's *Astron. Nachr.* No. 495, Bd. xxi. 1844, S. 235.

(⁴⁹²) p. 295.—Sir John Herschel, *Cape Obs.* p. 434.

(⁴⁹³) p. 297.—*Kosmos*, Bd. i. S. 207 and 442, Anm. 49; Eng. ed. p. 188.

(⁴⁹⁴) p. 298.—Gesenius, in the *Hallischen Litteratur-Zeitung*, 1822, No. 101 and 102 (*Ergänzungs bl.* S. 801—812). The Chaldeans regarded the Sun and Moon as the two principal divinities, and the five planets only as presided over by Genii.

(⁴⁹⁵) p. 298.—Plato, in the *Timæus*, p. 38, Steph.

(⁴⁹⁶) p. 298.—Böckh de *Platonico systemate cœlestium globorum et de vera indole astronomiæ Philolaicæ*, p. xvii.; and the same author in the *Philolaos*, 1819, S. 99.

(⁴⁹⁷) p. 298.—Jul. Firmicus Maternus, *Astron. libri viii.* (ed. Pruckner, Basil. 1551), lib. ii. cap. 4; of the time of Constantine.

(⁴⁹⁸) p. 298.—Humboldt, *Monumens des peuples indigènes de l'Amérique*, T. ii. p. 42—49. At that early date, 1812, I called attention to the points of analogy between the zodiac of Bianchini and that of Dendera. Compare Letronne, *Observations critiques sur les représentations zodiacales*, p. 97; and Lepsius, *Chronologie der Aegypter*, 1849, S. 80.

(⁴⁹⁹) p. 298.—Letronne sur l'origine du Zodiaque grec, p. 29; Lepsius, Chronologie, S. 83. Letronne contested the ancient Chaldean origin of the "planetary week" on account of the number 7.

(⁵⁰⁰) p. 298.—Vitruv. de Archit. ix. 4 (ed. Rode, 1800, p. 209). Neither Vitruvius nor Martianus Capella give the Egyptians as the authors of a system according to which Mercury and Venus were regarded as the satellites of the Sun, that orb being itself viewed as a planet. Vitruvius says:—"Mercurii autem et Veneris stellæ circum Solis radios. Solem ipsum, uti centrum, itineribus coronantes, regressus retrorsum et retardationes faciunt."

(⁵⁰¹) p. 298.—Martianus Mineus Felix Capella de nuptiis philos. et Mercurii, lib. viii. ed. Grotii, 1599, p. 289: "Nam Venus Mercuriusque licet ortus occasusque quotidianos ostendant, tamen eorum circuli Terras omnino non ambiunt, sed circa Solem laxiore ambitu circulantur. Denique circulorum suorum centrum in Sole constituunt, ita ut supra ipsum aliquando"..... As this passage is entitled "Quod Tellus non sit centrum omnibus planetis," it might indeed, as Gassendi asserts, have exercised some influence on the first views of Copernicus,—more so than the passages attributed to the great geometer, Apollonius of Perga. Copernicus, however, only says, "minime contemnendum arbitror, quod Martianus Capella scripsit, existimans quod Venus et Mercurius circumerrant Solem in medio existentem." Compare Kosmos, Bd. ii. S. 350 and 503, Anm. 34; Engl. ed. p. 309 and cix., Note 474.

(⁵⁰²) p. 299.—Henri Martin, in his commentary on the Timæus (Études sur le Timée de Platon, T. ii. p. 129—133), appears to me to have elucidated in a very happy manner the passage of Macrobius on the "ratio Chaldæorum," which had misled the excellent Ideler, in Wolff's and Buttmann's Museum der Alterthums-Wissenschaft, Bd. ii. S. 443, and in his Memoir on Eudoxus, p. 48. Macrobius (in Somn. Scipionis, lib. i. cap. 19, lib. ii. cap. 3, ed. 1694, pag. 64 and 90) does not appear to have known anything of the system of Vitruvius and Martianus Capella, in which Mercury and Venus are satellites of the Sun, which itself moves, together with the remaining planets, round the Earth, which is fixed in the centre. He merely enumerates the differences in the succession of the orbits of the Sun, Venus, Mercury, and the Moon, according to the assumptions of Cicero. He says, "Ciceroni, Archimedes et Chaldæorum ratio consentit, Plato Ægyptios secutus est." When Cicero, in the eloquent description of the whole planetary system (Somn. Scip. cap. 4), exclaims "hunc (Solem) ut comites consequuntur Veneris alter, alter Mercurii cursus," he only points to the nearness to each other of the orbits of the Sun and of those two inferior planets, after having

previously enumerated the three "cursus" of Saturn, Jupiter, and Mars, all revolving round the unmoving Earth. The orbit of a secondary planet or satellite cannot include the orbit of a primary planet, and yet Macrobius says decidedly—"Ægyptiorum ratio talis est: circulus, per quem Sol discurrit, a Mercurii circulo ut inferior ambitur, illum quoque superior circulus Veneris includit." All are permanently parallel orbits, one including another.

(⁵⁰³) p. 299.—Lepsius, *Chronologie der Aegypter*, Th. i. S. 207.

(⁵⁰⁴) p. 299.—The mutilated name of the planet Mars, in Vettius Valens and Cedrenus, may probably answer to the name of Her-tosch, as Seb to Saturn. (See last-quoted work, p. 90 and 93.)

(⁵⁰⁵) p. 300.—We find the most striking differences on comparing Aristot. *Metaph.* xii. cap. 8, pag. 1073, Bekker, with Pseudo-Aristot. *de Mundo*, cap. 2, pag. 392. In the last-mentioned work there already appear as the names of planets, Phæton, Pyrois, Hercules, Stilbon, and Juno; pointing to the time of Apuleius and the Antonines, when Chaldean astrology had already spread over the whole Roman empire, and denominations belonging to various nations were intermingled with each other. (Compare *Kosmos*, Bd. ii. S. 15 and 106, Anm. 18; Eng. ed. p. 14 and 111, Note 18.) Diodorus Siculus says expressly that the Chaldeans had first named the planets after their Babylonian deities, and that it was thus this class of names had passed to the Greeks. Ideler (Eudoxus, S. 48), on the contrary, attributes these appellations to the Egyptians, and grounds his opinion on the ancient existence on the banks of the Nile of a seven days' planetary week (*Handbuch der Chronologie*, Bd. i. S. 180); but this hypothesis has been effectually refuted by Lepsius (*Chronol. der Aeg.* Th. i. S. 131). I will here bring together the synonymous names borne by the five ancient planets, taken from Erasthænes, from the author of the *Epinomis* (Philippus Opuntius?), from Geminus, Pliny, Theon of Smyrna, Cleomedes, Achilles Tatius, Julius Firmicus, and Simplicius: their preservation has probably been principally caused by attachment to the dreams of astrology.

Saturn: *φαινων*, Nemesis; also called by five authors "a sun" (Theon Smyrn. p. 87 and 165, Martin).

Jupiter: *φαιδων*, Osiris.

Mars: *πυροεις*, Hercules.

Venus: *εωσφορος*, *φωσφορος*, Lucifer; *εσπερος*, Vesper; Juno; Isis.

Mercury: *στιλβων*; Apollo.

Achilles Tatius (*Isag. in Phæn. Arati*, cap. 17) thinks it strange that

Egyptians as well as Greeks should give the name of "the bright" to the faintest of all the planets (probably, he surmises, only because it brings good fortune). According to Diodorus, it was "because Saturn was the planet which made known the future with the most fulness and clearness." (Letronne, sur l'origine du Zodiaque grec, p. 33; and in the Journal des Savants, 1836, p. 17. Compare also Carteron, Analyse de Recherches Zodiacales, p. 97.) Names which pass from one nation to another by means of equivalents, do indeed often depend in their origin on accidental circumstances which it is impossible to trace; but yet it may be well to remark here, that, linguistically, *φαινειν* expresses merely shining; therefore, a faint, continuous, equable light: while *στιλβειν* supposes an interrupted more vividly bright and more *sparkling* light. The descriptive appellations—*φαινων* for the remoter planet, Saturn; and *στιλβων* for the nearer planet, Mercury—appear to me the more appropriate, because, as I have already remarked (Kosmos, Bd. iii. S. 84; Eng. ed. p. 66), in the daytime, in Fraunhofer's large Refractor, Saturn and Jupiter appear faint in their light, in comparison with the sparkling Mercury. There is indicated, as Professor Franz remarks, a successive increase of brightness from Saturn (*φαινων*) to Jupiter, the lustrous guider of the luminous chariot (*φαέδων*); to the coloured glowing Mars (*πυρόεις*); to Venus (*φωσφόρος*); and to Mercury (*στιλβων*).

The Indian appellation of the "slow-moving" (*sanaistschara*), for Saturn, being known to me, it led me to inquire from my celebrated friend Bopp, whether, in the Indian names for the planets, as in those of the Greeks, and possibly of the Chaldeans, it was possible to distinguish between mythological and descriptive names. I subjoin the information for which I am indebted to this great philologist; placing the planets, however, as in the above table, in the order of succession of their real distances from the Sun (beginning with the greatest distance), instead of in the order in which they are arranged in the Amarakosha (in Colebrooke, p. 17 and 18). According to the Sanscrit nomenclature, there appear in fact, among five names, to be three which are descriptive ones: those for Saturn, Mars, and Venus.

"*Saturn*: *sanaistschara*, from 'sanais, slow, and *tschara*, moving; also *sauri*, a name of Vishnu (derived as a patronymic from 'sûra, grandfather of Krishna), and 'sani. The planetary name 'sani-vara, for dies Saturni, is radically allied with the adverb 'sanais, slow. The appellations of the days of the week according to the planets do not, however, appear to have been known to Amarasinha. They are probably of later introduction.

“*Jupiter* : Vrihaspati; or, according to the more ancient Vedic mode of writing, which is followed by Lassen, Brihaspati : Lord of growth; a Vedic deity : from vrih (brib), to grow, and pati, lord.

“*Mars* : Angaraka (from angara, burning coal); also, lohitaṅga, the red body : from lôhita, red, and anga, body.

“*Venus* : a male planet, called 'sukra, *i. e.* the bright. Another appellation of this planet is daitya-guru : teacher, (guru) of the Titans, Daityas.

“*Mercury* : Budha (a planetary name not to be confounded with Buddha, the founder of a creed); also Rauhiniya, the son of the nymph Rohini, the consort of the Moon (soma); whence the planet is sometimes called saumya, a patronymic of the Sanscrit word for moon. The etymological root of both Budha and Buddha is budh, to know. It appears to me very improbable that Wuotan (Wotan, Odin) is connected with Budha. The conjecture has no doubt been principally founded on the external similarity of form, and on the agreement in the name of the day of the week, dies Mercurii, with the old Saxon Wôdanes-dag, and the Indian Budha-vara, Budha's day. Vâra signifies originally time, *e. g.* in bahuvârân, many times, or often; later it appears at the end of a composite form in the signification of day. Jacob Grimm (*Deutsche Mythologie*, S. 120) derives the Germanic Wuotan from the verb watan, vuot (our German waten; English, to wade), which signifies meare, transmeare, cum impetu ferri, and corresponds literally to the Latin vadere. Wuotan, Odinn, is, according to Jacob Grimm, the all-powerful, all-pervading Being : qui omnia permeat, as Lucan says of Jupiter.”

Compare on the Indian name of the day of the week, on Budha and Buddha, and the days of the week generally, my brother's remarks in his work, *Ueber die Verbindungen zwischen Java und Indien* (Kawi Sprache, Bd. i. S. 187—190).

(⁵⁰⁶) p. 300.—Compare Letronne sur l'Amulette de Jules César et les Signes planétaires, in the *Revue Archéologique*, Année iii. 1846, p. 261. Salmasius saw in the most ancient planetary sign for the planet Jupiter, the initial letter of Ζεύς; and in that for Mars, an abbreviation of the name Δούπιος. The solar disc, employed as a sign, was rendered almost unrecognisable by a triangular obliquely issuing bundle of rays. As the Earth (apart from the Philolaic Pythagorean system) was not reckoned among the planets, Letronne considers the planetary sign employed for the Earth to have come into use subsequent to Copernicus. The remarkable passage of Olympiodorus, on the consecration of metals to particular planets, is borrowed

from Proclus, and was discovered by Böekh. (In the Basle edition it is in p. 14, and in Schneider's in p. 30.) Compare for Olympiodorus: Aristot. Meteor. ed. Ideler, T. ii. p. 163. The Scholion to Pindar (Isthm.), in which the metals are compared to the planets, also belongs to the Neo-Platonic School. (Lobeck, Aglaophamus in Orph. T. ii. p. 936.) By the same connection of ideas planetary signs came gradually to be employed as signs for the metals, and in particular cases even furnished names to metals, as mercury for quicksilver, *argentum vivum*, and *hydrargyrus* of Pliny. In the valuable collection of Greek manuscripts in the Paris Library, there are two manuscripts on the cabalistic, so-called sacred, art; one of which (No. 2250) mentions the metals consecrated to the planets without planetary signs, but the other (No. 2329), which is a kind of Chemical Dictionary, and belongs to the 15th century, combines the names of the metals with a small number of planetary signs. (Hofer, *Histoire de la Chimie*, T. i. p. 250.) In the Paris manuscript No. 2250, quicksilver is attributed to Mercury, and silver to the Moon; while in No. 2329, on the contrary, quicksilver is given to the Moon, and tin to Jupiter. Olympiodorus assigned the latter metal to Mercury:—so fluctuating were the mystical relations of the heavenly bodies to the “powers of the metals.”

This is the place for alluding to the allotment to different planets of the several hours of the day, and of the several days of the short period of seven days, or the week, respecting the antiquity and the prevalence of which among remote nations, more correct views have very recently been put forward for the first time. The Egyptians, as is shown by Lepsins (*Chronologie der Aegypter*, S. 132), and testified by monuments reaching back to the very early times of the construction of the great pyramids, had originally short periods, similar to weeks, consisting not of seven, but of ten days. Three such decades formed one of the twelve months of the solar year. When we read in Dio Cassius (lib. xxxvii. cap. xviii.) “that the custom of calling the days of the week after the seven planets came first from the Egyptians, and had spread not very long ago from them to all other nations, and in particular to the Romans, among whom it had *already* become completely naturalised,” we must not forget that this writer lived so late as the reign of Alexander Severus, and that since the first invasion of Oriental astrology under the Cæsars, and particularly in consequence of the great assemblage and intercourse of persons of so many nations and races at Alexandria, it had become usual among the people of the West to give the name of Egyptian to whatever seemed to be ancient. Without doubt the week of seven days was

most original and most general among the Semitic nations; not only among the Hebrews, but also among the Araḗian Nomades long before Mahomet. I proposed to a learned investigator of Semitic antiquity, the Oriental traveller, Prof. Tischendorf, at Leipsic, the questions,—whether there were in the writings of the Old Testament, besides the Sabbath, any traces of names for the several days of the week (other than the second and third day of the *schebua*); and whether there could nowhere be found in the New Testament, at a time when foreign residents in Palestine certainly already pursued planetary astrology, any planetary denomination for a day of the week? The answer was: “Neither in the Old nor the New Testament are there any traces of appellations for any of the days of the week taken from the planets, and, moreover, none such can be found either in the *Mischna* or the *Talmud*. The custom was not to say ‘the second or the third of the *schebua*,’ but to count by the days of the month: the day before the Sabbath was called ‘the 6th day,’ without any addition. The word Sabbath was also applied directly to the week itself (Ideler, *Handbuch der Chronologie*, Bd. i. S. 480), whence we find in the *Talmud*, for the several days of the week: first, second, third of the Sabbath. The word *ἑβδομάς*, for *schebua*, is not in the New Testament. The *Talmud*, of which the redaction extends from the second into the fifth century, has *descriptive* Hebrew names for particular planets, *i. e.* the *bright* Venus and the *ruddy* Mars. The name of *Sabbatai* (properly, Sabbath-star), given to Saturn, is particularly remarkable, as is also the circumstance that among the Pharisaic names of stars enumerated by Epiphanius, the name *Hochab*, Sabbath, is used for the planet Saturn. May this have had any influence in causing the day of the Sabbath to become the day of Saturn; Saturday, the *Saturni sacra dies* of Tibullus (*Eleg.* i. 3, 18)? A passage of Tacitus (*Hist.* v. 4) suggests additional considerations, taking the name of Saturn as applicable both to the planet and to a partly legendary, partly historical personage.” (Compare also Fürst, *Kultur- und Litteratur-geschichte der Juden in Asien*, 1849, S. 40.)

The phases of the Moon in her different quarters must assuredly have earlier attracted the attention of hunting and pastoral nations than astrological fancies. We may, therefore, well assume with Ideler, that the week has arisen from the length of the synodical month, of which the fourth part contains on the average 7 days and $\frac{2}{3}$ ths; and that, on the other hand, references to the planetary series or the intervals between the planets, as well as to planetary hours and days, belong to a wholly different period, and to a more advanced, theory-loving civilisation.

Three different opinions have been propounded respecting the appellations of the different days of the week taken from the planets, and respecting the arrangement and sequence of the heavenly bodies,

Saturn,
Jupiter,
Mars,
Sun,
Venus,
Mercury, and
Moon,

as placed according to the oldest and most widely prevalent belief (Geminus, *Elem. Astr.* p. 4; Cicero, *Somn. Scip.* cap. 4; Firmicus, ii. 4), between the sphere of the fixed stars and the Earth,—itself immoveably at rest in the centre. Of the three views alluded to, one is taken from musical intervals; another from the astrological names of the planetary hours; and a third from the distribution of every three decans, or three planets who are the lords (domini) of these decans, among the twelve signs of the zodiac. We find the two first-named hypotheses in the remarkable passage in Dio Cassius, in which he wishes to explain (*lib. xxxvii. cap. 17*) why the day of Saturn, our Saturday, is kept by the Jews, according to their law, as the Sabbath. He says: “If we apply the musical interval, called *διὰ τεσσάρων*, the fourth, to the seven planets, according to their times of revolution, and assign to Saturn, which is the outermost of all, the first place, we come next to the fourth (the Sun), and then to the seventh (the Moon); and thus we obtain the planets in the order in which they follow each other in the names of the days of the week.” The commentary to this passage is given by Vincent, “*sur les Manuscrits grecs relatifs à la Musique*,” 1847, p. 138: compare also Lobeck, *Aglaophamus*, in *Orph.* p. 941—946. The second explanation of Dio Cassius is taken from the periodical series of the planetary hours. He says: “If we begin to count the hours of the day and night from the first hour of the day, calling the first hour that of Saturn, the second that of Jupiter, the third hour belonging to Mars, the fourth to the Sun, the fifth to Venus, the sixth to Mercury, and the seventh to the Moon, according to the order assigned by the Egyptians to the planets; and if we always begin again, and go through the same round,—we shall find that, after passing through the twenty-four hours, the first hour of the next day is that of the Sun, the first hour of the third day that of the Moon, the first of the fourth that of Mars,—and, in short, that the first hour of each day will be that of the planet from which the day is called.” Thus Paulus Alexandrinus, an astronomer and

mathematician of the fourth century, calls regent or ruler of each day of the week the planet whose name falls to the first hour of that day.

This mode of explanation of the names of the days of the week has been hitherto very generally received as the correct one; but Letronne grounds upon the long neglected zodiacal circle of Bianchini (which is preserved in the Louvre, and to which I myself, in the year 1812, recalled the attention of antiquarians, on account of the remarkable combination of a Greek with a Kirgiso-Tartar zodiac) the belief that a third mode of explanation corresponds best to the distribution of every three planets to a sign of the zodiac. (Letronne, "Observ. crit. et archéol. sur l'objet des représentations zodiacales," 1824, p. 97—99.) This distribution of the planets among the thirty-six decans of Dodecatomery is quite that which is described by Julius Firmicus Maternus (ii. 4) as "signorum decani eorumque domini." If we distinguish in each sign the planet which is the first of the three, we obtain the succession of the planetary days in the week. (In Virgo—*Sun*, Venus, Mercury; in Libra—*Moon*, Saturn, Jupiter; in Scorpio—*Mars*, Sun, Venus; in Sagittarius—*Mercury* may here serve as instances of the first four days of the week:—*Dies Solis, Lunæ, Martis, Mercurii*.) As, according to Diodorus, the Chaldeans originally counted only five planets (the starry ones), not seven, so all those combinations in which periodical series are formed of more than five planets, appear to have not an ancient Chaldean, but rather a very late astrological origin. (Letronne, sur l'origine du zodiaque grec, 1840, p. 29.)

Some of my readers may perhaps be pleased to find here a farther very short explanation of the agreement between the order of succession of the planets as days of the week, and their order of succession and distribution among the decans in the zodiac of Bianchini. If, taking the so-called seven planets in the order of succession in which they were arranged according to the custom of the ancients, and assigning to each a letter—(Saturn *a*, Jupiter *b*, Mars *c*, Sun *d*, Venus *e*, Mercury *f*, Moon *g*)—we make of these seven members the periodical series

$$a b c d e f g, \quad a b c d \dots\dots;$$

then we obtain,—1st, by missing two members in the distribution among the decans, each one of which contains three planets (of which the *first* in each zodiacal sign gives its name to the day of the week), the new periodical series,

$$a d g c f b e, \quad a d g c \dots\dots$$

i. e. Dies Saturni, Solis, Lunæ, Martis, &c.; and 2ndly, the same new series

$$a d g c \dots\dots$$

by the method given by Dio Cassius of the twenty-four planetary hours, according

to which the successive days of the week take their names from the planet which rules over the first hour of the day; so that we have alternately to take a member of the periodical planetary series of seven members, and to pass over or omit 23 members. Now, in a periodical series, it is indifferent whether we omit a certain number of members, or this number augmented by any multiple of the number of members in the period (which in this case is 7). By omitting 23 ($= 3 \times 7 + 2$) members in the second method, that of the planetary hours, we are conducted therefore to the same result as by the first method of the decans, in which only two members were passed over.

I have already referred in the preceding note (⁵⁰⁵), to the remarkable resemblance between the fourth day of the week, dies Mercurii, the Indian Budha-vâra, and the old Saxon Wodânes-dag. (Jacob Grimm, *Deutsche Mythologie*, 1844, Bd. i. S. 114.) The identity asserted by Sir Wm. Jones between Buddha and Ódin, Woden, Wuotan or Wotan, so celebrated in northern heroic Sagas, and in the history of northern civilisation, may perhaps be rendered still more interesting by remembering the name of Wotan as that of a half-mythical, half-historical personage in the central parts of the New Continent, respecting whom I collected many notices in my work on the *Monuments and Myths of the Aborigines of America* (*Vues des Cordillères et Monumens des Peuples indigènes de l'Amérique*, T. i. p. 208 and 382—384; T. ii. p. 356). According to the traditions of the natives of Chiapa and Soconusco, this American Wotan was the grandson of the man who in the great inundation saved himself in a boat and renewed the race of mankind. He caused great buildings to be constructed, during the erection of which (as during that of the Mexican pyramid of Cholula), confusion of tongues, strife, and dispersion of tribes ensued. His name passed (like the name of Ódin in the Germanic North) into the Calendar-system of the natives of Chiapa. One of the five-day periods, four of which formed the month of the Chiapaneks, as well as of the Aztecs, was called after him. While, among the Aztecs, the names and the signs of the different days were taken from animals and plants, the natives of Chiapa (properly, Teochiapan) designated the days of the month by the names of twenty leaders, who, *coming from the North*, had conducted them thus far towards the South. The four most heroic of these leaders—Wotan or Wodan, Lambat, Been, and Chinar—gave their names to the opening days of the small periods, or weeks of five days,—a post which among the Aztecs was occupied by the symbols of the four elements. Wotan and the other leaders belonged incontestably to the race of the Toltecs, whose invasion took place in the seventh century. Ixtlilxochitl (his Christian name was Fernando de Alva),

the first historian of his nation (the Aztecs), says decidedly, in the manuscripts prepared by him so early as the beginning of the 16th century, that the province of Teochiapán, and the whole of Guatemala, from one coast to the other, was peopled by Toltecs; and even that at the commencement of the Spanish Conquest there still lived in the village of Teopixca a family who boasted of their descent from Wotan. The Bishop of Chiapa, Francisco Nuñez de la Vega, who was President of a Provincial-Concilium in Guatemala, collected many things respecting the legends of the American Wotan in his "Preambulo de las Constituciones diocesanas." Whether the tradition of the first Scandinavian Odin (Odinn, Othinus) or Wuotan, said to have come from the banks of the Don, has any historic foundation, is still very uncertain (Jacob Grimm, *Deutsche Mythologie*, Bd. i. S. 120—150). The identity of the American and Scandinavian Wotan, which does not indeed rest solely on the mere similarity of sound, still remains as doubtful as does the identity of Wuotan (Odinn) and Buddha, or that of the names of the Indian founder of the Buddhistic religion and the planet Budha.

The supposed existence of a Peruvian week of seven days, so often adduced as a Semitic similarity between the two continents in respect to the manner of dividing time, rests, as Pater Acosta, who visited Peru soon after the Spanish Conquest, had already shown (*Hist. natural y moral de las Indias*, 1591, lib. vi. cap. 3), on a mere error; and the Inca Garcilaso de la Vega himself corrected his earlier statement (*Parte i. lib. ii. cap. 35*), by saying distinctly, that in each of the months, which were reckoned by the Moon, there were three festival days, and that the people were to work eight days and rest the ninth day (*Parte i. lib. vi. cap. 23*). The so-called Peruvian weeks were therefore of nine days. (See my "Vues des Cordillères," T. i. p. 341—343.)

⁽⁵⁰⁷⁾ p. 301.—Böckh über Philolaos, S. 102 and 117.

⁽⁵⁰⁸⁾ p. 304.—We ought to distinguish, in the history of discoveries, between the epoch when a discovery was made, and that of its first publication. By not attending to this distinction, discordant and erroneous dates have been introduced into astronomical compendiums. Thus, for example, Huygens discovered the sixth satellite of Saturn, Titan, on the 25th of March, 1655, (*Hugenii Opera varia*, 1724, p. 523), and published the discovery for the first time on the 5th of March, 1656. (*Systema Saturnium*, 1659, p. 2.) Huygens, who had been uninterruptedly occupied with Saturn since the month of March 1655, enjoyed the full and undoubted view of the open ring on the 17th of December, 1657 (*Syst. Sat.* p. 21), but did not publish

his scientific explanation of all the phænomena until 1659. (Galileo had only thought that he saw on either side of the planet two detached, circular disks.)

(⁵⁰⁹) p. 305.—Kosmos, Bd. i. S. 95; Engl. ed. p. 82. Compare also Encke in Schumacher's Astr. Nachr. Bd. xxvi. 1848, No. 622, S. 347.

(⁵¹⁰) p. 315.—Böckh de Platonico syst. p. xxiv., and in his Philolaos, S. 100. The order of arrangement of the planets, which, as we have just seen (Note ⁵¹⁰), gave occasion to the planetary appellations of the days of the week, and which was that of Geminius, is distinctly called by Ptolemy (Almag. xi. cap. 1) the most ancient. He blames the motives which had led "more recent" writers to "place Venus and Mercury beyond the Sun."

(⁵¹¹) p. 315.—The Pythagoreans defended the belief in the reality of the production of musical sounds by the revolution of the spheres, by asserting that we hear only when there is alternation of sound and of silence. (Aristot. de Cælo, ii. 9, pag. 290, No. 24—30, Bekker.) The music of the spheres is also said to remain unheard by reason of a deafening effect. (Cicero de rep. vi. 18.) Aristotle himself terms the Pythagorean myth on this subject, pleasing and ingenious, *κομψῶς και περιττῶς*, but *untrue* (l. c. No. 12—15).

(⁵¹²) p. 315.—Böckh, in the Philolaos, S. 90.

(⁵¹³) p. 316.—Plato de republica, x. p. 617. He estimates the distances of the planets according to two entirely different progressions—one duplicate, the other triplicate—whence there arises the series 1, 2, 3, 4, 9, 8, 27. It is the same series which is found in the Timæus (p. 35, Steph.), in speculations relative to the arithmetical division of the soul of the Universe which the Demiurgus undertakes. Plato has considered the two geometrical progressions 1 . . 2 . . 4 . . 8 and 1 . . 3 . . 9 . . 27 conjointly, taking each successive number alternately from either series; whence, as above, 1 . . 2 . . 3 . . 4 . . 9. Compare Böckh in the "Studien von Daub und Creuzer," Bd. iii. S. 34—43; Martin, Études sur le Timée, T. i. p. 384, and T. ii. p. 64. Compare also Prevost "sur l'âme d'après Platon," in the Mém. de l'Acad. de Berlin pour 1802, p. 90 and 97; and the same writer in the Bibliothèque britannique, Sciences et Arts, T. xxxvii. 1808, p. 153.

(⁵¹⁴) p. 316.—See the ingenious treatise of Professor Ferdinand Piper, entitled "Von der Harmonie der Sphären," 1850, S. 12—18. The younger Ideler has treated in detail, and with much learned criticism, the subject of the supposed relation of the seven vowels of the ancient Egyptian language to the seven planets; and Gustav Seyffarth's ideas (refuted even by the researches of Zoega and Tölke) respecting supposed astrological vowel-filled hymns of the Egyptian priests, discussing them in connection with passages

of the Pseudo-Demetrius Phalereus (perhaps Demetrius of Alexandria), an epigram of Eusebius, and a gnostic manuscript at Leyden. See Hermapion, 1841, Pars i. p. 196—214, and compare with it Lobeck, *Aglaoph.* T. ii. p. 932.

(⁶¹⁵) p. 316.—On the gradual development of Kepler's musical ideas, see Apelt's Commentary on the *Harmonice Mundi*, in his work entitled *Johann Kepler's Weltansicht*, 1849, S. 76—116. (Compare also Delambre, *Hist. de l'Astr. mod.* T. i. p. 352—360.)

(⁶¹⁶) p. 316.—*Kosmos*, Bd. ii. S. 353; Engl. ed. p. 313.

(⁶¹⁷) p. 317.—Tycho Brahe had annihilated the crystal spheres to which the planets were supposed to be attached. Kepler praises this enterprise, but yet persists in representing the sphere of the fixed stars as a solid globular shell of two German miles in thickness, on which shine twelve stars of the first magnitude, all at an equal distance from the Earth, and having a particular relation to the angles of an icosædron. The fixed stars "*lumina sua ab intus emittunt*:" the planets were also supposed to be self-luminous until he "*learnt better from Galileo!*" Although, like several of the ancients, and like Giordano Bruno, he regarded all the fixed stars as suns similar to our own, yet he was less favourable than I have stated in an earlier volume (*Kosmos*, Bd. ii. S. 365; Engl. ed. p. 324) to the opinion "which he had pondered," that they are all surrounded by planets. Compare Apelt's work, quoted above, S. 21—24.

(⁶¹⁸) p. 317.—Delambre, in the *Hist. de l'Astr. mod.* T. i. p. 314, in his astronomically but not astrologically complete extracts from Kepler's *Sämmtlichen Werken*, p. 314—615, first called attention to the planet conjectured by Kepler to exist between Mercury and Venus. "*On n'a fait aucune attention à cette supposition de Kepler, quand on a formé des projets de découvrir la planète qui (selon une autre de ses prédictions) devait circuler entre Mars et Jupiter.*"

(⁶¹⁹) p. 317.—The remarkable passage respecting the filling up of a gap or hiatus between Mars and Jupiter, is found in Kepler's *Prodromus Dissertationum cosmographicarum, continens Mysterium cosmographicum de admirabili proportione orbium coelestium*, 1596, p. 7:—"Cum igitur hac non succederet, alia via, mirum quam audaci, tentavi aditum. Inter Jovem et Martem interposui novum planetam, itemque alium inter Venerem et Mercurium, quos duos forte ob exilitatem non videamus, iisque sua tempora periodica ascripsi. Sic enim existimabam me aliquam æqualitatem proportionum effecturum, quæ proportiones inter binos versus Solem ordine minuerentur, versus fixas augerentur: ut propior est Terra Veneri quantitate

orbis terrestris, quam Mars Terræ in quantitate orbis Martis. Verum hoc pacto neque unius planetæ interpositio sufficiebat ingenti hiatu. Jovem inter et Martem: manebat enim major Jovis ad illum novum proportio, quam est Saturni ad Jovem. Rursus alio modo exploravi.....” Kepler was twenty-five years old when he wrote this. We see how his mobile spirit set up hypotheses, and quickly abandoned and exchanged them for others. Through all such changes he preserved a hopeful confidence of discovering *numerical laws*, even where, amongst the most varied perturbations of attracting forces (perturbations of which our ignorance of the accompanying conditions forbids all attempt at calculating the combined action), the matter of which the planetary orbs were formed has been consolidated into bodies revolving in some instances singly in simple orbits, almost parallel to each other; in others in groups, and in wonderfully intersecting and intertwining orbits.

(⁶²⁰) p. 318.—Newtoni, *Opuscula mathematica, philosophica et philologica*, 1744, T. ii. Opusc. xviii. p. 246: “Chordam musice divisam potius adhibui, non tantum quod cum phænomenis (lucis) optime convenit, sed quod fortasse, aliquid circa colorum harmonias (quarum pictores non penitus ignari sunt), sonorum concordantiis fortasse analogas, involvat. Quemadmodum verisimilius videbitur animadvertenti affinitatem, quæ est inter extimam Purpuram (Violarum colorem) ac Rubedinem, colorum extremitates, qualis inter octavæ terminos (qui pro unisonis quodammodo haberi possunt) reperitur.....” Compare also Prevost, in the *Mém. de l’Acad. de Berlin pour 1802*, p. 77 and 93.

(⁶²¹) p. 318.—Seneca, *Nat. Quæst. vii. 13*: “Non has tantum stellas quinque discurrere, sed solas observatas esse: ceterum innumerabiles ferri per occultum.”

(⁶²²) p. 319.—As I could not feel satisfied with the explanations which Heyne had given (*De Arcadibus luna antiquioribus*, in *Opusc. acad. Vol. ii. p. 332*), of the origin of the widely prevalent astronomical myth of the Proselenes, I was much rejoiced at receiving a new and very happy solution of the problem from my ingenious philological friend, Professor Johannes Franz. This solution is not connected either with the construction of the calendar by the Arcadians, or with their worship of the Moon. I confine myself to an extract from an inedited and more comprehensive discussion. “In a work in which I have imposed on myself the obligation of frequently connecting our completer knowledge with the knowledge of the ancients, and even with

tradition, more or less prevalent opinions or beliefs, I think that the following explanation may not be unwelcome to a portion of my readers :—

“ We begin with some leading passages from the ancients, which treat of the Proselenes. Stephanus, of Byzantium (V. *Ἀρκάδες*) mentions the logograph Hippias, of Rhegium, a contemporary of Darius and Xerxes, as the first who called the Arcadians *προσελήνους*. The Scholiasts ad Apollon. Rhod. iv. 264, and ad Aristoph. Nub. 397, concur in saying, that the high antiquity of the Arcadians is most clearly shown by their being called *προσέληνοι*; and that they would seem to have been there before the Moon, as is also said by Endoxus and Theodorus; to which the latter adds that the Moon appeared a short time before the combat of Hercules. Aristotle, in speaking of the civil constitution of the Tegeates, says that the barbarians who previously inhabited Arcadia were driven out by the later Arcadians before the Moon appeared, and were called on that account *ροσέληνοι*. Others say that Endymion discovered the revolutions of the Moon, and that as he was an Arcadian, his countrymen were called after him *προσέληνοι*. Lucian speaks in terms of censure, saying (Astrolog. 26) that the Arcadians, from want of understanding, and from folly, asserted that they were a people more ancient than the Moon. In Schol. ad Æschyl. Prom. 436, it is remarked: *προσελούμενον* is *ύβρίζόμενον*, whence also the Arcadians are termed *προσέληνοι*, because they have too much pride. The passages in Ovid respecting the prelunar existence of the Arcadians are well known. Very recently the idea has been propounded that the ancients were themselves generally deceived by the form *προσεληνοι*; the word (properly, *προελληνοι*) signifying prehellenic, as Arcadia was a Pelasgic country.”

“ If, now, it can be proved,” continues Professor Franz, “ that another nation connects its descent with another heavenly body, we may be spared the trouble of having recourse to illusive etymologies; and the means of such proof do actually exist in the best form. The learned Rhetor Menander (about A.D. 270), says in his writing “*de encomiis*” (sect. ii. cap. 3, ed. Heeren) as follows :—A third topic of praise is afforded by time, as is the case with all that is most ancient; as when we say of a city or of a country, that it was built or was settled before this or that star or luminary,—or coeval with the stars,—or before or soon after the flood: as the Athenians assert that they were coeval with the Sun, the Arcadians that they were more ancient than the Moon, and the Delphians that they originated immediately after the flood: for these are eras or periods of commencement in time.

“ Thus Delphi, whose connection with Deucalion’s flood is also otherwise testified (Pausan. x. 6), is surpassed in antiquity by Arcadia, and Arcadia by Athens. Apollonius Rhodius, who imitates older examples, speaks quite in accordance herewith where he says (iv. 261) that Egypt was inhabited before all other countries : “ when as yet not all the luminaries of heaven had begun their course ; as yet the people of Danaus were not, neither Deucalion’s race ; only the Arcadians were in existence ; of whom it is said that they lived before the Moon, feeding on acorns from the oaks of the mountains.” So also Nonnus (xli.) says of the Syrian Beroe, that it was inhabited before the Sun.

Such a custom of taking supposed epochs in the construction of the Universe as chronological eras, belongs to a period in modes of contemplation, in which all imagery is, as yet, more vivid than at later epochs, and is nearly allied to genealogical local poetry. Thus it is even not improbable that the tale of the combat of the giants in Arcadia, sung by an Arcadian poet, and to which allusion is made in the words referred to above of the ancient Theodorus “ (whom some regard as a Samothracian, and whose work must have been a very comprehensive one), may have given occasion to the diffusion of the epithet *προσέληνοι* applied to the Arcadians.” Respecting the double name of “ Arkades Pelasgoi,” and the distinction drawn between a more ancient and more modern population of Arcadia, compare the excellent work called “ der Peloponessos,” by Ernst Curtius, 1851, S. 160 and 180. In the New Continent, also, as I have shown elsewhere (see my “ Kleine Schriften,” Bd. i. S. 115), the tribe of the Muyscas or Mozcas, on the high table-land of Bogota, boasted in its historical myths of a proselenic antiquity. They connected the origin of the Moon with the tradition of a great inundation, which a woman who accompanied the wonder-working personage Botschika, occasioned by her magic arts. Botschika drove away the woman (who was called Hnythaca or Schia). She left the earth and became the Moon, “ which till then had never given light to the Muyscas.” Botschika, taking pity upon mankind, opened with a strong hand the steep rocky wall near Canoas, where the Rio de Funcha now precipitates itself, in the celebrated waterfall of the Tequendama. The valley, which had previously been filled with water, was thus laid dry,—a geognostical romance which is often repeated, as, for example, in the closed Alpine Valley of Cashmeer, where the powerful remover of the waters is called Kasyapa.

(523) p. 320.—“ Karl Bonnet, Betrachtung über die Natur, ubersetzt von Titius,” 2d edition, 1772, S. 7, Note 2, (the first edition was in 1766). In the

original work of Bonnet there is not even an allusion to such a law of distances. (Compare also Bode, *Anleit. zur Kenntniss des gestirnten Himmels*, 2te Aufl. 1772, S. 462.)

(⁵²⁴) p. 321.—As Titius made the distance from the Sun to Saturn, then regarded as the outermost planet, = 100, the several distances according to the so-called progression,

4, 4 + 3, 4 + 6, 4 + 12, 4 + 24, 4 + 48, ought to be,—

| | | | | | |
|-----------------|-----------------|------------------|------------------|------------------|------------------|
| Mercury. | Venus. | Earth. | Mars. | Small Planets. | Jupiter. |
| $\frac{4}{100}$ | $\frac{7}{100}$ | $\frac{10}{100}$ | $\frac{16}{100}$ | $\frac{28}{100}$ | $\frac{52}{100}$ |

whence, taking the distance of Saturn from the Sun at 197·3 millions of German geographical miles (789·2 Engl.), we have the following distances of the planets from the Sun, estimated according to the same scale :—

| Distances according to Titius in Geographical German Miles, 15 to a Degree. | Actual Distances in Miles, 15 to a Degree. |
|---|--|
| Mercury..... 7·9 millions. | 8·0 millions. |
| Venus..... 13·8 „ | 15·0 „ |
| Earth..... 19·7 „ | 20·7 „ |
| Mars 31·5 „ | 31·5 „ |
| Small planets..... 55·2 „ | 55·2 „ |
| Jupiter 102·6 „ | 107·5 „ |
| Saturn 197·3 „ | 197·3 „ |
| Uranus 386·7 „ | 396·7 „ |
| Neptune..... 765·5 „ | 621·2 „ |

(⁵²⁵) p. 321.—Wurm, in Bode's *Astron. Jahrbuch für das J. 1790*, S. 168 ; and Bode, *Von dem neuen zwischen Mars und Jupiter entdeckten achten Hauptplaneten des Sonnensystems*, 1802, S. 45. With Wurm's numerical correction, the series of distances from the Sun is :—

| | Parts. | | | | |
|--------------------|--------|---|-----|-------|---------|
| Mercury | 387 | | | | |
| Venus | 387 | + | | 293 | = 680 |
| Earth | 387 | + | 2 | × 293 | = 973 |
| Mars | 387 | + | 4 | × 293 | = 1559 |
| Small planets..... | 387 | + | 8 | × 293 | = 2731 |
| Jupiter | 387 | + | 16 | × 293 | = 5075 |
| Saturn | 387 | + | 32 | × 293 | = 9763 |
| Uranus | 387 | + | 64 | × 293 | = 19139 |
| Neptune..... | 387 | + | 128 | × 293 | = 37891 |

In order to supply the means of examining the accuracy of these results, I sub-join once more the actual mean distances of the planets as at present recognised, and in the same table the numbers which, two centuries and a half ago, Kepler regarded as the true values according to Tycho Brahe's observations. I take the latter from Newton's paper, entitled *De Mundi Systemate* (*Opuscula math., philos. et philol.* 1744, T. ii. p. 11).

| Planets. | True Distances. | Results of Kepler. |
|---------------|-----------------|--------------------|
| Mercury | 0·38709 | 0·38806 |
| Venus | 0·72333 | 0·72400 |
| Earth | 1·00000 | 1·00000 |
| Mars | 1·52369 | 1·52350 |
| Juno | 2·66870 | — |
| Jupiter | 5·20277 | 5·19650 |
| Saturn | 9·53885 | 9·51000 |
| Uranus | 19·18239 | — |
| Neptune | 30·03628 | — |

(⁵²⁶) p. 324.—The Sun, which Kepler, probably from enthusiasm for the “*divina inventa*” of his justly celebrated contemporary William Gilbert, regarded as magnetic, and whose rotation in the same direction as the planets he maintained before the solar spots had been discovered, is declared by Kepler to be “the densest of all celestial bodies, because he moves all the rest which belong to his system.” (*Comment. de motibus Stellæ Martis*, cap. 23; and in *Astronomiæ pars optica*, cap. 6.)

(⁵²⁷) p. 324.—Newton *de Mundi Systemate*, in *Opusculis*, T. ii. p. 17: “*Corpora Veneris et Mercurii majore Solis calore magis concocta et coagulata sunt. Planetæ posteriores, defectu caloris, carent substantiis illis metallicis et mineris ponderosis quibus Terra referta est. Densiora corpora quæ Soli propiora: ea ratione constabit optime pondera Planetarum omnium esse inter se ut vires.*”

(⁵²⁸) p. 328.—Mädler, *Astronomie*, § 193.

(⁵²⁹) p. 329.—Humboldt *de Distributione geographica Plantarum*, p. 104 (*Ansichten der Natur*, Bd. i. S. 131 bis 133).

(⁵³⁰) p. 330.—L'étendue entière de cette variation serait d'environ 12 degrés, mais l'action du Soleil et de la Lune l'a réduit à peu près à trois degrés (centésimaux). Laplace, *Expos. du Syst. du Monde*, p. 303.

(⁵³¹) p. 330.—I have shewn elsewhere by the comparison of numerous mean annual temperatures, that in Europe, from the North Cape to Palermo. a dif-

ference of one degree of geographical latitude corresponds very nearly to $0^{\circ}.5$ of the Centigrade thermometer ($0^{\circ}.9$ Fahr.), but that in the system of temperatures on the American coast from Boston to Charlestown, the same difference of latitude corresponds to $0^{\circ}.9$ Centigrade ($1^{\circ}.62$ Fahr.); *Asie Centrale*, T. iii. p. 229.

(⁵³²) p. 332.—*Kosmos*, Bd. ii. S. 402, Anm. 6 (Eng. ed. p. xxvii. Note 146).

(⁵³³) p. 332.—Laplace, *Expos. du Système du Monde* (5ème éd.) p. 303, 345, 403, 406, and 408; the same in the *Connaissance des tems pour 1811*, p. 386; Biot, *Traité élém. d'Astr. physique*, T. i. p. 61, T. iv. p. 90—99, and 614—623.

(⁵³⁴) p. 333.—Garcilaso, *Comment. Reales*, Parte i. lib. ii. cap. 22—26; Prescott, *Hist. of the Conquest of Peru*, Vol. i. p. 126. The Mexicans had among their twenty hieroglyphic signs of days, one which they held in particular honour, called *Ollin-tonatiuh*, or “that of the four motions of the Sun,” and which was prefixed to the great cycle renewed every $52 = 4 \times 13$ years, and had reference to the Sun’s path (expressed hieroglyphically by foot-steps), intersecting the solstices and equinoxes. In the finely painted Aztec manuscript, formerly preserved in the Villa of Cardinal Borgia at Veletri, and from which I have borrowed much important information, there is the remarkable astrological sign of a Cross, having written near it signs of days which would designate truly the passages of the Sun through the Zenith of the city of Mexico (*Tenochtitlan*), the Equator, and the Solstices, if the points (round disks), appended to the signs of days on account of the periodical series were equally complete in all the three passages spoken of. (Humboldt, *Vues des Cordillères*, Pl. xxxvii. No. 8, p. 164, 189, and 237). *Nezahualpilli*, King of Tezcuco, who was passionately devoted to the observation of the stars, had erected a building which Torquemada somewhat boldly terms an Astronomical Observatory, and of which the ruins were still seen by him. (*Monarquía Indiana*, lib. ii. cap. 64.) In the *Raccolta di Mendoza*, we see the representation of a priest observing the stars; as is expressed by a dotted line going from his eye to the observed star (*Vues des Cordillères*, Pl. lviii. No. 8, p. 289.)

(⁵³⁵) p. 335.—John Herschel, on the astronomical causes which may influence geological phenomena, in the *Transact. of the Geological Society of London*, 2d Ser. Vol. iii. P. i. p. 298: the same, in his *Treatise of Astronomy*, 1833 (*Cab. Cyclop.* Vol. xliii.) § 315.

(⁵³⁶) p. 336.—Arago, in the *Annuaire pour 1834*, p. 199.

(⁵³⁷) p. 336.—“Il s’ensuit (du théorème dû à Lambert) que la quantité de

chaleur envoyée par le Soleil à la Terre est la même en allant de l'équinoxe du printemps à l'équinoxe d'automne qu'en revenant de celui-ci au premier. Le tems plus long que le Soleil emploie dans le premier trajet, est exactement compensé par son éloignement aussi plus grand; et les quantités de chaleur qu'il envoie à la Terre sont les mêmes pendant qu'il se trouve dans l'un ou l'autre hémisphère, boréal ou austral."—Poisson, sur la Stabilité du système planétaire, in the *Connaiss. des tems pour 1836*, p. 54.

(⁵³⁸) p. 337.—Arago, in the *Annuaire* above cited, p. 200—204. L'excentricité," says Poisson, in the *Connaissance des Tems*, above cited, pp. 38 and 52, "ayant toujours été et devant toujours demeurer très petite, l'influence des variations séculaires de la quantité de chaleur solaire reçue par la Terre sur la température moyenne paraît aussi devoir être très limitée.—On ne saurait admettre que l'excentricité de la Terre, qui est actuellement environ un soixantième, ait jamais été ou devienne jamais un quart, comme celle de Junon ou de Pallas."

(⁵³⁹) p. 338.—*Outlines*, § 432.

(⁵⁴⁰) p. 340.—The same, § 548.

(⁵⁴¹) p. 341.—See in Mädler's *Astronomie*, S. 218, his attempt to determine the diameter of Vesta (66 ? German or 264 ? English geographical miles) with a magnifying power of 1000.

(⁵⁴²) p. 342.—In the statement formerly made, in the first volume of this work (p. 88—89), the equatorial semi-diameter of Saturn was taken as the basis.

(⁵⁴³) p. 342.—Compare *Kosmos*, Bd. iii. S. 281, Engl. ed. p. 195.

(⁵⁴⁴) p. 342.—In the *Picture of Nature*, in the first volume of *Cosmos*, I have treated in some detail of the Sun's movement of translation, S. 149—151; Engl. ed. p. 134—135. (Compare also Vol. iii. S. 266, Engl. ed. p. 181.)

(⁵⁴⁵) p. 345.—*Kosmos*, Bd. iii. S. 389 and 411, Anm. 19 and 20; Engl. edit. p. 378 and 379, Notes 478 and 479.

(⁵⁴⁶) p. 345.—Compare the Observations of the Swedish mathematician, Bigerus Vassenius, at Gothenburg, during the total solar eclipse of the 2d of May, 1733, and Arago's comments on them in the *Annuaire du Bureau des Longitudes pour 1846*, p. 441 and 462. Dr. Galle, who observed on the 28th of July, 1851, at Frauenburg, saw the "freely suspended small cloud connected by three or even more threads with the hooked or curved gibbosity."

(⁵⁴⁷) p. 345.—Compare what was observed on the 8th of July, 1842, by a very practised observer, Captain Bérard, of the French navy, at Toulon.

“ Il vit une bande rouge très mince, dentelée irrégulièrement.” (Work above cited, p. 416.)

(⁵⁴⁸) p. 346.—During the total solar eclipse of the 8th of July, 1842, this outline of the Moon had been distinctly perceived by four observers: such a circumstance had never been described as having taken place on previous similar occasions. The possibility of seeing the outer contour of the Moon appears to depend on the light given by the third outermost solar envelope and the corona. “ La Lune se projette *en partie* sur l’atmosphère du Soleil. Dans la portion de la lunette où l’image de la Lune se forme, il n’y a que la lumière provenant de l’atmosphère terrestre. La Lune ne fournit rien de sensible et, semblable à un écran, elle arrête tout ce qui provient de plus loin et lui correspond. En dehors de cette image, et précisément à partir de son bord, le champ est éclairé *à la fois* par la lumière de l’atmosphère terrestre et par la *lumière de l’atmosphère solaire*. Supposons que ces deux lumières réunies forment un total plus fort de $\frac{1}{60}$ que la lumière atmosphérique terrestre, et, dès ce moment, le bord de la lune sera visible. Ce genre de vision peut prendre le nom de *vision négative*; c’est en effet par une *moindre intensité* de la portion du champ de la lunette où existe l’image de la Lune, que le *contour* de cette image est aperçu. Si l’image était *plus intense* que le reste du champ, la vision serait positive.” Arago, in the work above cited, p. 384. (Compare also on this subject, Kosmos, Bd. iii. S. 70 and 114, Anm. 19; Engl. ed. p. 53, and Note 108.)

(⁵⁴⁹) p. 346.—Kosmos, Bd. iii. S. 383—386, Eng. ed. p. 272—275.

(⁵⁵⁰) p. 346.—Lepsius, Chronologie der Aegypter, Th. i. S. 92—96.

(⁵⁵¹) p. 346.—Kosmos, Bd. iii. S. 469, Anm. 13; Eng. ed. Note 505.

(⁵⁵²) p. 346.—Kosmos, Bd. ii. S. 258, Engl. ed. p. 222.

(⁵⁵³) p. 347.—Lalande, in the Mém. de l’Acad. des Sciences pour 1766, p. 498; Delambre, Hist. de l’Astr. ancienne, T. ii. p. 320.

(⁵⁵⁴) p. 347.—Kosmos, Bd. iii. S. 468; Engl. ed. p. cvii.

(⁵⁵⁵) p. 347.—On the occasion of the transit of Mercury of the 4th of May, 1832, Mädler and Wilhelm Beer (Beiträge zur phys. Kenntniss der himmlischen Körper, 1841, S. 145), found the diameter of the planet 583 German, or 2332 English geographical miles; but in the edition of his Astronomie, published in 1849, Mädler preferred Bessel’s result.

(⁵⁵⁶) 348.—Laplace, Exposition du Syst. du Monde, 1824, p. 209. The celebrated author himself confessed, however, that he had based his determination of the mass of Mercury on the “hypothèse très précaire qui suppose les densités de Mercure et de la Terre réciproques à leur moyenne distance du

Soleil." I have not thought it necessary to notice either the supposed mountain ranges of 58,900 feet high which Schröter imagined himself to have measured on Mercury's disk, the existence of which was already doubted by Kaiser (*Sternenhimmell*, 1850, § 57); or Lemonnier's and Messier's statement (*Delambre, Hist. de l'Astronomie au 18ème siècle*, p. 222), of the visibility of an atmosphere of Mercury during the planet's transit across the Sun's disk; or the suppositions of trains of clouds passing over the planet, and transitory obscurations of its surface. During the transit of Mercury which I observed in Peru on the 8th of November, 1802, I paid great attention to the sharpness of the outline of the planet during the emersion, but I did not remark anything resembling an envelope.

(⁵⁵⁷) p. 348.—“The part of the orbit of Venus in which the planet may appear to us the brightest, so that it can be seen with the naked eye at noon, is situated intermediately between the inferior conjunction and the greatest digression, near to the latter, and nearly 40 degrees from the Sun, or from the place of the inferior conjunction. On a mean or average, Venus appears to us most bright and beautiful when distant 40° east or west of the Sun, when her apparent diameter, which at the inferior conjunction may increase to 66", is only about 40", and when the greatest breadth of the illuminated portion scarcely measures 10". The nearness of the Earth then gives to the narrow bow a light so intense, that, in the absence of the Sun, it even casts shadows.” (*Littrow, Theorische Astronomie*, 1834, Th. ii. S. 68.) Whether Copernicus predicted the necessity of a future discovery of the phases of Venus (as has been repeatedly stated, in *Smith's Optics*, Sect. 1050, and in several other books), has recently been shewn by Professor De Morgan's more exact examination of the work *De Revolutionibus*, as it has come down to us, to be extremely doubtful. (See the letter of Adams to the Rev. R. Main, dated 7th Sept. 1846, in *Rep. of the Royal Astron. Soc.* Vol. vii. No. 9, p. 142. Compare also *Kosmos*, Bd. ii. S. 362; Eng. ed. p. 321.)

(⁵⁵⁸) p. 350.—*Delambre, Hist. de l'Astr. au 18ème siècle*, p. 256—258. Bianchini's result has been defended by Hussey and Flaugergues: Hansen, whose authority stands justly so high, up to 1836 also regarded it as the more probable.

(⁵⁵⁹) p. 350.—Arago, on the remarkable Lilienthal observation of the 12th of August, 1790, in the *Annuaire* for 1842, p. 539. “Ce qui favorise aussi la probabilité de l'existence d'une atmosphère qui enveloppe Vénus, c'est le résultat optique obtenu par l'emploi d'une lunette prismatique. L'intensité de la lumière de l'intérieur du croissant est sensiblement plus faible que celle

des points situés dans la partie circulaire du disque de la planète." (Arago, Manuscripts of 1847).

(⁵⁶⁰) p. 350.—Wilhelm Beer und Mädler, Beiträge zur physischen Kenntniss der himmlischen Körper, S. 148. The so-called satellite, or moon of Venus, which Fontana, Dominique Cassini, and Short, thought they had recognised, for which Lambert computed tables, and which was said to have been seen at Crefeld (Berliner Jahrbuch, 1778, S. 186), fully three hours after the emersion of Venus, in the middle of the Sun's disk, belongs to the astronomical myths of an uncritical period.

(⁵⁶¹) p. 350.—Philos. Transact. 1795, Vol. lxxvi. p. 214.

(⁵⁶²) p. 352.—Kosmos, Bd. iii. S. 103 and 133, Anm. 73; Engl. ed. p. 84, and Note 162.

(⁵⁶³) p. 352.—"La lumière de la Lune est jaune, tandis que celle de Vénus est blanche. Pendant le jour la Lune paraît blanche parcequ'à la lumière du disque lunaire se mêle la lumière bleue de cette partie de l'atmosphère que la lumière jaune de la Lune traverse." (Arago, in MSS. of 1847.) The most refrangible colours in the spectrum, those from blue to violet, unite in order to form white with their complementary colours, the less refrangible ones, from red to green. (Kosmos, Bd. iii. S. 309, Anm. 19; Engl. ed. p. lxxvii. Note 347.)

(⁵⁶⁴) p. 353.—Forbes on the Refraction and Polarisation of Heat, in the Transactions of the Royal Soc. of Edinburgh, Vol. xiii. 1836, p. 131.

(⁵⁶⁵) p. 354.—Lettre de Mr. Melloni à Mr. Arago sur la Puissance calorifique de la Lumière de la Lune, in the Comptes rendus, T. xxii. 1846, p. 541—544. Compare also, for the historical statements, the "Jahresbericht der physikalischen Gesellschaft zu Berlin," Bd. ii. S. 272. It has always appeared to me rather remarkable that, from the earliest times, when warmth was only determined by the feelings, the Moon first gave rise to the idea that light and warmth might be found separated. Among the Indians, the Moon, regarded as the King of the Stars, is surnamed in Sanscrit the "cold" ('sitala, hima) and also the cold-darting or cold-radiating (himân'su); while the Sun, with its many rays depicted as hands, is termed the "Creator of Heat" (nidâghakara). The spots on the Moon, in which western nations thought they could make out a face, represent, in the view of the Indians, a roebuck or a hare: hence the Sanscrit names of the Moon "Roe-bearer" (mrigadhara) or "Hare-bearer" (sa'sabhrî). (Schutz, "Five Cantos of the Bhatti-Kâvya," 1837, S. 19—23.) The Greeks complained "that the light of the Sun, reflected by the Moon, loses all heat, so that only feeble remains thereof come

to us." (Plutarch, in the Conversation "de facie quæ in orbe Lunæ apparet," *Moralia* ed. Wyttenbach, T. iv. Oxon. 1797, p. 793.) In Macrobius (Comm. in *Somnium Scip.* i. 19, ed Lud. Janus, 1848, p. 105) it is said: "Luna speculi instar lumen quo illustratur.....rursus emittit nullum tamen ad nos perferentem sensum caloris: quia lucis radius, cum ad nos de origine sua, id est de Sole, pervenit, naturam secum ignis de quo nascitur devehit; cum vero in lunæ corpus infunditur et inde resplendet, solam refundit claritatem, non calorem." (So also Macrobius, *Saturnal.* lib. vii. cap. 16, ed. Bip. T. ii. p. 277.)

(⁵⁶⁶) p. 354.—Mädler, *Astr.* § 112.

(⁵⁶⁷) p. 355.—See Lambert, "sur la Lumière cendrée de la Lune," in the *Mém. de l'Acad. de Berlin*, Année 1773, p. 46: "la Terre, vue des planètes, pourra paroître d'une lumière verdâtre, à peu près comme Mars nous paroît d'une couleur rougeâtre." We do not mean by this to agree so far with that ingenious writer as to surmise that the planet Mars is covered with a red vegetation like the rose-coloured bushes of the Bougainvillæa. (Humboldt *Ansichten der Natur*, Bd. ii. S. 334; Engl. ed. "Aspects of Nature in Different Lands and Different Climates," Vol. ii. p. 279.) "In middle Europe, when the Moon, a short time *before* new moon, stands in the morning hours in the eastern sky, it receives the Earth-light principally from the great plateaus and plains of Asia and Africa: but when, *after* the time of new moon, it stands in the evening in the western sky, it can only receive the fainter reflection coming from the narrower American continent, and principally from the wide expanse of ocean." (Wilhelm Beer und Mädler, *der Mond nach seinen kosmischen Verhältnissen*, § 106, S. 152.)

(⁵⁶⁸) p. 355.—Séance de l'Académie des Sciences le 5 août 1833: "Mr. Arago signale la comparaison de l'intensité lumineuse de la portion de la Lune que les rayons solaires éclairent directement, avec celle de la partie du même astre qui reçoit seulement les rayons réfléchis par la Terre. Il croit d'après les expériences qu'il a déjà tentées à cet égard, qu'on pourra, avec des instrumens perfectionnés, saisir dans la *lumière cendrée* les différences de l'éclat plus ou moins nuageux de l'atmosphère de notre globe. Il n'est donc pas impossible, malgré tout ce qu'un pareil résultat exciterait de surprise au premier coup d'œil, qu'un jour les météorologistes aillent puiser dans l'aspect de la Lune des notions précieuses sur *l'état moyen* de diaphanéité de l'atmosphère terrestre, dans les hémisphères qui successivement concourent à la production de la lumière cendrée."

(⁵⁶⁹) p. 355.—Venturi, *Essai sur les Ouvrages de Léonard de Vinci*, 1797 p. 11.

(⁵⁷⁰) p. 355.—Kepler, *Paralip. vel Astronomiæ pars Optica*, 1604, p. 297.

(⁵⁷¹) p. 356.—“On conçoit que la vivacité de la lumière rouge ne dépend pas uniquement de l'état de l'atmosphère, qui refracte, plus ou moins affaiblis, les rayons solaires, en les infléchissant dans le cône d'ombre, mais qu'elle est modifiée surtout par la transparence variable de la partie de l'atmosphère à travers laquelle nous apercevons la Lune éclipcée. Sous les tropiques une grande sérénité du ciel, une dissémination uniforme des vapeurs, diminuent l'extinction de la lumière que le disque lunaire nous renvoie.” (Humboldt, *Voyage aux Régions équinoxiales*, T. iii. p. 544; and *Recueil d'Observ. astronomiques*, Vol. ii. p. 145.) Arago remarks: “Les rayons solaires arrivent à notre satellite par l'effet d'une réfraction et à la suite d'une absorption dans les couches les plus basses de l'atmosphère terrestre; pourroient-ils avoir une autre teinte que le rouge?” (*Annuaire pour 1842*, p. 528.)

(⁵⁷²) p. 356.—Babinet explains the redness as a consequence of diffraction, in a notice on the different portions of white, blue, and red light, produced when there is inflexion. See Babinet's considerations on the total eclipse of the Moon on the 19th of March, 1848, in Moigno's *Répertoire d'Optique moderne*, 1850, T. iv. p. 1656. “La lumière diffractée qui pénètre dans l'ombre de la terre, prédomine toujours et même a été seule sensible. Elle est d'autant plus rouge ou orangée qu'elle se trouve plus près du centre de l'ombre géométrique; car ce sont les rayons les moins réfrangibles qui se propagent le plus abondamment par diffraction, à mesure qu'on s'éloigne de la propagation en ligne droite.” The phænomena of diffraction take place in vacuo also, according to the ingenious investigations of Magnus, on the occasion of a discussion between Airy and Faraday. On explanations by diffraction, see, generally, Arago in the *Annuaire pour 1846*, p. 452—455.

(⁵⁷³) p. 357.—Plutarch (*de facie in orbe Lunæ*), *Moral. ed Wytttenb.* T. iv. p. 780—783: “The fiery coal-glowing (*ἀνθρακωειδής*) colour of the darkened Moon (about the hour of midnight) is, as mathematicians maintain, by no means to be regarded, seeing that the change is from black to red and blueish, as belonging to the earthy surface of that body.” Dion Cassius, also (lx. 26; ed Sturz, T. iii. p. 779),—who had besides occupied himself in much detail with the subject of lunar eclipses, and with the remarkable edicts of the Emperor Claudius, in which the dimensions of the darkened portion were announced beforehand,—calls attention to the great alterations in the colour of the Moon during the conjunction. He says (lxv. 11; T. iv. p. 185, Sturz): “Great was the confusion created in the camp of Vitellius by the eclipse which took place that night; yet it was not so much the eclipse itself—although to

minds already disturbed this might appear ominous of misfortune—as it was the circumstance of the Moon's varying colours—blood-red, black, and other mournful hues—which filled their souls with uneasy apprehensions.”

(⁵⁷⁴) p. 357.—Schröter, *Selenotopographische Fragmente*, Th. i. 1791, S. 668; Th. ii. 1802, S. 52.

(⁵⁷⁵) p. 357.—Bessel, “über eine angenommene Atmosphäre des Mondes,” in Schumacher's *Astron. Nachr.* No. 263, S. 416—420. Compare also Beer und Mädler, “*der Mond*,” § 83 and 107, S. 133 and 153; as well as Arago, in the *Annuaire* for 1846, p. 346—353. The argument taken from the greater or less distinctness with which the smaller features of the Moon's surface can be recognised, so often adduced in proof of the reality of a lunar atmosphere, and of “passing lunar mists in the valleys of the Moon,” is the most untenable of all, seeing the changes continually taking place in the upper strata of our own atmosphere. Considerations respecting the shape of one of the Moon's horns in the solar eclipse of the 5th of September, 1793, led William Herschel to form even at that time a decided opinion *against* the hypothesis of a lunar atmosphere. (*Phil. Trans.* Vol. lxxxiv. p. 167.)

(⁵⁷⁶) p. 358.—Mädler, in Schumacher's *Jahrbuch für 1840*, S. 188.

(⁵⁷⁷) p. 358.—Sir John Herschel (*Outlines*, p. 247) calls attention to the immersion of double stars, which, from the great proximity of the individuals of which they consist, cannot be separated by the telescope.

(⁵⁷⁸) p. 358.—Plateau, “sur l'Irradiation,” in the *Mém. de l'Acad. royale des Sciences et Belles-Lettres de Bruxelles*, T. xi. p. 142; and “Ergänzungsband (supplementary volume) zu Poggendorff's *Annalen*, 1842, S. 79—128, 193—232, and 405—443. “The phænomenon of irradiation is probably caused by the stimulus produced by light extending itself on the retina a little beyond the outline of the image.”

(⁵⁷⁹) p. 358.—Arago, in the *Comptes rendus*, T. viii. 1839, p. 713 and 883. “Les phénomènes d'irradiation signalés par Mr. Plateau sont regardés par Mr. Arago comme les effets des aberrations de réfrangibilité et de sphéricité de l'œil, combinés avec l'indistinction de la vision, conséquence des circonstances dans lesquelles les observateurs se sont placés. Des mesures exactes prises sur des disques noirs à fond blanc et des disques blancs à fond noir, qui étaient placés au Palais du Luxembourg, visibles à l'Observatoire, n'ont pas indiqué les effets de l'irradiation.”

(⁵⁸⁰) p. 359.—*Plut. Moral.* ed. W. Steub. T. iv. p. 786—789. The shadow of Mount Athos, as has also been remarked by the traveller, Pierre Belon (*Observations de Singularités trouvées en Grèce, Asie etc.* 1554, livre i.

chap. 25) reached to the broken figure of a cow on the market-place of the town of Myrine in the island of Lemnos.

(⁵⁸¹) p. 359.—For evidence of the visibility of these four objects, see S. 241, 338, 191, and 290, in Beer and Mädler's "der Mond." It is scarcely necessary to tell my readers that all that relates to the topography of the Moon's surface is taken from the excellent work of these my two friends, of one of whom, Wilhelm Beer, we have to lament the too early loss. The study of lunar topography will be facilitated by the use of the fine map in a single sheet ("Uebersichtsblatt"), published by Mädler in 1837, three years after the publication of the larger map of the Moon consisting of four sheets.

(⁵⁸²) p. 359.—Plut. de facie in orbe Lunæ, p. 726—729, Wytttenb. The passage is at the same time not without interest for ancient geography: see Humboldt, Examen critique de l'Hist. de la Géogr. T. i. p. 145. Respecting other opinions of the ancients, see Anaxagoras and Democritus, in Plut. de plac. Philos. ii. 25; Parmenides, in Stob. p. 419, 453, 516 and 563, ed. Heeren; Schneider, Eclogæ physicæ, Vol. i. 433—443. (According to a very remarkable passage of Plutarch, in the Life of Nicias, cap. 42, Anaxagoras himself, who termed "the mountainous Moon another Earth," made a drawing of the Moon's disk: compare also Origenes, Philosophumena, cap. 8, ed. Mülleri, 1851, p. 14.) I was once very much astonished to hear a very accomplished Persian, of Ispahan, who had certainly never read a Greek book, to whom I was shewing in Paris the spots on the Moon's face through a large telescope, propound the same hypothesis of reflection as that of Agesianax, referred to in the text, as prevalent in his own country. "It is ourselves that we see in the Moon," said the Persian, "that is the map of our Earth." One of the interlocutors in Plutarch's Conversation on the Moon would not have expressed himself otherwise. Human beings in the Moon, if we could imagine such to exist in the absence of air and water, would see the rotating Earth with her spots suspended like one of our "Mappe-mondes," or "Maps of the World," against a sky almost black in the day-time, occupying a space fourteen times larger than that which the full moon covers to our eyes, and always in the same place. The study of geography would, however, be somewhat impeded by our atmosphere with its continued variations dimming and confusing the outlines of the continents. Compare Mädler's Astr. S. 169; and Sir John Herschel's Outlines, § 436.

(⁵⁸³) p. 361.—Beer und Mädler, S. 273.

(⁵⁸⁴) p. 362.—Schumacher's Jahrb. für 1841, S. 270.

(⁵⁸⁵) p. 363.—Mädler, Astr. S. 166.

(⁵⁸⁶) p. 363.—The highest summit of the Himalayas,—and, according to our present knowledge, the highest on the surface of the earth,—Kinchin-junga, is, according to Waugh's recent measurement, 4406 toises, or 28178 English feet high (1.16 German geographical mile; 4.64 English geogr. miles); while the highest summit among the lunar mountains is, according to Mädler, 3800 toises, or exactly one German geographical mile. The diameter of the Moon is 454, and that of the Earth 1718 German geographical miles, whence the ratios of the highest summits to the diameters are in the case of the Moon $\frac{1}{454}$, and in that of the Earth $\frac{1}{1718}$.

(⁵⁸⁷) p. 364.—See for the six elevations which exceed 3000 toises, Beer und Mädler, S. 99, 125, 234, 242, 330, and 331.

(⁵⁸⁸) p. 366.—Robert Hooke, *Micrographia*, 1667, Obs. lx. p. 242—246. “These seem to me to have been the effects of some motions within the body of the Moon, analogous to our earthquakes, by the eruption of which, as it has thrown up a brim or ridge round about, higher than the ambient surface of the Moon, so has it left a hole or depression in the middle, proportionably lower.” Hooke says of his experiments with “boyling alabaster,” that, “presently ceasing to boyl, the whole surface will appear all over covered with small pits, exactly shaped like these of the Moon.—The earthy part of the Moon has been undermined or heaved up by eruptions of vapours, and thrown into the same kind of figured holes as the powder of alabaster. It is not improbable, also, that there may be generated, within the body of the Moon, divers such kind of internal fires and heats as may produce exhalations.”

(⁵⁸⁹) p. 366.—*Kosmos*, Bd. ii. S. 508, Anm. 43; Eng. ed. p. civ. Note 483.

(⁵⁹⁰) p. 366.—Beer und Mädler, S. 126. Ptolemy has a diameter of 96 English geographical miles, and Alphonso and Hipparchus 76 such miles.

(⁵⁹¹) p. 367.—Arzachel and Hercules form exceptions: the first has a crater at the summit, and the second a lateral crater. These geologically important points deserve fresh examination with more perfect instruments. (Schröter, *Selenotopographische Fragmente*, Th. ii. tab. 44 and 68, fig. 23.) Of lava-streams forming accumulations in low depressions, nothing has yet been observed. The rays which proceed in three directions from Aristotle are chains of hills. (Beer und Mädler, S. 236.)

(⁵⁹²) p. 367.—Beer und Mädler, S. 151; Arago, in the *Annuaire* for 1842, p. 526. (Compare also Immanuel Kant, *Schriften der physischen Geographie*, 1839, S. 393—402). Recent more careful and full examination has given reason to believe that the observed temporary alterations on the Moon's surface (the appearance of new central mountains and craters in the *Mare Crisium*,

and in Hevelius and Cleomedes), are to be attributed to an illusion similar to that which occasioned the belief in volcanic eruptions visible to us in the Moon. See Schröter, *Seleuotopogr. Fragm. Th. i. S. 412—523*; *Th. ii. S. 268—272*. The question, what are the smallest objects whose height and other dimensions can be measured in the present state of our instrumental means, is one to which it is difficult to give a general answer. We find in Dr. Robinson's account of *Jard Rosse's* magnificent reflector, that in it an extent of 80 to 90 yards can be recognised with great clearness. Mädler reckons that, in his observations, shadows of 3 seconds were still measurable, which, under certain suppositions respecting the situation of the mountain and the height of the Sun, would correspond to an elevation of 120 French (128 English) feet; but he notices at the same time that the shadow must have a convenient breadth in order to be appreciable, or even visible. The shadow of the Great Pyramid of Cheops would, according to the known dimensions of that monument, be scarcely one-ninth of a second in breadth, even at its widest part, and would therefore remain invisible (Mädler, in *Schumacher's Jahrbuch* for 1841, S. 264). Arago reminds his readers, that, with a magnifying power of 6000 (which, besides, could not be applied to the Moon with a proportionally successful result), the mountains of the Moon would appear of the size of Mont Blanc seen with the naked eye from the Lake of Geneva.

(⁵⁹³) p. 367.—The "rills" are not numerous; they are at most 100 or 120 miles long; sometimes forked (Gassendi), rarely resembling veins (Triesnecker), always shining; do not run across the mountains; are peculiar to the flatter districts; do not become either broader or narrower, and have nothing marked about their extremities. Beer und Mädler, S. 131, 225, and 249.

(⁵⁹⁴) p. 368.—See my description of the "Nocturnal Life of Animals in the Primeval Forests," in the *Ansichten der Natur* (3te Ausg.), Bd. i. S. 334; *Aspects of Nature in Different Lands and Different Climates*, Vol. i. p. 270. Laplace's speculations (I am unwilling to apply to them a different term) on the manner in which he supposes perpetual moonlight might have been ensured (*Exposition du Système du Monde*, 1824, p. 232), have been refuted in a memoir by Liouville, "Sur un cas particulier du problème des trois corps." "Quelques partisans des causes finales," said Laplace, "ont imaginé que la lune a été donnée à la terre pour l'éclairer pendant les nuits; dans ce cas, la nature n'aurait point atteint le but qu'elle se serait proposé, puisque nous sommes souvent privés à la fois de la lumière du soleil et de celle de la lune. Pour y parvenir il eût suffi de mettre à l'origine la lune en opposition

avec le soleil, dans le plan même de l'écliptique, à une distance égale à la centième partie de la distance de la terre au soleil, et de donner à la lune et à la terre des vitesses parallèles et proportionnelles à leurs distances à cet astre. Alors la lune, sans cesse en opposition au soleil, eût décrit autour de lui une ellipse semblable à celle de la terre; ces deux astres se seraient succédé l'un à l'autre sur l'horizon; et comme à cette distance la lune n'eût point été éclipsée, sa lumière aurait certainement remplacé celle du soleil." Liouville finds, in opposition to this—"que si la lune avait occupé à l'origine la position particulière que l'illustre auteur de la *Mécanique céleste* lui assigne, elle n'aurait pu s'y maintenir que pendant un tems très court."

(⁵⁹⁵) p. 368.—On the transporting power of Tides, see Sir Henry De la Beche, *Geological Manual*, 1833, p. 111.

(⁵⁹⁶) p. 368.—Arago, "Sur la question de savoir, si la lune exerce sur notre atmosphère une influence appréciable," in the *Annuaire pour 1833*, p. 157—206. The principal authorities are:—Scheibler (*Untersuch. über Einfluss des Mondes auf die Veränderungen in unserer Atmosphäre*, 1830, S. 20); Flaugergaes (twenty years' observations at Viviers); *Bibl. universelle, Sciences et Arts*, T. xl. 1829, p. 265—283; and in Kastner's *Archiv f. die ges. Naturlehre*, Bd. xvii. 1829, S. 32—50; and Eisenlohr, in *Pogg. Ann. der Physik*. Bd. xxxv. 1835, S. 141—160, and 309—329. Sir John Herschel considers it very probable that a very high temperature (much above the boiling point of water) prevails on the surface of the Moon, which is exposed for 14 days together to the uninterrupted and unmitigated influence of the Sun. The Moon must hence, when in opposition, or a few days afterwards, be in some small degree a source of heat to the Earth: this heat, proceeding from a body much below the temperature of ignition, cannot, however, reach the surface of the Earth itself, but is absorbed in the upper strata of our atmosphere, where it changes visible cloud into transparent vapour. The phenomenon of the rapid dispersion of clouds by the full Moon, when the cloudy canopy is not too dense, is regarded by Sir John Herschel as a "meteorological fact," which (he adds) "is further confirmed by Humboldt's own experience, and by the very general belief of Spanish mariners in the American tropical seas." See Report of the Fifteenth Meeting of the British Association for the Advancement of Science, 1846, Notices, p. 5; and *Outlines of Astronomy*, p. 261.

(⁵⁹⁷) p. 369.—Beer und Mädler, *Beiträge zur phys. Kenntniss des Sonnensystems*, 1841, S. 113, aus *Beobachtungen von 1830 und 1832*; Mädler, *Astronomie*, 1849, S. 206. The first, and considerable, correction of the time of rotation found by Dominique Cassini (24 hours, 40 minutes), was the

result of laborious observations by William Herschel (between 1777 and 1781), which gave 24 hours, 39 minutes, 21·7 seconds. Kunowsky found, in 1821, 24 hours, 36 minutes, 40 seconds, which is very near to Mädler's result. Cassini's earliest observation of the rotation of a spot of Mars (Delambre, *Hist. de l'Astr. moderne*, T. ii. p. 694), appears to have been made soon after the year 1670; but in the very rare treatise (Kern, *Diss. de Scintillatione Stellarum*, Wittenb. 1686, § 8), I find Salvator Serra and Father Ægidius Franciscus de Cottignez, Astronomer of the Collegio Romano, named as the discoverers of the rotation of Mars and Jupiter.

(⁵⁹⁸) p. 369.—Laplace, *Expos. du Syst. du Monde*, p. 36. Schröter's very imperfect measurements of the diameters of the planet gave the ellipticity of Mars as only $\frac{1}{80}$.

(⁵⁹⁹) p. 370.—Beer und Mädler, *Beiträge*, S. 111.

(⁶⁰⁰) p. 370.—Sir John Herschel, *Outlines*, § 510.

(⁶⁰¹) p. 370.—Beer und Mädler, *Beiträge*, S. 117—125.

(⁶⁰²) p. 370.—Mädler, in *Schumacher's Astr. Nachr.* No. 192.

(⁶⁰³) p. 371.—*Kosmos*, Bd. iii. S. 427—429; Engl. ed. p. 304—306.

Compare also, for what has been said in the present volume respecting the chronology of the discoveries of the small planets, S. 426 and 460; Engl. ed. p. 303 and 338;—respecting the proportion of their magnitudes to that of meteoric asteroids or aerolites, S. 432; Engl. ed. p. 309;—and respecting Kepler's conjecture of the existence of a planet in the great planetary gap between Mars and Jupiter (a conjecture which yet was by no means the occasion of the discovery of the first discovered of the small planets, Ceres), S. 439—444, and Anm. 31—33, S. 483; Engl. ed. p. 317—322, and Notes 523—525, p. cxix.—cxx. The bitter censure which has been expressed against a highly esteemed philosopher,—“because at a time when he might indeed have known Piazzi's discovery for five months, but did not know it, he denied, not so much the probability, but rather only the necessity, of there being a planet situated between Mars and Jupiter,”—appears to me but little justified. Hegel, in his *Dissertatio de Orbitis Planetarum*, written in the spring and summer of 1801, discusses the ideas of the ancients respecting the distances of the planets; and in remarking the series of which Plato speaks in the *Timæus* (p. 35, Steph.): 1 . 2 . 3 . 4 . 9 . 8 . 27 (compare *Kosmos*, Bd. iii. S. 477, Anm. 21; Engl. ed. p. cxv. Note 513) says, he denies the possibility of a gap. He says merely, ‘*Quæ series si verior naturæ ordo sit, quam arithmetica progressio, inter quartum et quintum locum magnum esse spatium, neque ibi planetam desiderari apparet*’ (*Hegel's Werke*, Bd. xvi. 1834, S. 28; and

Hegel's "Leben von Rosenkranz," 1844, S. 154). Kant, in his *Naturgeschichte des Himmels*, 1755, merely deems that, in the formation of the planets, Jupiter, by its enormous force of attraction, occasioned the smallness of Mars. He mentions only once, and then in a very indefinite manner, "the members of the solar system which are far asunder, and between which the intermediate parts have not yet been discovered;—Glieder des Sonnensystems, die weit von einander abstehen, und zwischen denen man die Zwischen-theile noch nicht entdeckt hat" (Immanuel Kant, *Sämmtliche Werke*, Th. vi. 1839, S. 87, 110, and 196).

⁽⁶⁰⁴⁾ p. 372.—Respecting the influence of improved star-maps on the discovery of the small planets, see *Kosmos*, Bd. iii. S. 155 and 156; Engl. ed. p. 98 and 99.

⁽⁶⁰⁵⁾ p. 372.—D'Arrest über das System der kleinen Planeten zwischen Mars und Jupiter (D'Arrest on the System of the Small Planets between Mars and Jupiter), 1851, S. 8.

⁽⁶⁰⁶⁾ p. 372.—*Kosmos*, Bd. iii. S. 428 and 456; Engl. ed. p. 305—306, and 333—334.

⁽⁶⁰⁷⁾ p. 374.—Benjamin Abthorp Gould (now at Cambridge, Massachusetts, U.S.), *Untersuchungen über die gegenseitige Lage der Bahnen zwischen Mars und Jupiter* (Investigations respecting the Positions, relative to each other, of the Orbits between Mars and Jupiter), 1848, S. 9—12.

⁽⁶⁰⁸⁾ p. 374.—D'Arrest, work above cited, S. 30.

⁽⁶⁰⁹⁾ p. 374.—Zach, *Monatl. Corresp.* Bd. vi. S. 88.

⁽⁶¹⁰⁾ p. 375.—Gauss, in the same, Bd. xxvi. S. 299.

⁽⁶¹¹⁾ p. 375.—Mr. Daniel Kirkwood (of the Pottsville Academy) has thought it possible to undertake the hypothetical reconstruction of the original shattered planet from the surviving fragments, after the manner followed in regard to the remains of extinct animals. He assigns to the planet a diameter larger than Mars (more than 1080 German, 4320 English, geographical miles), and a rotation slower than that of any other planet, making the length of its day $57\frac{1}{2}$ hours (*Rep. of the British Assoc.* 1850, p. xxxv.)

⁽⁶¹²⁾ p. 376.—Beer und Mädler, *Beiträge zur phys. Kenntniss der himml. Körper*, S. 104—106. Older and more uncertain observations of Hussey even gave $\frac{1}{24}$. Laplace (*Syst. du Monde*, p. 266) finds theoretically, with increasing density of the strata, between $\frac{1}{24}$ and $\frac{5}{48}$.

⁽⁶¹³⁾ p. 376.—Newton's immortal work, *Philosophia Naturalis Principia Mathematica*, was published in May 1687, and the *Memoirs of the Paris Academy*, containing the notice of Cassini's determination of the ellipticity

($\frac{1}{15}$), did not appear until 1691; so that Newton, who might certainly have known Richer's pendulum experiments at Cayenne from the Voyage printed in 1679, must have been informed of the figure of Jupiter by verbal communication, and by the correspondence by letter which was then carried on with so much activity. On this subject, and on Huygens' only apparently-early knowledge of Richer's pendulum observations, see Kosmos, Bd. i. S. 420, Anm. 99; Engl. ed. p. xlii. Note 129; and Bd. ii. S. 520, Anm. 2; Engl. ed. p. cxxv. Note 542.

(⁶¹⁴) p. 376.—Airy, in the Mem. of the Royal Astron. Society, Vol. ix. p. 7; Vol. x. p. 43.

(⁶¹⁵) p. 377.—Still in the year 1824. (Laplace, Expos. du Syst. du Monde, p. 207).

(⁶¹⁶) p. 377.—Delambre, Hist. de l'Astr. moderne, T. ii. p. 754.

(⁶¹⁷) p. 678.—“ On sait qu'il existe au-dessus et au-dessous de l'équateur de Jupiter deux bandes moins brillantes que la surface générale. Si on les examine avec une lunette, elles paraissent moins distinctes à mesure qu'elles s'éloignent du centre, et même elles deviennent tout-à-fait invisibles près des bords de la planète. Toutes ces apparences s'expliquent en admettant l'existence d'une atmosphère de nuages interrompue aux environs de l'équateur par une zone diaphane, produite peut-être par les vents alisés. L'atmosphère de nuages réfléchissant plus de lumière que le corps solide de Jupiter, les parties de ce corps que l'on verra à travers la zone diaphane, auront moins d'éclat que le reste, et formeront les bandes obscures. A mesure qu'on s'éloignera du centre, le rayon visuel de l'observateur traversera des épaisseurs de plus en plus grandes de la zone diaphane, en sorte qu'à la lumière réfléchie par le corps solide de la planète s'ajoutera la lumière réfléchie par cette zone plus épaisse. Les bandes seront par cette raison moins obscures en s'éloignant du centre. Enfin aux bords mêmes la lumière réfléchie par la zone vue dans la plus grande épaisseur pourra faire disparaître la différence d'intensité qui existe entre les quantités de lumière réfléchie par la planète et par l'atmosphère de nuages; on cessera alors d'apercevoir les bandes qui n'existent qu'en vertu de cette différence. On observe dans les pays de montagnes quelque chose d'analogue: quand on se trouve près d'une forêt de sapins, elle paraît noire; mais à mesure qu'on s'en éloigne, les couches d'atmosphère interposées deviennent de plus en plus épaisses et réfléchissent de la lumière. La différence de teinte entre la forêt et les objets voisins diminue de plus en plus; elle finit par se confondre avec eux, si l'on s'en éloigne d'une distance convenable.” (From Arago's Discourses on Astronomy, 1841).

(⁶¹⁸) p. 379.—Kosmos, Bd. ii. S. 357—359 and 509, Anm. 44; Engl. ed. p. 316—318, and cxiv. Note 484.

(⁶¹⁹) p. 380.—Sir John Herschel, Outlines, § 540.

(⁶²⁰) p. 381.—The earliest careful observations of William Herschel, in Nov. 1793, gave for the rotation of Saturn 10 hours, 16 minutes, 44 seconds. It has been erroneously stated, that, forty years before William Herschel, the great philosopher Kant, in his ingenious Allgemeine Naturgeschichte des Himmels, inferred truly the time of rotation of Saturn from theoretical considerations. The number which he assigned was 6 hours, 23 minutes, 53 seconds. He called his determination the “mathematical computation of an unknown movement of a heavenly body, which is perhaps the only prediction of its kind in natural science, and must await its confirmation from future observations.” The hoped-for confirmation did not arrive; on the contrary, observation has shewn that the anticipation was in error 4 hours, or three-fifths of its amount. In the same work he says of Saturn’s ring, that of the accumulated particles of which it consists, those of the interior margin perform their course in 10 hours, and those of the exterior margin in 15 hours. The first of these two numbers, applied to the ring, is the only one which is, accidentally, near to the observed time of rotation of the planet. Compare Kant, Sämmtliche Werke, Th. vi. 1839, S. 135 and 140.

(⁶²¹) p. 381.—Laplace (Expos. du Syst. du Monde, p. 43) estimates the compression at the poles at $\frac{1}{11}$. The singular supposed deviation of Saturn from a spheroidal figure, in conformity with which William Herschel, by a series of elaborate observations, made, moreover, with very different telescopes, found the major axis of the planet, not in the equator itself, but in a diameter crossing the equatorial diameter at an angle of about 45°, has not been confirmed by Bessel, but, on the contrary, was believed by him to have been erroneous.

(⁶²²) p. 382.—Arago, Annuaire pour 1842, p. 555.

(⁶²³) p. 382.—This difference of the intensity of light of the inner and the outer ring was already noticed by Dominique Cassini (Mém de l’Académie des Sciences, Année 1715, p. 13).

(⁶²⁴) p. 382.—Kosmos, Bd. ii. S. 359; Engl. ed. p. 318—319. The *publication* of the discovery, or rather of the complete explanation of all the phænomena presented by Saturn and his ring, was not made until four years later, in 1659, in the Systema Saturnium.

(⁶²⁵) p. 384.—Such mountain-like inequalities have recently been noticed by

Lassell, at Liverpool, with a twenty-foot reflector made by himself (Rep. of the British Association, 1850, p. xxxv.)

⁽⁶²⁶⁾ p. 384.—Compare Harding's *Kleine Ephemeriden für 1835*, S. 100; and Struve, in *Schum. Astr. Nachrichten*, No. 139 S. 389.

⁽⁶²⁷⁾ p. 384.—We read in the *Actis Eruditorum pro anno 1684*, p. 424, as an extract from the "*Systema phænomenorum Saturni, autore Galletio, proposito ecl. Avenionensis*:"—"Nonnunquam corpus Saturni *non exacte annuli medium* obtinere visum fuit. Hinc evenit, ut, quum planeta orientalis est, centrum ejus extremitati orientali annuli proprius videatur, et major pars ab occidentali latere sit cum ampliore obscuritate."

⁽⁶²⁸⁾ p. 385.—Horner, in *Gehler's Neuem physik. Wörterbuch* (New Physical Dictionary), Bd. viii. 1836, S. 174.

⁽⁶²⁹⁾ p. 385.—Benjamin Peirce on the Constitution of Saturn's ring, in *Gould's Astron. Journal*, 1851, Vol. ii. p. 16. "The ring consists of a stream, or of streams, of a fluid rather denser than water flowing around the primary." Compare also *Silliman's Amer. Journal*, 2d series, Vol. xii. 1851, p. 99; and respecting the inequalities of the ring, and the perturbing, and thereby maintaining, influences of the satellites, *John Herschel, Outlines*, p. 320.

⁽⁶³⁰⁾ p. 386.—Sir John Herschel, *Results of Astron. Observ. at the Cape of Good Hope*, p. 414—430; the same, in the *Outlines of Astr.* p. 650; and upon the Law of the Distances, § 550.

⁽⁶³¹⁾ p. 387.—Fries, *Vorlesungen über die Sternkunde*, 1833, S. 325; Challis, in the *Transact. of the Cambridge Philos. Society*, Vol. iii. p. 171.

⁽⁶³²⁾ p. 387.—William Herschel, *Account of a Comet*, in the *Phil. Trans.* for 1781, Vol. lxxi. p. 492.

⁽⁶³³⁾ p. 388.—*Kosmos*, Bd. iii. S. 445; Engl. edit. p. 323.

⁽⁶³⁴⁾ p. 388.—Mädler, in *Schumacher's Astr. Nachr.* No. 493. (Compare, respecting the ellipticity or compression at the poles of Uranus, *Arago, Annuaire for 1842*, p. 577—579.)

⁽⁶³⁵⁾ p. 390.—For the observations of Lassell, at Starfield (Liverpool), and of Otto Struve, compare *Monthly Notices of the Royal Astron. Soc.* Vol. viii. 1848, p. 43—47, and 135—139; also *Schum. Astr. Nachr.* No. 623, S. 365.

⁽⁶³⁶⁾ p. 390.—Bernhard von Lindenau, *Beitrag zur Gesch. der Neptun's-Entdeckung* (Contribution to the History of the Discovery of Neptune), in *Ergänz. Heft zu Schum. Astr. Nachr.* 1849, S. 17.

⁽⁶³⁷⁾ p. 391.—*Astr. Nachr.* No. 580.

(⁶³⁸) p. 391.—Le Verrier, *Recherches sur les Mouvements de la Planète Herschel*, 1846, in the *Connaissance des Temps pour l'an 1849*, p. 254.

(⁶³⁹) p. 391.—The very important element of the mass of Neptune has gradually increased from $\frac{1}{20897}$ according to Adams, $\frac{1}{19840}$ according to Peirce, $\frac{1}{19400}$ according to Bond, and $\frac{1}{18780}$ according to John Herschel; to $\frac{1}{15480}$ according to Lassell, and $\frac{1}{14440}$ according to Otto and August Struve. The last-named Pulkowa result has been adopted in the text.

(⁶⁴⁰) p. 392.—Airy, in the *Monthly Notices of the Royal Astr. Soc.* Vol. vii. No. 9 (Nov. 1846), p. 121—152; Bernhard von Lindenau, *Beitrag zur Gesch. der Neptun's-Entdeckung*, S. 1—32 and 235—238. Le Verrier, at the instance of Arago, began in the summer of 1845, to work at the theory of Uranus. He laid the results of his investigation before the Institute on the 10th of Nov. 1845, the 1st of June, 31st of August, and 5th of Oct. 1846, and published them at once; but his greatest and most important work, which contained the solution of the whole problem, only appeared in the *Connaissance des Temps pour l'an 1849*. Adams, without printing anything, laid the first results which he had obtained for the perturbing planet before Professor Challis, in September 1845, and the same, with some modification, in the following month, Oct. 1845, before the Astronomer-Royal,—still without publishing anything. The Astronomer-Royal received from Adams his final results, with some fresh corrections relating to a diminution of the distance, in the beginning of September 1846. The young Cambridge geometrician has expressed himself with noble modesty and self-denial on the subject of this chronological succession of labours, which were all directed to the same great object:—"I mention these earlier dates merely to shew that my results were arrived at independently, and previously to the publication of M. Le Verrier, and not with the intention of interfering with his just claims to the honours of the discovery; for there is no doubt that his researches were first published to the world, and led to the actual discovery of the planet by Dr. Galle: so that the facts stated above cannot detract in the slightest degree from the credit due to M. Le Verrier." As in the history of the discovery of Neptune mention has often been made of the early participation of the great astronomer of Königsberg in the expectation already expressed in 1834 by Alexis Bouvard (the author of the *Tables of Uranus*), that the perturbations of Uranus might be caused by a planet still unknown to us, I think it may perhaps be agreeable to some of my readers that I should publish here a portion of a letter written to me by Bessel, under date 8th May, 1840,—two years, therefore, before his conver-

sation with Sir John Herschel, during his visit to Collingwood. "You wish for tidings respecting the planet beyond Uranus. I might refer you to friends at Königsberg who, from a misunderstanding, think they know more about it than I do myself. I had chosen for a public lecture (on the 28th of Feb. 1840), the subject of the connection between astronomical observations and astronomy. The public knows of no difference between the two, and it was desirable to give them juster views in this respect. In shewing the development of astronomical knowledge from observations, I was naturally led to remark that we cannot yet by any means assert that our theory explains all the motions of the planets. Uranus was adduced in proof of this, as the old observations of that planet do not suit at all with the elements which can be inferred from the later observations made from 1783 to 1820. I think I once before told you that I had worked much at this question, but that I had not arrived at more than the *certainty* that the existing theory, or rather its application to the solar system, *so far as it is known* to us, does not suffice to solve the enigma presented by Uranus. I do not, however, believe that we ought on this account to regard it as not susceptible of solution. We must first know accurately and completely all that has been observed respecting Uranus. I have got one of my young auditors, Fleming, to reduce and compare all the observations, and thus I now have all the existing data before me. If the old observations do not suit well with the theory, the later ones do so still less; for the error is again already a full minute, and it increases annually by seven or eight seconds, so that it will soon be considerably larger. I have thence thought that a time would come in which the solution of the enigma might perhaps be found in a new planet, whose elements might be recognised from its effects on Uranus, and confirmed by those on Saturn. I was far from saying that this time had actually arrived, but I mean now to try *how far* the existing facts may lead. This is a work which I have had by me so many years, and I have already pursued so many different views for its sake, that its completion has peculiar attractions for me, and I shall, therefore, omit nothing to bring it about as soon as possible. I have great confidence in Fleming, who at Dantzic, whither he is now called, will prosecute for Jupiter and Saturn the same reduction of observations as that which he has now performed for Uranus. It is, in my estimation, a fortunate circumstance that he has, for the present, no means of making observations, and that he is not engaged in any lectures. No doubt a time will arrive for him also when he will have to make observations *for a definite object*; and then he will, I trust, be as far from wanting the requisite means as he is now from wanting the skill."

(⁶⁴¹) p. 393.—The first letter in which Lassell announced the discovery was dated the 6th of August, 1847. (Schumacher's *Astr. Nach.* No. 611, S. 165).

(⁶⁴²) p. 393.—Otto Struve, in the *Astr. Nachr.* No. 629. August Struve, at Dorpat, computed the orbit of the first satellite of Neptune from the observations at Pulkowa.

(⁶⁴³) p. 393.—W. C. Bond, in the Proceedings of the American Academy of Arts and Sciences, Vol. ii. p. 137 and 140.

(⁶⁴⁴) p. 393.—Schum. *Astr. Nachr.* No. 729, S. 143.

(⁶⁴⁵) p. 395.—Kant says: "The last planets beyond Saturn will be found to bear an increasing resemblance to comets, until one class of bodies is connected with or passes by gradual transition into the other. This supposition is supported by the law according to which the excentricity of the planetary orbits increases with their distance from the Sun. The remoter planets approach thereby nearer to the definition of comets. The last planet, and first comet, may be the body which at its perihelion shall be found to intersect the orbit of the next planet, perhaps Saturn. Our theory of the mechanical formation of the heavenly bodies is also clearly proved (!) by the magnitude of the planetary masses increasing with their distance from the Sun." Kant, *Naturgesch. des Himmels* (1755) in his *Sämmtl. Werken*, Th. vi. S. 88 and 195. In the beginning of the 5th Part (S. 131) he had spoken of the "earlier comet-like nature which Saturn had laid aside."

(⁶⁴⁶) p. 396.—Stephen Alexander "on the Similarity of Arrangements of the Asteroids and the Comets of Short Periods, and the Possibility of their Common Origin," in *Gould's Astron. Journal*, No. 19, p. 147, and No. 20, p. 181. The author distinguishes, with Hind (*Schum. Astr. Nachr.* No. 724) "the comets of short period, whose semi-axes are all nearly the same with those of the small planets between Mars and Jupiter; and the other class, including the comets, whose mean distance or semi-axis is somewhat less than that of Uranus." He concludes the first memoir with the statement that "different facts and coincidences agree in indicating a near appulse, if not an actual collision, of Mars with a large comet in 1315 or 1316; that the comet was thereby broken into three parts, whose orbits (it may be presumed) received even then their present form, viz. that still presented by the comets of 1812, 1815, and 1846, which are fragments of the dissevered comet."

(⁶⁴⁷) p. 397.—Laplace, *Expos. du Syst. du Monde* (éd. 1824), p. 414.

(⁶⁴⁸) p. 397:—On comets, see *Kosmos*, Bd. i. S. 105—120, and 389—393, Anm. 12—27; Engl. ed. p. 91—105, and p. xvii.—xx. Notes 42—57.

(⁶⁴⁹) p. 398.—In seven half-centuries, from 1500 to 1850, there have appeared in all 52 comets visible to the naked eye in Europe, or taking each interval of half a century separately and successively, respectively—13, 10, 2, 10, 4, 4, and 9. Taking them thus in half-centuries, and giving the year of the appearance of each comet, we have:—

| | |
|------------|-----------|
| 1500—1550 | 1700—1750 |
| 13 comets. | 1702 |
| | 1744 |
| | 1748 (2) |
| 1550—1600 | — |
| 10 comets. | 4 comets. |
| | 1750—1800 |
| 1600—1650 | 1759 |
| 1607 | 1766 |
| 1618 | 1769 |
| — | 1781 |
| 2 comets. | — |
| | 4 comets. |
| 1650—1700 | 1800—1850 |
| 1652 | 1807 |
| 1664 | 1811 |
| 1665 | 1819 |
| 1668 | 1823 |
| 1672 | 1830 |
| 1680 | 1835 |
| 1682 | 1843 |
| 1686 | 1845 |
| 1689 | 1847 |
| 1696 | — |
| — | 9 Comets. |
| 10 comets. | |

Of the 23 comets stated above to have been visible to the naked eye in Europe in the 16th century (the age of Apianus, Girolamo Fracastoro, the Landgrave William the IVth of Hesse, Mästlin, and Tycho Brahe), ten have

been described by Pingré, viz. those of 1500, 1505, 1506, 1512, 1514, 1516, 1518, 1521, 1522, and 1530; as well as the comets of 1531, 1532, 1533, 1556, 1558, 1569, 1577, 1580, 1582, 1585, 1590, 1593, and 1596.

(⁶⁵⁰) p. 399.—This is the “malignant comet” which was supposed to announce (or occasion), in storm and shipwreck, the death of the celebrated Portuguese discoverer, Bartholomew Diaz, when he sailed with Cabral from Brazil to the Cape of Good Hope. Humboldt, *Examen crit. de l’Hist. de la Géogr.* T. i. p. 296, and T. v. p. 80 (Sousa, *Asia Portug.* T. i. P. i. cap. 5, p. 45).

(⁶⁵¹) p. 399.—Laugier, in the *Connaissance des Temps pour l’an 1846*, p. 99. Compare also Edouard Biot, *Recherches sur les Anciennes Apparitions Chinoises de la Comète de Halley antérieures à l’Annee 1378*, work before cited, p. 70—84.

(⁶⁵²) p. 399.—On the comet discovered by Galle in March 1840, see Schumacher’s *Astr. Nachr.* Bd. 17, S. 188.

(⁶⁵³) p. 399.—See my *Vues des Cordillères* (éd. in-folio), Pl. lv. fig. 8, p. 281—282. The Mexicans had also a very correct view of the cause of a solar eclipse. The same Mexican manuscript, executed at least a quarter of a century before the arrival of the Spaniards, represents the Sun as almost covered by the disk of the Moon, and shews the stars visible at the same time.

(⁶⁵⁴) p. 400.—This origin of the *tail* from the *front* part of the head of the comet which engaged so much of Bessel’s attention, is in accordance with the view already taken by Newton and by Winthrop. (Compare Newton, *Princip.* p. 511; and *Phil. Trans.* Vol. lvii. for the year 1767, p. 140, fig. 5.) Newton thought that the tail was developed in greatest strength and length when near to the Sun, because the celestial air (that which with Encke we call the “resisting medium”) is there most dense, and the “*particulæ candæ*,” being strongly heated, ascend most easily, being upborne by the denser celestial air. Winthrop thought that the principal effect does not take place until a little after the perihelion, because, according to the law established by Newton (*Princip.* p. 424 and 466), maxima are always in arrear (as in periodical changes of temperature, as well as in the tides of the sea).

(⁶⁵⁵) p. 400.—Arago, in the *Annuaire* for 1844, p. 395. The observation was made by the younger Amici.

(⁶⁵⁶) p. 400.—On the comet of 1843, which in the month of March of that year shone out with a lustre unexampled in the North of Europe, and which approached nearer to the Sun than any other observed and calculated comet, see Sir John Herschel’s *Outlines of Astronomy*, § 589—597; and Peirce’s

American Almanac for 1844, p. 42. External or physiognomic resemblances, the uncertainty of which had, however, been pointed out so long ago as by Seneca in his Nat. Quæst. lib. vii. cap. 11 and 17, had at first given occasion to this comet being supposed to be identical with those of 1668 and 1689. (Kosmos, Bd. i. S. 144 and 410, ALM. 62; Engl. ed. p. 129 and xxxiii. Note 92: and Galle, in "Olbers Cometenbahnen," No. 42 and 50.) Boguslawski (Schum. Astr. Nachr. No. 545, S. 272) believed, on the other hand, that the earlier appearances of this comet, assigning to it a period of revolution of 147 years, had been those of 1695, 1548, and 1401: he even calls it "the comet of Aristotle," because he traces it back to 371 B.C., and, with the talented Hellenist, Thiersch, of Munich, considers it to be the comet mentioned in the Meteorol. of Aristotle, Book i. cap. 6. I would remark, however, that the name "Comet of Aristotle" is liable to much uncertainty in respect to its signification. If the comet which Aristotle makes to have disappeared in the constellation of Orion, and which he connects with the earthquake in Achaia, be meant, it must not be forgotten that this comet is stated by Calisthenes to have appeared *before*, by Diodorus *after*, and by Aristotle *at the time of*, the earthquake. The 6th and 8th chapters of Aristotle's Meteorology treat of four comets, the epochs of whose appearance are indicated by references to the Archons at Athens, and to different calamitous events. He there mentions successively the "western" comet, which appeared at the time of the great earthquake in Achaia, with which great inundations were connected (cap. 6, 8); then the comet which appeared in the time of the Archon Eucles, the son of Molon (cap. 6, 10); and subsequently the Stagirite speaks again of the western comet, that of the great earthquake, and names in connection with it the Archon Asteus, a name which incorrect readings have converted into Aristæus, and who, on that account, Pingré, in his Cométographie, erroneously regards as the same person as Aristhenes or Alcisthenes. The lustre of this comet of Asteus extended over a third part of the heavens: its tail, therefore, which was called "the way" (*ὁδός*), was 60° in length. It stretched to the neighbourhood of Orion, where it was dissolved. In cap. 7, 9, mention is made of the comet which appeared simultaneously with the celebrated fall of a meteoric stone at Ægos Potamoi (Kosmos, Bd. i. S. 124, 397, and 407; Engl. ed. p. 109, xxiii. and xxxi. Note 87), and which cannot well be a mere confusion with the aerolite-cloud described by Damachos as having shone and sent forth shooting stars during a period of 70 days. Lastly, Aristotle names, in cap. 7, 10, a comet which was seen under the Archon Nicomachus, and to which a tempest at Corinth was ascribed. These

four appearances of comets fall in the long period of 32 Olympiads, viz. the comet contemporaneous with the aerolitic fall, according to the Parian chronicle, Ol. 78, 1 (468 B.C.), under the Archon Theagenides; the great comet of Asteus, which appeared at the time of the earthquake in Achaia, and disappeared in the constellation of Orion, in Ol. 101, 4 (373 B.C.); the comet of Eucles, the son of Molon, erroneously called Euclides by Diodorus (xii. 53), in Ol. 88, 2 (427 B.C.), as is also confirmed by the Commentary of Johannes Philoponos; and the comet of Nicomachus, in Ol. 109, 4 (341 B.C.) In Pliny, ii. 25, the 108th Olympiad is assigned to the jubæ effigies mutata in hastam. Seneca also agrees in the immediate connection of the comet of Asteus (Ol. 101, 4) with the earthquake in Achaia, inasmuch as he mentions in the following manner the destruction of Bura and Helice, which towns are not expressly named by Aristotle: "Effigiem ignis longi fuisse, Callisthenes tradit, antequam Burin et Helicen mare absconderet. Aristoteles ait, non trabem illam, sed cometam fuisse." (Seneca, Nat. Quæst. vii. 5.) Strabo (viii. p. 384, Cas.) places the destruction of these two often mentioned cities two years before the battle of Leuctra, whence we should again have the date Ol. 101, 4. Lastly, when Diodorus Siculus has described the same event in more detail as taking place under the Archon Asteus (xv. 48 and 49), he places the bright "shadow-casting" comet (xv. 50) under the Archon Alcisthenes, a year later, Ol. 102, 1 (372 B.C.), and makes it a herald of the downfall of the Lacedæmonian dominion; but Diodorus had the habit of transferring an event from one year to another, and the more ancient and secure authorities, Aristotle and the Parian Chronicle, testify in favour of the epoch of Asteus in preference to that of Alcisthenes. Now as, by the assumption of a period of revolution of $147\frac{3}{4}$ years for the fine comet of 1843, Boguslawski traces it through 1695, 1548, 1401, and 1106, back to 371 years before our era, we find it agree with the comet of the earthquake in Achaia, according to Aristotle within two, and according to Diodorus even within one, year, which, if we could know anything of the similarity of the orbits, would, indeed, be a very small error considering the probable perturbations in so long an interval. If Pingré, in his *Cométographie*, 1783, T. i. p. 259—262 (on the authority of Diodorus, and taking Alcisthenes instead of Asteus as the name of the Archon), places the appearance of the comet in Orion of which we are speaking in Ol. 102, and yet calls the date July 371 instead of 372 B.C., it is no doubt because he agrees with some astronomers in marking the first year before the Christian Era as anno 0. It must be remarked, in conclusion, that Sir John Herschel takes for the bright comet of 1843 quite

a different period of revolution, viz. 175 years, which would trace it back to the years 1668, 1493, and 1318. (Compare *Outlines of Astronomy*, p. 370 to p. 372, with Galle, in *Olbers Cometenbahnen*, S. 208, and *Kosmos*, Bd. i. S. 144, Engl. ed. p. 93.) Other combinations of Peirce and Clausen even give periods of revolution of $21\frac{1}{2}$ or $7\frac{1}{2}$ —years,—sufficient proof of how hazardous it is to trace back the comet of 1843 to the time of the Archon Asteus. The mention in the *Meteorol. lib. i. cap. 7, 10*, of a comet under the Archon Nicomachus, has the advantage of informing us that Aristotle was at least 44 years old when that work was written. It has always surprised me that this great man, who must have been already 14 years old at the time of the earthquake of Achaia, and of the appearance of the great comet in Orion with a tail of 60° in length, should have spoken with so little animation of so brilliant an object, contenting himself with merely enumerating it as one of the comets “that had been seen in his time.” The surprise is increased on finding it said in the same chapter that he had seen with his own eyes something nebulous, or even a faint appearance of a mane (*κόμη*), round a fixed star in the “thighbone of the Dog” (perhaps Procyon in *Canis minor*), *Meteorol. i. 6, 9*. Aristotle also speaks (*i. 6, 11*) of his observation of the occultation of a star in Gemini by the disk of Jupiter. What is said of a nebulous mane or vaporous envelope of Procyon (?), reminds me of a phænomenon repeatedly spoken of in the ancient Mexican imperial annals, according to the *Codex Tellerianus*. “This year” (it is said) “Citlalcholoa” (the planet Venus, also called in Aztec *Tlazoteotl*, see my *Vues des Cordillères*, T. ii. p. 303) “was again seen to smoke.” The appearances seen respectively in the Greek and Mexican sky were probably small halos round the star and the planet, the phænomenon being one of atmospheric refraction.

(⁶⁵⁷) p. 400.—Edouard Biot, in the *Comptes rendus*, t. xvi. 1843, p. 751.

(⁶⁵⁸) p. 401.—Galle, in the appendix to “*Olbers Cometenbahnen*,” S. 221, No. 130. (On the probable passage of the two-tailed comet of 1823, see *Edinb. Rev.* 1848, No. 175, p. 193.) The memoir referred to in the text, containing the true elements of the comet of 1680, does away with Halley’s fanciful idea, according to which that comet, having a supposed period of revolution of 575 years, would have appeared at certain great epochs in the history of mankind: at the time of the Flood according to the Hebrews, at the time of Oxyges according to the Greeks, the Trojan War, the destruction of Nineveh, the death of Julius Cæsar, &c. Encke’s calculation gives the comet’s period 8814 years. Its least distance from the surface of the Sun, on the 17th Dec. 1680, was only 32000 German, or 128000 English, geogra-

phical miles ; being 80000 English geographical miles less than the distance of the Moon from the Earth. The aphelion of the comet is 853·3 distances of the Earth from the Sun, and the ratio of its least to its greatest distance from the Sun is as 1 : 140000.

(⁶⁵⁹) p. 401.—Arago, in the *Annuaire pour 1832*, p. 236—255.

(⁶⁶⁰) p. 402.—Sir John Herschel, *Outlines*, § 592.

(⁶⁶¹) p. 402.—Bernhard von Lindenau, in *Schum. Astr. Nachr.* No. 698, S. 25.

(⁶⁶²) p. 402.—*Kosmos*, Bd. iii. S. 46—49 ; Engl. ed. p. 36—39.

(⁶⁶³) p. 403.—Le Verrier, in the *Comptes rendus*, t. xix. 1844, p. 982—993.

(⁶⁶⁴) p. 404.—Newton assumed that the brightest comets possess only a light reflected from the Sun. Splendent cometæ luce Solis a se reflexa. (*Princ. mathem.* ed. Le Seur et Jacquier, 1760, T. iii. p. 577.)

(⁶⁶⁵) p. 404.—Bessell, in *Schumacher's Jahrbuch für 1837*, S. 169.

(⁶⁶⁶) p. 404.—*Kosmos*, Bd. i. S. 113, and Bd. iii. S. 50 ; Engl. ed. Vol. i. p. 99, and Vol. iii. p. 40.

(⁶⁶⁷) p. 405.—Valz, *Essai sur la Détermination de la Densité de l'Étner dans l'Espace planétaire*, 1830, p. 2 ; and *Kosmos*, Bd. i. S. 112 ; Engl. ed. Vol. i. p. 98. Hevelius, who was always so careful and unprejudiced an observer, had already had his attention drawn to the enlargement of the nuclei of comets with increasing distance from the Sun (Pingré, *Cométographie*, T. ii. p. 193). Determinations of the diameter of Encke's comet when near the Sun are very difficult, if exactness is aimed at. The comet is a nebulous mass, in which the middle, or a part of the middle, is strikingly the brightest. From this place, which has not at all the appearance of a disk, and cannot be called a comet's head, the light decreases rapidly on all sides. At the same time the nebulosity is prolonged in one direction, so that this prolongation appears like a tail. Measurements of the comet's dimensions refer, therefore, to this nebulosity, the circumference of which, without having any very well-defined outline, diminishes when the comet is at its perihelion.

(⁶⁶⁸) p. 405.—Sir John Herschel, *Results of Astron. Observ. at the Cape of Good Hope*, 1847, § 366, Pl. xv. and xvi.

(⁶⁶⁹) p. 406.—Although still later (5th of March) the distance between the two comets was seen to increase to 9° 19', yet this increase, as Plantamour has shewn, was only apparent, being dependent on increased approximation to the Earth. From February to the 10th of March, the two portions of the double comet continued to be at an equal distance from each other.

(⁶⁷⁰) p. 406.—Le 19 février 1846, on aperçoit le foud noir du ciel qui

sépare les deux comètes. (Otto Struve, in the *Bulletin physico-mathématique de l'Acad. des Sciences de St.-Petersbourg*, T. vi. No. 4.)

(671) p. 406.—Compare “*Outlines of Astronomy*,” § 580—588; Galle, in *Olbers Cometenbahnen*, S. 232.

(672) p. 407.—“*Ephorus non religiosissimæ fidei, sæpe decipitur, sæpe decipit. Sicut hic cometem, qui omnium mortalium oculis custoditus est, quia ingentis rei traxit eventus, cum Helicen et Burin ortu suo merserit, ait illum discessisse in duas stellas: quod præter illum nemo tradidit. Quis enim posset observare illud momentum quo cometes solutus et in duas partes redactus est? Quomodo autem, si est qui viderit cometem in duas derimi, nemo vidit fieri ex duabus?*” (Seneca, *Nat. Quæst. lib. vii. cap. 16.*)

(673) p. 407.—Edouard Biot, *Recherches sur les Comètes de la Collection de Ma-tuan-lin*, in the *Comptes rendus*, T. xx. 1845, p. 334.

(674) p. 408.—Galle, in “*Olbers Methode der Cometenbahnen*,” S. 232, No. 174. The comets of Colla and Bremiker, of the years 1845 and 1840, combine elliptic orbits with not very long periods of revolution (not long, I mean, if compared with the periods of 3065 and 8800 years of the comets of 1811 and 1680). The comets of Colla and Bremiker appear to have periods of only 249 and 344 years. (See Galle, in the last-quoted work, S. 229 and 231.)

(675) p. 409.—The short period of revolution of 1204 days was recognised by Eneke on the reappearance of his comet in 1819. See the first calculated elliptic orbits in the Berlin “*Astron. Jahrbuch*” for 1822, S. 193; and for the constants of “the resisting medium” assumed for the explanation of the accelerated revolution, see Eneke’s “*Vierte Abhandl.*” in the “*Schriften der Berliner Akademie*” for 1844. (Compare Arago, in the *Annuaire pour 1832*, p. 181, in the “*Lettre à Mr. Alexandre de Humboldt*,” 1840, p. 12; and Galle, in *Olbers Cometenbahnen*, S. 221.) In reference to the history of Eneke’s comet, it remains to be noticed that, so far as our knowledge of observations extends, it was first seen, 17 Jan. 1786, by Mechain, on two days; then by Miss Caroline Herschel, 7—27 Nov. 1795; then by Bouvard, Pons, and Huth, Oct. 20—Nov. 19, 1805; and lastly—this being its tenth return since its discovery by Mechain in 1786—from the 26th of November, 1818, to the 12th of January, 1819, by Pons. The first return *calculated beforehand* by Eneke was observed by Rümker at Paramatta (Galle, *Olbers Methode der Cometenbahnen*, S. 215, 217, 221, and 222).—Biela’s, or, as it is also called, Gambart and Biela’s interior comet, was first seen on the 8th of March, 1772, by Montaigne; then by Pons on the 10th of November, 1805; then on the 27th of February, 1826, at Josephstadt, in Bohemia, by Herr von

1667, and on the 28th of March, 1668, at Newcastle, by Samuel, by which the other astronomers of the court of 1772 was sent, and not Samuel, but, on the other hand, the latter determined the elliptic elements earlier than Halley, and struck a correspondence with Cassini. (Astruc, in the Annuaire pour 1788, p. 124, and in the *Comptes Rendus*, T. iii. 1789, p. 412.) The first predicted return of Halley's comet was observed in October and December 1758, by Hevelius, at the Cape of Good Hope. The astronomical operations of Halley's comet were done on 17 seventh support, and also 1778, at the end of the year 1785. See Halley, in *Philos. S. Soc.* 27, 172, 187, and 188.

(7) p. 408.—*Philos. S. Soc.*

(8) p. 411.—*Philos. S. Soc.* p. 408, p. 409, p. 410, p. 411, and p. 412. Halley's prediction was respecting comets as wandering, while (p. 411) Halley's opinion is respecting a stationary comet, it appeared to many, was, by the discovery which, at the time of the great astronomer, has been made is equal to the probability of a stationary comet, as there is no way, and by the circumstances that comets are found to have a motion of which is peculiarly Halley's, which is a common orbital velocity, it is not wandering. (Compare *Comptes Rendus*, T. iii. 1789, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 193, 194, 195, 196, 197, 198, 199, 200, 201, 202, 203, 204, 205, 206, 207, 208, 209, 210, 211, 212, 213, 214, 215, 216, 217, 218, 219, 220, 221, 222, 223, 224, 225, 226, 227, 228, 229, 230, 231, 232, 233, 234, 235, 236, 237, 238, 239, 240, 241, 242, 243, 244, 245, 246, 247, 248, 249, 250, 251, 252, 253, 254, 255, 256, 257, 258, 259, 260, 261, 262, 263, 264, 265, 266, 267, 268, 269, 270, 271, 272, 273, 274, 275, 276, 277, 278, 279, 280, 281, 282, 283, 284, 285, 286, 287, 288, 289, 290, 291, 292, 293, 294, 295, 296, 297, 298, 299, 300, 301, 302, 303, 304, 305, 306, 307, 308, 309, 310, 311, 312, 313, 314, 315, 316, 317, 318, 319, 320, 321, 322, 323, 324, 325, 326, 327, 328, 329, 330, 331, 332, 333, 334, 335, 336, 337, 338, 339, 340, 341, 342, 343, 344, 345, 346, 347, 348, 349, 350, 351, 352, 353, 354, 355, 356, 357, 358, 359, 360, 361, 362, 363, 364, 365, 366, 367, 368, 369, 370, 371, 372, 373, 374, 375, 376, 377, 378, 379, 380, 381, 382, 383, 384, 385, 386, 387, 388, 389, 390, 391, 392, 393, 394, 395, 396, 397, 398, 399, 400, 401, 402, 403, 404, 405, 406, 407, 408, 409, 410, 411, 412, 413, 414, 415, 416, 417, 418, 419, 420, 421, 422, 423, 424, 425, 426, 427, 428, 429, 430, 431, 432, 433, 434, 435, 436, 437, 438, 439, 440, 441, 442, 443, 444, 445, 446, 447, 448, 449, 450, 451, 452, 453, 454, 455, 456, 457, 458, 459, 460, 461, 462, 463, 464, 465, 466, 467, 468, 469, 470, 471, 472, 473, 474, 475, 476, 477, 478, 479, 480, 481, 482, 483, 484, 485, 486, 487, 488, 489, 490, 491, 492, 493, 494, 495, 496, 497, 498, 499, 500, 501, 502, 503, 504, 505, 506, 507, 508, 509, 510, 511, 512, 513, 514, 515, 516, 517, 518, 519, 520, 521, 522, 523, 524, 525, 526, 527, 528, 529, 530, 531, 532, 533, 534, 535, 536, 537, 538, 539, 540, 541, 542, 543, 544, 545, 546, 547, 548, 549, 550, 551, 552, 553, 554, 555, 556, 557, 558, 559, 560, 561, 562, 563, 564, 565, 566, 567, 568, 569, 570, 571, 572, 573, 574, 575, 576, 577, 578, 579, 580, 581, 582, 583, 584, 585, 586, 587, 588, 589, 590, 591, 592, 593, 594, 595, 596, 597, 598, 599, 600, 601, 602, 603, 604, 605, 606, 607, 608, 609, 610, 611, 612, 613, 614, 615, 616, 617, 618, 619, 620, 621, 622, 623, 624, 625, 626, 627, 628, 629, 630, 631, 632, 633, 634, 635, 636, 637, 638, 639, 640, 641, 642, 643, 644, 645, 646, 647, 648, 649, 650, 651, 652, 653, 654, 655, 656, 657, 658, 659, 660, 661, 662, 663, 664, 665, 666, 667, 668, 669, 670, 671, 672, 673, 674, 675, 676, 677, 678, 679, 680, 681, 682, 683, 684, 685, 686, 687, 688, 689, 690, 691, 692, 693, 694, 695, 696, 697, 698, 699, 700, 701, 702, 703, 704, 705, 706, 707, 708, 709, 710, 711, 712, 713, 714, 715, 716, 717, 718, 719, 720, 721, 722, 723, 724, 725, 726, 727, 728, 729, 730, 731, 732, 733, 734, 735, 736, 737, 738, 739, 740, 741, 742, 743, 744, 745, 746, 747, 748, 749, 750, 751, 752, 753, 754, 755, 756, 757, 758, 759, 760, 761, 762, 763, 764, 765, 766, 767, 768, 769, 770, 771, 772, 773, 774, 775, 776, 777, 778, 779, 780, 781, 782, 783, 784, 785, 786, 787, 788, 789, 790, 791, 792, 793, 794, 795, 796, 797, 798, 799, 800, 801, 802, 803, 804, 805, 806, 807, 808, 809, 810, 811, 812, 813, 814, 815, 816, 817, 818, 819, 820, 821, 822, 823, 824, 825, 826, 827, 828, 829, 830, 831, 832, 833, 834, 835, 836, 837, 838, 839, 840, 841, 842, 843, 844, 845, 846, 847, 848, 849, 850, 851, 852, 853, 854, 855, 856, 857, 858, 859, 860, 861, 862, 863, 864, 865, 866, 867, 868, 869, 870, 871, 872, 873, 874, 875, 876, 877, 878, 879, 880, 881, 882, 883, 884, 885, 886, 887, 888, 889, 890, 891, 892, 893, 894, 895, 896, 897, 898, 899, 900, 901, 902, 903, 904, 905, 906, 907, 908, 909, 910, 911, 912, 913, 914, 915, 916, 917, 918, 919, 920, 921, 922, 923, 924, 925, 926, 927, 928, 929, 930, 931, 932, 933, 934, 935, 936, 937, 938, 939, 940, 941, 942, 943, 944, 945, 946, 947, 948, 949, 950, 951, 952, 953, 954, 955, 956, 957, 958, 959, 960, 961, 962, 963, 964, 965, 966, 967, 968, 969, 970, 971, 972, 973, 974, 975, 976, 977, 978, 979, 980, 981, 982, 983, 984, 985, 986, 987, 988, 989, 990, 991, 992, 993, 994, 995, 996, 997, 998, 999, 1000.)

(9) p. 412.—*Philos. S. Soc.* in the French, Chaldean, and other languages, as well as with the Pythagoreans, and generally in the ancient world there was a division of opinion. Since *Philos. S. Soc.* iii. 2, follows the opposite statements of Eudoxius, Pythagoras, and Hipparchus. The latter is a writer seldom named, yet *Philos.* (iii. 2) terms him "greatly ancient in genius," and he is also mentioned, though without praise, in *Comptes Rendus* de la Acad. cap. 17, and *Soc. Sci. Phil.* p. 12, p. 13, p. 14, p. 15, p. 16, p. 17, p. 18, p. 19, p. 20, p. 21, p. 22, p. 23, p. 24, p. 25, p. 26, p. 27, p. 28, p. 29, p. 30, p. 31, p. 32, p. 33, p. 34, p. 35, p. 36, p. 37, p. 38, p. 39, p. 40, p. 41, p. 42, p. 43, p. 44, p. 45, p. 46, p. 47, p. 48, p. 49, p. 50, p. 51, p. 52, p. 53, p. 54, p. 55, p. 56, p. 57, p. 58, p. 59, p. 60, p. 61, p. 62, p. 63, p. 64, p. 65, p. 66, p. 67, p. 68, p. 69, p. 70, p. 71, p. 72, p. 73, p. 74, p. 75, p. 76, p. 77, p. 78, p. 79, p. 80, p. 81, p. 82, p. 83, p. 84, p. 85, p. 86, p. 87, p. 88, p. 89, p. 90, p. 91, p. 92, p. 93, p. 94, p. 95, p. 96, p. 97, p. 98, p. 99, p. 100, p. 101, p. 102, p. 103, p. 104, p. 105, p. 106, p. 107, p. 108, p. 109, p. 110, p. 111, p. 112, p. 113, p. 114, p. 115, p. 116, p. 117, p. 118, p. 119, p. 120, p. 121, p. 122, p. 123, p. 124, p. 125, p. 126, p. 127, p. 128, p. 129, p. 130, p. 131, p. 132, p. 133, p. 134, p. 135, p. 136, p. 137, p. 138, p. 139, p. 140, p. 141, p. 142, p. 143, p. 144, p. 145, p. 146, 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“comets belong to the number of those planets which, like Mercury, are a long time before they can become visible by ascending above the horizon in their course.” In the very fragmentary Pseudo-Plutarch it is said that comets “rise at fixed periods after having completed their course.” Many things respecting the nature of comets contained in scattered writings of Arrian, of whom Stobæus might have made use, and of Charimander, whose name alone has been preserved by Seneca and Pappus, have been lost to us. Stobæus cites as the opinion of the Chaldæans (*Eclog. lib. i. cap. 25, p. 61, Christ. Piantinus*), “that comets are so rarely visible because in their long course they hide themselves far away from us in the depths of æther (or of space), like fishes in the depths of the ocean.” The most pleasing, and, notwithstanding the rhetorical colouring of the passage, the soundest remarks, and most consonant with our present opinions on the subject of comets, which we meet with among ancient writers, are by Seneca. We read in *Nat. Quæst. lib. vii. cap. 22, 25, and 31*: “Non enim existimo cometem subitaneum ignem, sed inter æterna opera naturæ.—Quid enim miramur, cometas, tam rarum mundi spectaculum, nondum teneri legibus certis? nec initia illorum finesque patescere, quorum ex iugentibus intervallis recursus est? Nondum sunt anni quingenti, ex quo Græci.....stellis numeros et nomina fecit. Multæque hodie sunt gentes, quæ tantum facie noverint cælum, quæ nondum sciant, cur luna deficiat, quare obumbretur. Hoc apud nos quoque nuper ratio ad certum perduxit. Veniet tempus, quo ista, quæ nunc latent, in lucem dies extrahat et longioris ævi diligentia.—Veniet tempus, quo posteri nostri tam aperta nos nescisse mirentur.—Eleusis servat, quod ostendat revisentibus. Rerum natura sacra sua non simul tradit. Initiatos nos credimus; in vestibulo ejus hæremus. Illa arcana non promiscue nec omnibus patent, reducta et in interiore clausa sunt. Ex quibus aliud hæc ætas, aliud quæ post nos subibit, despiciet. Tarde magna proveniunt.”

(679) p. 421.—The spectacle of the starry heavens presents to our view objects not contemporaneous: much has long since disappeared, even before it became visible to our eyes, and in much the order and arrangement have changed. (*Kosmos, Bd. i. S. 161 and 416; Bd. iii. S. 90 and 125: Engl. edit. Vol. i. p. 145 and xxxix.; Vol. iii. p. 72 and xxx.* Compare *Bacou, Nov. Organ. Lond. 1733, p. 371; and William Herschel, in the Phil. Trans. for 1802, p. 498.*)

(⁶⁹⁰) p. 421.—Kosmos, Bd. i. S. 137, 142, and 407, Anm. 55; Engl. ed. p. 122, 126—127, and xxxii. Note 90.

(⁶⁹¹) p. 422.—See the opinions of the Greeks on the fall of meteoric stones, in Kosmos, Bd. i. S. 138, 139, 395, 397, 401, 402, 407, Anm. 31, 32, 39, 57—59; Bd. ii. S. 501, Anm. 27: Engl. ed. Vol. i. p. 123, 124, xxi. xxii. xxiii. xxvii. and xxxi.—xxxii. Notes 61, 62, 69, and 87—89; Vol. ii. p. cvii. Note 467.

(⁶⁹²) p. 422.—Brandis, *Gesch. der Griechisch-Röm. Philosophie*, Th. i. S. 272—277, against Schleiermacher, in the *Abhandl. der Berl. Akad.* aus den J. 1804—1811 (Berl. 1815), S. 79—124.

(⁶⁹³) p. 423.—If Stobæus in the same passage (*Ecl. phys.* p. 508) makes Diogenes of Apollonia call the stars “bodies of a substance resembling pumice-stone” (porous stones, therefore), this description may have been favoured by the very prevalent idea in antiquity, that all celestial bodies were fed by humid exhalations. The Sun “gives back that which he has sucked up” (*Aristot. Meteorol.* ed. Ideler, T. i. p. 509; *Seneca, Nat. Quæst.* iv. 2). The “pumice-like bodies” seen as shooting stars were also supposed to have their own exhalations. “These bodies, which cannot be seen so long as they wander about in space, are stones which kindle and then become extinguished, when they fall to the earth” (*Plat. de plac. Philos.* ii. 13). Pliny (ii. 59) believed that many meteoric stones fall—“*decidere tamen crebro, non erit dubium:*” he also knew that their fall, while the air is clear, is accompanied by a loud noise (ii. 43). The seemingly analogous passage of Seneca, in which he names Anaximenes (*Nat. Quæst.* lib. ii. 17), refers probably to the thunder from a storm-cloud.

(⁶⁹⁴) p. 423.—The remarkable passage in *Plut. Lys.* cap. 12, translated closely, is as follows:—“It is a probable opinion which was held by those who said that, shooting stars are not emanations or overflowings from the æthereal fire, which become extinguished in the air immediately after being kindled; neither are they produced by ignition and combustion of a quantity of air which has detached itself towards the higher regions; but rather they are heavenly bodies which fall or are cast down in consequence of an intermission, or irregularity, of the force of rotation, and are precipitated not only on inhabited countries, but also, and in greater numbers, beyond these, into the great sea, so that they remain concealed.”

(⁶⁹⁵) p. 423.—On absolute dark bodies, or bodies in which the luminous process ceases (periodically?); on the opinions of modern authorities (Laplace and Bessel); and on Bessel’s observation, confirmed by Peters at Königs-

berg, of an alteration in the proper motion of Procyon,—see *Kosmos*, Bd. iii. S. 267—269; Engl. edit. p. 182 and 183.

(⁶⁸⁶) p. 424.—Compare *Kosmos*, Bd. iii. S. 42—44, and 54, Anm. 17; Engl. edit. p. 33—35, and x. Note 63.

(⁶⁸⁷) p. 424.—The remarkable passage alluded to in the text (*Plutarch, de facie in orbe Lunæ*, p. 923), closely translated, is as follows:—“Yet the Moon is kept from (or helped against) falling, by its own motion, and by the impetuosity of its revolution, as things placed in slings are hindered from falling by being whirled round in a circle.”

(⁶⁸⁸) p. 426.—*Kosmos*, Bd. i. S. 126; Engl. edit. p. 112.

(⁶⁸⁹) p. 426.—*Coulvier-Gravier and Saigey, Recherches sur les Etoiles filantes*, 1847, p. 69—86.

(⁶⁹⁰) p. 426.—“Die periodischen Sternschnuppen und die Resultate der Erscheinungen, abgeleitet aus den während der letzten 10 Jahre zu Aachen angestellten Beobachtungen, von Eduard Heis” (*On Periodical Shooting Stars, and the Results derived from Observations of these Phænomena, made during the last Ten Years at Aix-la-Chapelle, by Edward Heis*), 1849, S. 7 and 26—30.

(⁶⁹¹) p. 426.—The assignment of the North Pole as a centre of radiation or point of departure of shooting stars in the August period, rests only on the observations of a single year, 1839 (10th of August). A traveller in the East, Dr. Asahel Grant, writes from Mardin, in Mesopotamia, that about midnight the sky was as it were furrowed by shooting stars, which all proceeded from the vicinity of the North Pole (Heis, S. 28, according to a letter from Herrick to Quetelet, and according to Dr. Grant's journals).

(⁶⁹²) p. 427.—This superiority of the point of departure in Perseus over that in Leo in respect to the number of shooting stars, was, however, far from shewing itself in the Bremer observations of the night 13 to 14 Nov. 1838. In a very rich fall of shooting stars, a very practised observer, Roswinkel, saw almost all the paths take their departure from the constellation of Leo and the southern part of Ursa Major; while, on the night of the 12th to the 13th of November, when the number of shooting stars was but little inferior, only four of their paths proceeded from Leo. Olbers (*Schum. Astr. Nachr. No. 372*) adds, very significantly: “The paths on this night shewed nothing of parallelism, and no reference to the constellation of Leo; and, on account of this absence of parallelism, they would appear to belong to the class of sporadic, not to that of periodic, shooting stars. The November phænomenon of this year could not indeed be compared in brilliancy to those of the years 1799, 1832, and 1833.”

(⁶⁹³) p. 428.—Saigey, p. 151; and on Erman's determination of the points of "convergence," diametrically opposite to the points of radiation or departure, Saigey, p. 125—129.

(⁶⁹⁴) p. 428.—Heis, *Period. Sternschn.* S. 6. (Compare *Aristot. Problem.* xxvi. 23; *Seneca, Nat. Quæst. lib. i. 14*: "ventum significat stellarum discurrentium lapsus, et quidem ab ea parte qua erumpit.") I myself long believed (and particularly while I was staying at Marseilles, at the time of the French expedition to Egypt) in the influence of wind on the direction of shooting stars.

(⁶⁹⁵) p. 429.—*Kosmos*, Bd. i. S. 395; *Engl. edit.* p. xxi.

(⁶⁹⁶) p. 429.—I am indebted for all the part of the text to which marks of quotation are appended, to the kind communications of Herr Julius Schmidt, Adjunct to the Astronomical Observatory at Bonn. On his earlier investigations, from 1842 to 1844, see Saigey, p. 159.

(⁶⁹⁷) p. 431.—Yet I saw myself, in the Pacific ($13\frac{1}{2}^{\circ}$ N. lat.), a considerable fall of shooting stars on the 16th of March, 1803. Two streams of meteors were also seen in the month of March, in China, 687 years before our era. (*Kosmos*, Bd. i. S. 133; *Engl. edit.* p. 118.)

(⁶⁹⁸) p. 433.—A fall of shooting stars quite similar to that of 1836, October 21, Old Style, of which the younger Boguslawski found the account in *Benesse de Horovic Chronicon Ecclesiæ Pragensis* (*Kosmos*, Bd. i. S. 133; *Engl. ed.* p. 118), is described in a discursive manner in the celebrated historical work of Duarte Nunez do Lião (*Chronicas dos Reis de Portugal reformadas, Parte i. Lisb. 1600, fol. 187*), but is there transferred to the night from the 22d to the 23d of October. Were two streams seen on different nights in Bohemia and on the Tagus, or may we not rather suppose that one of the two chroniclers was in error by a day? The following are the words of the Portuguese historian:—"Vindo o anno de 1366 sendo andados xxii dias do mes de Outubro, tres meses antes do fallecimento del Rei D. Pedro (de Portugal), se fez no ceo hum movimento de estrellas, qual os homões não virão nem ouvirão. E foi que desda meã noite por diante correrão todalas strellas do Levante para o Ponente, e acabado de serem juntas começarão a correr humas para huma parte e outras para outra. E depois descerão do ceo tantas e tam spessas, que tanto que forão baxas no ar, parecião grandes fogueiras, e que o ceo e o ar ardião, e que a mesma terra queria arder. O ceo parecia partido em muito spaço. Os que isto vião, houverão tam grande medo e pavor, que stavão como attonitos, e cuidavão todos de ser mortos, e que era vinda a fim do mundo."

(⁶⁹⁹) p. 433.—Still closer coincidences in point of time might have been

cited if they had been known ; for example, the streams of meteors observed by Klöden, at Potsdam, 1823, 12—13 Nov. ; by Bérard, on the Spanish coast, 1831, 12—13 Nov. ; and by Count Suchtelen, at Orenburg, 1832, Nov. 12—13. (Kosmos, Bd. i. S. 129, Engl. edit. p. 114 ; and Schumacher's *Astr. Nachr.* No. 303, S. 242.) The great phænomenon of the 11th and 12th November, 1799, described by Bonpland and myself (*Voyage aux Régions équinoxiales*, livre iv. chap. 10, T. iv. p. 34—53, éd. in-8vo.), lasted from 2 h. to 4 h. A.M. Throughout our entire journey through the forest region of the Orinoco, and as far south as the Rio Negro, we found that this extraordinary fall of meteors had been seen by the missionaries, and in some cases had been noted in their ecclesiastical records. It had also been seen and had astonished the Esquimaux in Labrador and in Greenland, as far as Lichtenau and New Herrnhut, in latitude $64^{\circ} 14'$. This phænomenon, which was visible in America at the same time at the equator and near the polar circle, was also seen in Europe by the Minister Zeising, at Itterstedt, near Weimar. The periodicity of the stream of St. Lawrence (10th of August) did not draw general attention until much later than the November phænomenon. I have collected with care all the accounts with which I am acquainted, of accurately observed and considerable falls of meteors of the 12th to the 13th of November, up to 1846. I find fifteen such falls:—in 1799, 1818, 1822, 1823, 1831, 1832, 1833, 1834, 1835, 1836, 1837, 1838, 1839, 1841, and 1846. All which differ more than a day or two—as Nov. 10, 1787, and Nov. 8, 1813—are excluded. This degree of periodicity, almost to a single day, is the more surprising, because bodies of such small mass are so easily liable to perturbation, and the breadth of the ring in which the meteors are imagined to be included may comprise several days of the Earth's course in its orbit. The most brilliant November streams have been those of 1799, 1831, 1833, and 1834. [Where, in my description of the meteors of 1799, it is said that a ball of fire had a diameter of 1° or $1\frac{1}{2}^{\circ}$, it should have been—1 or $1\frac{1}{4}$ diameters of the Moon.] This is the place for mentioning also the ball of fire which attracted the special attention of Monsieur Petit, Director of the Astronomical Observatory of Toulouse, and of which he has computed the revolution round the Earth. (*Comptes rendus*, 9 Août 1847 ; and *Schum. Astr. Nachr.* No. 701, S. 71.)

(⁷⁰⁰) p. 437.—Forster, *Mémoire sur les Etoiles filantes*, p. 31.

(⁷⁰¹) p. 438.—Kosmos, Bd. i. S. 131 and 405 ; Engl. ed. p. 116 and xxix.

(⁷⁰²) p. 438.—Kämtz, *Lehrbuch der Meteorologie*, Bd. iii. S. 277.

(⁷⁰³) p. 439.—The great fall of aerolites of Crema and the banks of the

Adda has been described with great liveliness, but unfortunately in too rhetorical a manner, and with a great want of clearness, by the celebrated Petrus Martyr, of Anghiera (*Opus Epistolarum*, Amst. 1670, No. cccclxv. pag. 245—246). The fall of stones was immediately preceded by an almost total obscuration of the Sun at noon, on the 4th of September, 1511. “*Fama est, Pavonem immensum in aërea Cremensi plaga fuisse visum. Pavo visus in pyramidem converti, adeoque celeri ab occidente in orientem raptari cursu, ut in horæ momento magnam hemisphæri partem, doctorum inspectantium sententia, pervolasse credatur. Ex nubium illico densitate tenebras ferunt surrexisse, quales viventium nullus unquam se cognovisse fateatur. Per eam noctis faciem, cum formidolosis fulguribus, inaudita tonitrua regionem circumsepserunt.*” The temporary illuminations were so intense as to enable the inhabitants round Bergamo to see the whole plain of Crema during the darkness which otherwise prevailed. “*Ex horrendo illo fragore quid irata natura in eam regionem pepererit, percunctaberis. Saxa demisit in Cremensi planitie (ubi nullus unquam æquans ovum lapis visus fuit) immense magnitudinis, ponderis egregii. Decem fuisse reperta centrilibralia saxa ferunt.*” Birds, sheep, and even fish, were killed. Among all these exaggerations, we can still recognise that the meteoric cloud from which the stones fell must have been of uncommon blackness and density. The “*Pavo*” was doubtless a ball of fire with a train or tail both wide and long. The tremendous noise issuing from the meteoric cloud is here described as the thunder accompanying the lightnings (?). Anghiera received himself, in Spain, a fragment the size of a man’s fist (*ex frustis disruptorum saxorum*), and shewed it to the King, Ferdinand of Arragon, in the presence of the celebrated warrior, Gonzalo de Cordova. His letter concludes with the words “*mira super hisce prodigiis conscripta fanaticæ, physicæ, theologicæ ad nos missa sunt ex Italia. Quid portendant, quomodoque gignantur, tibi utraque servo, si aliquando ad nos veneris*” (written from Burgos to Fagiardus). Cardanus, speaking still more precisely (*Opera*, ed. Lugd. 1663, T. iii. lib. xv. cap. 72, p. 279), states that there fell 1200 aerolites, and that among them was one weighing 120 pounds, very dense, and of a blackness like that of iron. He also says that the noise lasted two hours: “*ut mirum sit, tantam molem in aëre sustineri potuisse.*” He takes the ball of fire with a tail or train for a comet, and makes the mistake of a year in the date of the phenomenon: “*Vidimus anno 1510.....*” Cardanus was between nine and ten years old when it occurred.

(704) p. 439.—Recently, in the fall of aerolites at Braunau (July 14, 1847), the masses of stone which fell were, six hours afterwards, still so hot that

they could not be touched without burning the hand. I have already treated, in my *Asie centrale* (T. i. p. 408), of the analogy presented by the Scythian myth of "the sacred gold" to a fall of meteors. "Targitao filios fuisse tres, Leipoxaiu et Arpoxaiu, minimumque natu Colaxain. His regnantibus de cœlo delapsa aurea instrumenta, aratrum et jugum et bipennem et phialam, decidisse in Scythicam terram. Et illorum natu maximum, qui primus conspexisset, propius accedentem capere ista voluisse; sed, eo accedente aurum arsisse. Quo digresso, accessisse alterum, et itidem arsisse aurum. Hos igitur ardens aurum repudiassse; accedente vero natu minimo, fuisse extinctum, huncque illud domum suam contulisse: qua re intellecta, fratres majores ultro universum regnum minimo natu tradidisse" (Herodot. iv. 5 and 7, according to the version of Schweighauser). But perhaps the myth of the sacred gold may be only an ethnographical myth, containing an allusion to three king's sons, ancestors or founders of three tribes of Scythians (?), and to the pre-eminence attained by the tribe of the youngest son, or that of the Paralati (?) (Brandstätter, *Scythica, de aurea caterva*, 1837, p. 69 and 81).

(705) p. 441.—Of metals, there have been discovered in meteoric stones,—nickel by Howard, cobalt by Stromeyer, copper and chrome by Laugier, and tin by Berzelius.

(706) p. 442.—Rammelsberg, in Poggendorff's *Annalen*, Bd. lxxiv. 1849, S. 442.

(707) p. 445.—Shepard in Silliman's *American Journal of Science and Arts*, 2d series, Vol. ii. 1846, p. 377; Rammelsberg, in Poggend. *Ann.* Bd. lxxiii. 1848, S. 585.

(708) p. 445.—Compare *Kosmos*, Bd. i. S. 135; Engl. edit. p. 120.

(709) p. 446.—*Zeitschrift der deutschen geolog. Gesellschaft*, Bd. i. S. 232. All those parts in the text, between p. 442 and p. 445, which are distinguished by marks of quotation, are taken from Professor Rammelsberg's manuscripts of May 1851.



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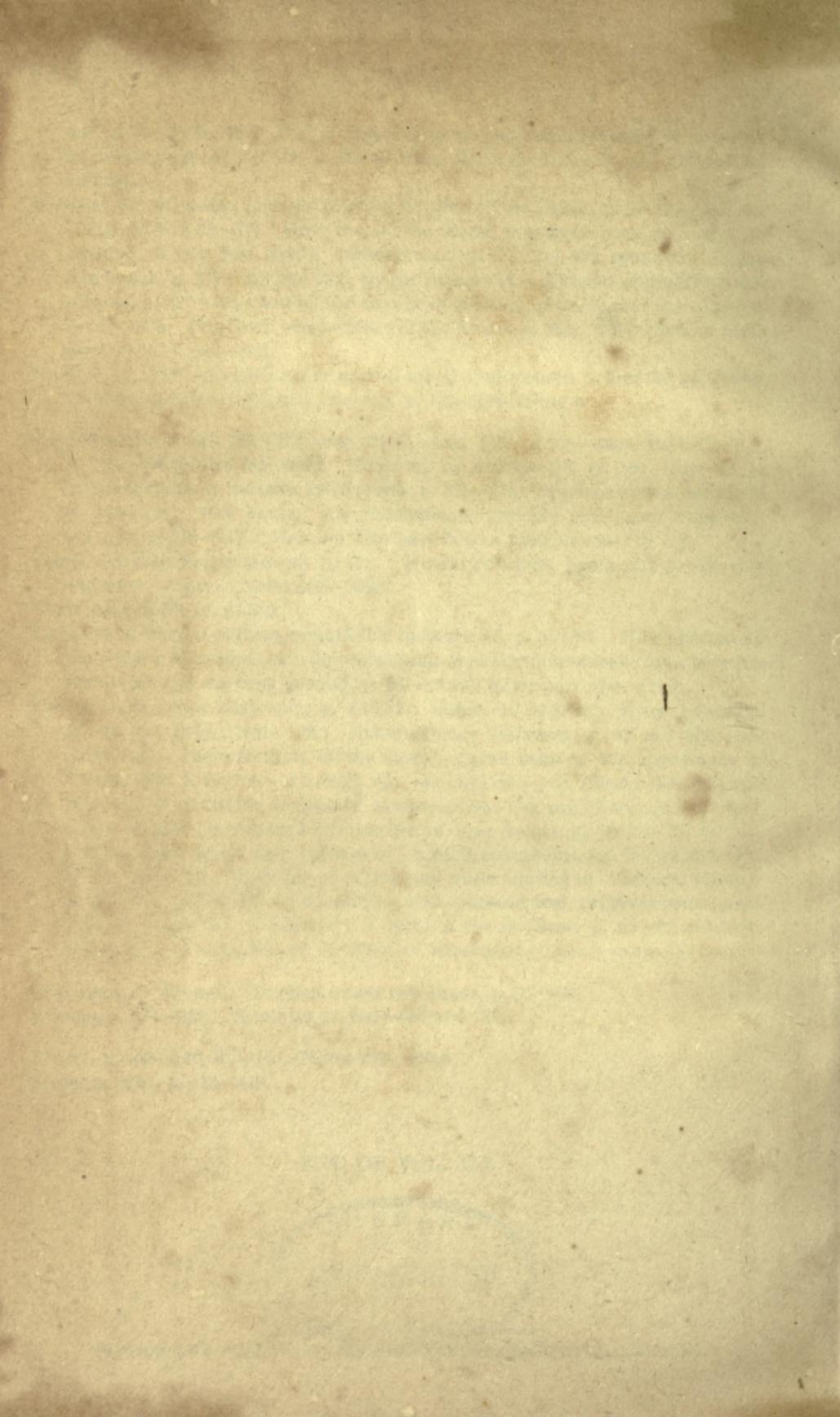
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