A CYCLE OF CELESTIAL OBJECTS,

Pamphlets

FOR THE USE OF NAVAL, MILITARY, AND PRIVATE ASTRONOMERS.

OBSERVED, REDUCED, AND DISCUSSED

BY

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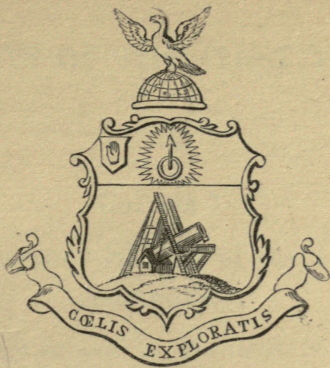

TO

SIR JOHN FREDERICK WILLIAM HERSCHEL, BART.,

&c. &c. &c.

AS A TESTIMONY OF THE HIGHEST ADMIRATION AND ESTEEM;
A MEMORIAL OF LONG-CONTINUED FRIENDSHIP;
AND A GRATEFUL ACKNOWLEDGMENT OF IMPORTANT ADVICE
IN THE PURSUIT OF PRACTICAL ASTRONOMY:

AND AS A HEART-FELT TOKEN OF RESPECT FOR THE MEMORY OF
HIS EXCELLENT FATHER—WHOSE INDEFATIGABLE ZEAL,
NEVER-FAILING RESOURCES, DEPTH OF INQUIRY,
AND ALMOST UNRIVALLED QUICKNESS OF
CONCEPTION, HAVE RENDERED
HIS LIFE AN ERA IN
ASTRONOMICAL
SCIENCE—

THIS CYCLE OF CELESTIAL OBJECTS

IS MOST RESPECTFULLY INSCRIBED,

BY HIS FAITHFUL FRIEND,

WILLIAM HENRY SMYTH.

CONTENTS OF THE FIRST VOLUME.

CHAPTER V.

Notanda on the Bedford Catalogue.

Appendix.

ILLUSTRATIONS AND DIAGRAMS.

VOLUME I.

ILLUSTRATIONS AND DIAGRAMS.

VOLUME II.

PROLEGOMENA.

CHAPTER I.

AN INTRODUCTORY SKETCH OF THE PROGRESS OF ASTRONOMY.

THE heavens declare the glory of GOD, and the firmament showeth His handiwork.

UNDER this somewhat startling title, the reader is not about to be inflicted with a detailed history of astronomy: it is only intended to place before him, a condensed introduction to the present conditions of the science, in fact—a reminder. It is in the heavens that the Sovereign Wisdom manifests order and harmony, regularity and proportion, greatness and majesty, arrangement and destination, in astounding immensity: and it is in the heavens that the *amateur* is to gather the practical results of his studies. Now, as the development of the wonderful mechanism there exhibited, apparently so baffling to reason, is due to the genius and perseverance of both theoretical and practical astronomers, a rapid sketch of their services, with the most correct ascertainable dates, may be a proper prelude to the matters and opinions hereinafter delivered.

Astronomy, the name generally applied to the laws by which the motions of the heavenly bodies, as well as of the earth, are regulated, is the most exalted and advanced pursuit of the human mind, and the noblest record of the perseverance of its intellectual powers. The study of the celestial motions claims pre-eminence as a science of theory and practice, of calculation and prediction; by extracting laws from what has occurred, and applying those laws to phenomena which must again occur. It is, in fact, almost the only branch of natural knowledge, in which effects are completely subjugated to causes, and consequences are clearly foretold. This "boast of reason" differs from other natural sciences, in that its whole foundation is purely mathematical, and demonstrative of the precise mechanism of inanimate and inert matter; and its high value consists in its being, not the mere knowledge of a collection of isolated facts, but a perfect theory, by which those facts are compacted into one study. It differs from many pursuits of human wisdom, inasmuch as observation has given birth, tutelage, and perception to theory; but those who cannot surmount the difficulties of the higher analytics, must take much for granted, and rest satisfied with the justness of the conclusions, however incomprehensible the method which leads to them may appear. Based, as it were, upon its own revenues, and increased by the contributions of other sciences and arts, Astronomy has arrived at its present excellence. The very word is a most comprehensive term through all its bearings, and the more this science is cultivated, the more is the supremacy of man over the brute creation verified; for its higher walks demand scrupulous observation, accurate reduction, strong exercise of thought, deductive reasoning, and, indeed, a more varied and assiduous application of the eye and brain than any other pursuit, to say nothing of that important "organ of all organs," the hand.

The greatest men of all ages have pronounced this science, to be the most sublime and surpassing of all that can be tested by human genius, and to be worthy of a life of study: yet there are still people, aye, and we fear some of them are in high places, who ask,—"Of what use is astronomy?" "Are there material as well as intellectual results?" Now albeit such questions may not be really worthy of a reply, it can be stated that this noble pursuit regulates the times, seasons, and proportionate parts of the year—that by its aid we find the form, mass, and magnitude of the planetary bodies—the figure and geographical details of our own globe, with a standard for its weights and measures—and that navigation owns it as the great and only accurate guide in conducting ships over the trackless ocean, and thereby establishing a correspondence between distant nations. This was well expressed by La Caille, himself one of the most skilful observers of the heavens, in these terms: "L'astronomie est l'arbitre de la division civile du temps, l'ame de la chronologie et de la géographie, et l'unique guide des navigateurs." A knowledge of astronomical principles has always been considered so essential to seamen of skill, that it is hardly conceivable that ignorance of them could be for a moment tolerated, much less defended, in any of the nautical classes. Nevertheless, it is certainly true, that in our enlightened age, and in this nursery of sailors, some are to be found, who, without expressly denying the use of scientific knowledge to practical men, do indirectly discourage its cultivation.

Independently, however, of its mechanical uses, the department of Urania is entitled to the strict regard of the educated classes, as furnishing the most exquisite proof of what the human intellect is capable. By it the mind is elevated to the consideration of orbs and objects which are undeniably the most conspicuous, the most beautiful, and the most important that can engage its powers: and while improving the understanding, it captivates the imagination. In a word, to astronomy are unveiled spaces and magnitudes of infinite extent, motions and forms of incomprehensible grandeur, and order and harmony of unspeakable sublimity. The philosopher, baffled with speculation on viewing the endless variety of divine effects, applies with awe and wonder to the investigation of what is reducible to certainty, in order the better to estimate the astonishing appropriateness of each of the myriads of parts which constitute the stupendous and inconceivable whole: and man is the more favoured by his beneficent Maker, in being permitted to attain and enjoy this gleam of heavenly glory.

Although the accumulated mists of ages obscure the rise of this science, there can be little doubt of its having been nearly coeval with the world, when the Word said, "Let there be lights in the firmament of the heavens, to divide the day from the night; and let them be for signs, and for seasons, and for days, and for years." Gassendus finely imputed the origin of astronomy to admiration; and it is easy to conceive that the contemplation of the celestial bodies must have been among the first of man's excitements to mental delight. But while its antiquity is thus carried to the very creation, its exact history is only to be traced by gleams through the darkness in which it is involved. The division of time seems to have been the first effort of formal application, and the alternating of day and night gave an obvious scale; the remarkable variations in the form of the moon, in regular recurrence, would then become indices for the division of time into periods exceeding those marked out by the intervals between the sun's rising and setting; and this is still the principal almanac of some of the nomade tribes of the East. The Chaldæans, a pastoral people, are considered to have been the first who successfully cultivated the *science* of astronomy; and the Babylonian observations, transmitted to Aristotle by Callisthenes, are placed about B.C. 2250*. From thence it is held to have spread into Egypt, and the Phœnicians were the first who applied it to navigation: other writers, however, and ingenious ones too, claim these honours for the Chinese, and the Hindús. The pretensions of the celestial empire are sufficiently slight; for though the Chinese records are said to go back to nearly 3000 B.C., Sir G. Staunton informs me that the eclipses and comets mentioned in the works of Confucius and elsewhere, are merely announced as facts; and that, as far as he understands, their observations were confined to noting merely the time when the more palpable phenomena occurred. A conjunction of Mars, Jupiter, Saturn, and Mercury, in the constellation *Shi*, was assumed as an epoch by the Emperor Chwen-hio; and M. Bailly found that the conjunction must have happened on February 28, B.C. 2449, between *a* Arietis and the Pleiades. The principal mathematicians were held more responsible than in these degenerate days, since it is recorded, that in the reign of the worthy Emperor Chou-kang, his two chief astronomers, *Ho* and *Hi*, were condemned to death, on account of their neglecting to announce the precise time of a solar eclipse, which took place B.C. 2169. Laplace speaks confidently of

* The three well-known lunar eclipses observed at Babylon in the reign of Mardocempadius, happened: I. 19th March, 720 B.C.; II. 8th March, 719 B.C.; III. 4th September, 719 B.C. The longitudes of the stars Regulus and Cor Hydræ are said, in the *Iessod olam*, to have been ascertained 1985 years before the time of Ptolemy; the story, however, is questionable. But the longitude of Aldebaran soars still higher: Mr. E. Bernard, in the *Philosophical Transactions* for 1684, gives it 25° 17′ ♓, or above 3000 B.C., as settled by the "thrice great" Thoth, Hermes, or Mercurius Trismegistus, of Egypt.

Chinese observations B.C. 1100, when the length of the shadow of a gnomon at Layang was found to be equal to one foot and a half, the gnomon itself being eight feet in length. But it is difficult to establish any of their scientific claims, till the astronomer Kosheou-kieu made good observations, and introduced spherical trigonometry A.D. 1280. Yet it may be admitted that the motions of the planets were known to them, and that they had the Metonic and Calippic periods. But the precession of the equinoxes only reached them about A.D. 400. The Hindu claim to antiquity stands on higher ground, as a curious but involved historical problem; and without joining the partizanship of either Bailly or Delambre, Playfair or Leslie, I cannot but be somewhat influenced by the learning and sagacity of Sir William Jones; the science and judgment of my friend Mr. T. C. Colebrooke, late president of the Astronomical Society; the persevering spirit of inquiry of Mr. Davis; and the talents of Schlegel. The epoch claimed for the conjunction of the planets, as the opening of their tables of Trivalore, in the beginning of the Kali-yuga, the present Iron or corrupt age, (17th February, B.C. 3102,) may be fanciful enough; but the result of much research leads me to respect the antiquity of the *Súrhya Siddhánta*, the *Viga Ganita*, the *Siddhánta Sphuta*, and the *Brahma Siddhánta*, against which Mr. Bentley has chosen so rabidly to run *ámuk*. About a couple of centuries ago, the literati of Europe were equally amused and irritated at the monomaniac absurdities of Hardouin, who, poor man, asserted that all the writings attributed to the classical ancients, with some few exceptions, were supposititious, and the fabrications of a monk in the thirteenth century. So in our day, with an equally reckless intrepidity of assertion, Mr. Bentley steps forth to shew that the Hindú works are wholesale forgeries; and all who discredit his senseless theory are calumniators, conspiring to overturn the Mosaic account. But his own argument to prove that the Brahmanical Tables must have been constructed at the time when they represented the state of the heavens, was well upset by Mr. Colebrooke, in showing from Bentley's own instance of a certain set of existing Tables, that they must have been written fourteen hundred years hence! On the whole, we must allow that the early Hindús applied intensely to the pure sciences, since they could compute the mean motions and true places of the planets, and calculate lunar and solar eclipses; they understood the astronomical sphere and its circles, suspected a libration of the equinoctial points, had a glimpse of geometry, were expert in instrumental observations, and enriched science with those powerful organs—arithmetic and algebra. Dropping Mr. Bentley astern, it may be summed up, that the various discussions have been ably argued, and some of the details are still far from being definitively settled: although there is no question that astronomy was in a very advanced state in the East, its exact history must yet be commenced with that extraordinary people the Greeks; who seem, unquestionably, to have received their first instruction from the Egyptians.

Before, however, we quit the *inferential* field, a few words may be added. Strong symptoms of doubt upon the exact magnitude of our scientific debt to the Grecians, and the reason for so questioning it, may frequently appear in these pages. Passing, for the present, the 15,000 years of the Egyptian planispheres, it seems obvious on consideration, that a much earlier astronomy prevailed than even the Egyptian or Chaldaic, whence so many assume their starting point; the usual age given to the celebrated Babylonian observations sent to Aristotle*, being more than 4000 years. That the Jews had a knowledge of the zodiac 5400 years ago, has had more than one strenuous assertor. In the first chapter of Genesis, 14th verse, the uses of the heavenly bodies with regard to the earth, are considered to be set forth: they were for signs of the progress of the seasons, by the sun's apparent path through the zodiac: they were for seasons and years, by means of the earth's annual revolution round the sun: and they were also for days, by means of the diurnal revolution of the earth round its own axis. In Joseph's dream, the sun, moon, and eleven asterisms bow down to him, the twelfth; and the allegorical images of Jacob's blessing have

* Callisthenes is thought to have obtained his information from the College of Priests attached to the temple of Belus. This is the man, for whose diabolical treatment Alexander, great as he was, ought to have been scourged, hung, drawn, and quartered.

been identified by several writers with the signs of the Via solis, whence God—as bow-man—becomes Sagittarius. Hebrew antiquaries have long recognised Enoch as the inventor of the Dodecatemory divisions; and both Berosus and Josephus declare that Abraham was famous for his celestial observations: but the claims of Jewish philosophy aim still higher. From the sublime description of the primæval cosmogony, contained in the first chapter of Genesis, it is contended that light existed before the creation of the sun*; and there are Hebrews who are anxious to claim this miracle as the basis of the Newtonian doctrines. According to their argument, the attentive inquirer discovers the creation of primitive light pre-existent to its present source of *emanation*, but not of *existence*—the sun; into which, on the fourth day, this primitive light was collected: "he finds," say they, "the existence of day and night previous to the creation of the sun as a luminary: and, in answer to the inquiry of how this was effected, he discovers that it could have been accomplished in no other way than by the revolution of the earth, caused by the first impulse of motion given to it by the Divine Spirit: and he will thus discern that the revolution of the earth, and not that of the sun, was considered by the ancient Jews, as by the Newtonian philosophers, to be the cause of day and night. The fact that we have gained from the previous examination is, that the earth revolved; but if we proceed a little further, we shall perceive in what manner this is performed. 'And the *evening* and the *morning* was *one* day;' thereby informing us that the course of this revolution was from evening, place of sun-setting, or *west*, to morning, place of sunrise, or *east;* and thus clearly pointing out to us the revolution of the terrene globe from west to east." There is a notable difference between this extraordinary, though fanciful, claim

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* It is worthy of note, that Halley is here a champion of the book of Genesis. In mentioning that nebulæ, or lucid spots, shine by their own proper lustre, he says: "This seems fully to reconcile that difficulty which some have moved against the description Moses gives of the creation, alleging that light could not be created without the sun. But in the instances of nebulæ the contrary is manifested; for some of these bright spots discover no sign of a star in the middle of them; and the irregular form of those that have, shews them not to proceed from the illumination of a central body."

upon Newton, and the ravings of the lately redoubtable Richard Brothers, against all who doubt the immobility of the earth. This "divine theorist," as his school calls him, asserts that there is no earth but this we live on, no sun but the one we see plainly, and no people but ourselves; the earth is at rest, but the sun is in motion; the earth is larger than the sun, and the sun larger than the moon. He also declares, that if the Copernican system be true, "God would appear a designing liar, the first chapter of Genesis false, and the whole Scripture a contemptible imposition." Yet has this gross blockhead even now a tail of admirers and followers!

Thales of Miletus, who founded the Ionian school about B.C. 600, is considered as the first person who propagated any truly scientific knowledge of astronomy; and from the undoubted fact, that the elements of the solar and lunar motions had been ascertained with precision long before any observations are known to have been made by the Greeks, it is inferred that he acquired his knowledge in Phœnicia or Egypt. He taught his countrymen the movements of the sun and moon, whence he explained the inequality of the days and nights, and the determination of the solar year; and he showed to the Greek sailors, who only knew how to observe the Great Bear, how much more sure a guide the Polar-star is to the mariner*. He divided the heavens into five zones, and was acquainted with the true cause of eclipses; even predicting one that occurred during a battle between the Medes and Lydians. This interesting phenomenon has been ably and elegantly discussed by my friend, Mr. Francis Baily†, who took the pains to calculate all the solar eclipses that were likely to have been visible in Asia Minor, from the year 650 to 580 B.C., and ultimately decided upon that which happened on the morning of the 30th September, 610, as the one mentioned by Herodotus.

Anaximander was a disciple of Thales, and succeeded him

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* As obviousness to the sight is a condition requisite in a nautical *lode-star*, we cannot look to that which was then nearest the Pole as the one used by the Phœnician mariners; but α Ursæ Minoris must have been a prominent object, therefore it may have been assumed as the polar guide.

† *Philosophical Transactions,* 1811.

as head of the school of Miletus, about B.C. 548. He is said to have had some idea of the earth's axial movement, and he distinctly asserted its sphericity; whence he invented globes, and is considered to be the first who constructed maps and charts. He taught that the moon shines by a light reflected from the sun; and he erected a gnomon at Sparta, that enabled him to observe the times of the solstices and the equinoxes with tolerable precision. Aristagoras, prince of Miletus, must have profited by Anaximander's progress in geography; for, in his noted attempt to bribe Cleomenes, Herodotus says that he appeared before the king of Sparta with a tablet of brass in his hand, upon which was inscribed "every part of the habitable world, the seas, and the rivers."

Pythagoras, who founded the school of Croton some time about B.C. 500, greatly enlarged the science, and sketched all the grand views on which it at present reposes, by sagacious conjectures based upon geometrical deductions; but it is unfortunate for an accurate knowledge of what he did, that his works are lost. Seconded by his earliest scholars, he clearly demonstrated, from the varying altitudes of the stars by change of place, the spherical shape of the earth, at which Anaximander had only guessed: and there are various evidences to show that, about this time, the notion of the earth's being suspended *in equilibrio*, and supported by the air, was widely prevalent; or, as Socrates says in Plato's *Phœdo*, that it is wrapped about and pressed equally in every direction by the universe. It was Pythagoras who first gave substance to the floating idea of Apollonius Pergæus, that the sun was fixed in the centre of the planetary orbits, and that the earth moved round it with the other planets; who taught, in fact, the system which now immortalizes the name of Copernicus. But these were the conjectures of a sagacious mind, not possessed of the evidence requisite to give stability to its opinions. It was fortunate that Pythagoras escaped the persecution of ignorance and fanaticism which attended genius even in free and enlightened Greece; for he was not only guilty of those heterodox notions, but also broached the doctrine of a plurality of worlds, and the music of the spheres. It was he who first conceived the bold idea that the planets are inhabited, and that the myriads of stars which stud the immensity of space, are so many suns destined to afford light and heat around them. His sagacity detected that Venus was the morning and evening star: and he divided the universe into twelve spheres. It is moreover asserted, that he saw in comets, which all the world then held to be mere atmospheric meteors, permanent stars revolving round the sun under peculiar laws. All this points him out as an extraordinary philosopher for his era; and,—together with his great geometrical discovery, that the square of the side which subtends the right angle of a triangle is equal to the sum of the two squares of its remaining sides,—amply relieves his reputation from the tinge of *charlatanerie* which his dreams about music, his monads, his beans, his pretended recollections of his own transmigrations, and even portions of his *teetotalism*, gave rise to. Such a man ought not to have perished from hunger in his old age.

Anaxagoras shortly afterwards was banished for impiety in robbing the sun of its divinity, by pronouncing it to be a mass of fiery matter, and teaching that the moon under eclipse, was capable of being affected by the earth's shadow, a portion of the universe so much less noble: indeed, it was only the interposition of Pericles that saved his life. He was the first who wrote on the phases of the moon, and her rotatory motion about the earth; and he made sound conjectures with regard to the Via Lactea. Democritus maintained, so far back as B.C. 450, that more planets would be discovered.

Practical astronomy appears to have been but little indebted to either the Ionian or Crotoniate schools, though brilliant conceptions and gleams of light were elicited. The measuring of time being a principal object even in their primitive method of observing, many efforts were made by the ancients to determine accurately, and to compare and reconcile with each other, the motions of the sun and moon, on which this measure universally depends. They accordingly applied themselves to the study of this subject with great industry; and by combining all the observations then known, formed a luni-solar period, or cycle of nineteen years, or rather, 6940 days. The honour of this period has been claimed for Euctemon, Philippus, and Numa Pompilius; but the best authorities ascribe the invention to Meton the Athenian, whose name it bears. The Metonic cycle was published at the general meeting of the Greeks, assembled for the celebration of the Olympic games; and it was received with so much applause, that a statue was decreed to the inventor, and he was declared victor in the first order. The scheme of the festivals, arranged according to the new cycle, was publicly proposed, inscribed on a marble pillar in letters of *gold;* and hence the number which expresses the order of the current year in that cycle, is still called the Golden Number. The Greeks denominated it *Ἑννεακαιδεκαετηρὶς*, *Enneacaidecaetéris*, from considering that, at the end of each cycle, the same lunations would not only return on the same days, but precisely at the same hour and minute of the day; this, however, is not absolutely the case, for the lunation falls only within an hour and a half of the same time. An interval, therefore, of 6940 days is neither exactly equal to 19 tropical years, nor to 235 lunations; it exceeds the former by about $9\frac{1}{2}$ hours, and the latter by $7\frac{1}{2}$ hours. In about four cycles these errors would accumulate to more than a day; consequently, the several phases of the moon, which are very remarkable appearances, would be really observed to happen a day sooner than the time computed by the calendar. To remedy this defect, Calippus, who lived about a century after Meton, introduced the improvement known by his name; and which, by a proemptosis, or leap, of a day in four periods, anticipates the full moons by only 5^h 53^m in seventy-six years.

As this was a principal feature in the improvement of astronomy, and the first acquisition of a tolerably accurate knowledge of the mean motions of the sun and moon, it should be added, that the Metonic cycle was adopted on the 16th of July, in the year B.C. 433; and the new moon which happened at 7^h 43^m P.M. was the precise era of its commencement. The first day was reckoned from sunset.

The motions of the heavenly bodies were more obvious to the senses than their magnitudes, so that the ancient approximations were of the rudest stamp. The Egyptians are said to have considered the diameter of Saturn as being double that of the moon, and the diameter of the sun as half the sum of the other two diameters. Plato, in the *Epinomis*, evidently considers that the planets had been demonstrated to be of a vast size; from which, and from their periods of revolution, he infers that the deity is the cause of their motions.

Eudoxus of Cnidus, who died about B.C. 368, was particularly distinguished for his knowledge of the astronomy of the time, and is said to have established an observatory. He estimated the lunar month at $29^d\ 12^h\ 43^m\ 38^s$, introduced the year of $365\frac{1}{4}$ days, invented a complicated set of concentric spheres to show the rising and setting of the heavenly bodies for the climate or region of Greece, and wrote some scientific works. Of the latter, the *Φαινόμενα*, *Phænomena*, still exists in the poetical version of Aratus, who *published* it nearly a century after the death of Eudoxus, by order of Antiochus, king of Macedon. This is a truly valuable relic, especially as the works of Archytas, Aristotle, and Eudemus, on astronomy, are lost; and strong doubt is abroad as to the *Golden Verses* on the sphere, attributed to Empedocles, B.C. 450. The versatile genius of Aristotle was directed as well to the practical as to the theoretical branches of the science, and an occultation of Mars by the moon, and one of a star by Jupiter, were observed by him about 357 B.C.* This great and extraordinary philosopher attempted to approximate to the figure and size of the earth by astronomical observations; deriving proofs of its sphericity from the appearance of the circular shadow which it projects on the disc of the moon in eclipses, as well as from the unequal elevation of the solar meridian in different latitudes; and inferring from the same conditions, that the globe is not a very large one. He introduced the celebrated principle of nature's abhorrence of a vacuum.

The first who taught the classification of climates according to the length of days and nights, was Pytheas; who measured the latitude of Marseilles so far back as B.C. 330, by observing the length of the meridian shadow of the sun, at the time of the summer solstice, by a gnomon: this he considered as equal both

* An occultation of Saturn is recorded by Ptolemy—*Almagest*, l. xi.—as having been observed in the year 228 B.C.

at Marseilles and Byzantium, but the difference in their latitudes is $2°\frac{1}{4}$. This philosopher travelled to various parts of the globe, for the purpose of observing the phenomena of nature; and his Ultima Thule, where he saw the sun touch the northern side of the horizon on the day of the summer solstice, is conjectured to be Iceland. It was he who discovered that the Polar-star was not precisely at the pole itself; and he pointed out the coincidence of the tides with the motion of the moon. Practice was now advancing. Timocharis and Aristyllus, about 300 B.C., made those important observations of the positions of the stars with regard to the equator, and the equinoxes, which afterwards enabled Hipparchus to discover the slow and almost insensible motion of the latter *in antecedentia*, now called the precession. The celebrated Euclid, whose geometrical *Elements* have been so universally employed in all sound instruction, produced an astronomical work entitled *Phænomena*, treating of the visible movements of the heavenly bodies. About the same time, Autolycus published another elementary book on the science. Aristarchus of Samos, (B.C. 280,) notwithstanding Delambre's severity in thinking it unfortunate for the Samian's fame that his works have descended to us entire, was a very sagacious astronomer. He made the first attempt to measure the relative distances of the sun and moon, by observing their angular distance at the time of half-moon; and his method of determining the ratio, though not very accurate, is yet ingenious. He also was one of those who maintained the stability of the sun; a doctrine which nearly proved fatal to him, as he was publicly accused of impiety to the gods, and disturbing their peace.

The school of Alexandria, deservedly conspicuous in pursuit of the sciences, had made so close an alliance between astronomy and geography, that the latter became a real science. Thus, while they made observations with trigonometrical instruments, for determining the positions of the stars and the course of the planets, the measure of the earth upon geometrical principles was not neglected. Apollonius of Perga abandoned the homocentric system of planetary motions, and introduced the epicycles and their deferents, which implies a knowledge of the apsides, stationary points, and the extents of the arc-movements. Eratosthenes, of Cyrene, librarian of the Alexandrian Museum, about 240 B.C., was so pre-eminent in science, that he was styled the Father of Chronology, the Cosmographer, and the Measurer of the Universe. He made use of the celebrated armillary spheres, which he erected in the portico at Alexandria, and which remained standing till the time of Ptolemy. Assuming the latitude* as equal to 30° 58′, he observed the obliquity of the ecliptic, making it 23° 51′ 50″, which, all things considered, is a very surprising result. He compiled and published the *Catasterisms*, an enumeration of 475 of the principal stars, according to the constellations to which they belong. He also attempted the arduous task, of determining the circumference of the globe by an actual measurement of one of its great circles, making his computation upon the whole by uniting certain accurate observations made in the heavens, with a corresponding distance carefully surveyed in a north and south direction on the earth. The segment of the meridian which he fixed upon for this purpose was that between Alexandria and Syene. He had been informed, that, on the day of the summer solstice, the sun was vertical at noon in the city of Syene, on the borders of Ethiopia, under the tropic of Cancer. A well is particularly mentioned as having been illuminated to the bottom by the sun at noon on the solstitial day. He assumed that Alexandria and Syene were both under the same meridian; and from these data, by means of a concave hemisphere, with a stile fixed in its centre, he found that the shadow of the meridian sun caused by the stile at Alexandria, was one-fiftieth of the whole circumference. Hence he inferred, that the arc of the heavens comprised between Alexandria and Syene must be the same; and that the distance between the two cities must likewise be a similar arc, or one-fiftieth part of the circumference of the earth.

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* My own observations, made on Point Eunostos, in 1822, gave the latitude 31° 11′ 31″ north; the longitude 29° 51′ 58″ east of Greenwich; the magnetic variation 11° westerly, and the dip of the needle 59° 45′. I also ascended the column called Pompey's Pillar, to take a round of theodolite angles; on this occasion I observed the sun's meridian altitude with an artificial horizon, from the summit, as being probably close to the very spot where Eratosthenes made his observations. The result obtained for the latitude was 31° 09′ 49″; but the mercury was much agitated.

On measuring this distance, by observing the difference of latitude between the two places, he found it to be 5000 stadia, which gave 250,000 stadia for the circumference of the earth. As there were different stadia then in use, it is not well ascertained how many feet his stadium contained. If it was the Egyptian stadium, this measurement exceeds the modern measures by a sixth part: as the principle of the method employed is the same in both, the greater accuracy of our results is chiefly due to the improved construction of the necessary instruments*. About the same time, Archimedes of Syracuse observed the solstices, constructed an ingenious planetarium, and attempted to measure the sun's diameter: his *forte*, however, lay in the mathematical investigations of mechanical dynamics.

At length, about a century and a half before the Christian era, Hipparchus appeared; and of all the ancient astronomers, no one so largely enriched the science, or acquired so great a name as he. This "truth-loving" astronomer commenced his Uranian services by writing a commentary on Aratus, when a youth; and one of his first cares was to rectify the year, which before his time was made to consist of 365 days 6 hours; and this he found to be a little too much: he determined the length of the tropical year with a precision not previously attained, and came within four minutes and a half of the real time. He determined the mean motion of the sun and its apogee, and found that the sun was longer in traversing the six northern signs of the ecliptic than the other half of it; and deduced from this the ex-centricity of the solar orbit. He also made a similar

* Nouet, astronomer to the French expedition under Bonaparte, measured the arc between Alexandria and Syene, making it $= 7° 24'$, and obtaining 56,880 toises to the degree. He also considered the Egyptian stade as equal to 711 French feet, and the Greek stade as being 487 $\frac{543}{1000}$ feet; but, says Delambre, "malheureusement ses conclusions étaient un peu hypothétiques." The well at Syene is a knotty puzzle; the mention of it in history is too respectable to admit of disbelief,—but whether it were within or without the tropic is a paradox. Strabo believed it to be within, but Mr. W. R. Hamilton searched for it in vain. Bruce gave $23° 28'$ as the latitude of Es-souan (*Syene*), while Nouet placed it in $24° 8' 6''$, and M. Coulier registers it $24° 5' 23''$. Such discrepancies among the talented moderns, would perhaps have made even the ancients smile.

scrutiny into the motions of the moon, her nodes, and her apogee; her parallax, ex-centricity, the equation of her centre, and the inclination of her orbit; and his inquiries led him to suspect another inequality in the moon's motion, the evection. He was the first who constructed regular tables; who employed processes analogous to those of plane and spherical trigonometry; and who suggested the application of this science to familiar purposes of every-day use in geography, by determining the situation of places by their latitudes and longitudes, from a first meridian referred to the Fortunate or Canary Isles. He calculated eclipses, and used the results in improving the elements; and he substituted a more complete mode of measuring the ratio of the distance of the sun and moon from the earth, than the one given by Aristarchus: he made use chiefly of parallaxes, which is the method now in use. On the disappearance of a large star from the heavens, or, as others have it, having observed a new one, he began to question whether there might not be changes occasionally taking place among these luminaries, and therefore commenced making a Catalogue of them, noting down the position and magnitude of each star, together with its alineation, with a view to any variations which might be observed in future ages: and this Catalogue of 1081 stars, preserved to us by Ptolemy, is one of the most valuable bequests of antiquity. Ptolemy tells us, that after this Catalogue was completed, that great astronomer made a representation of the heavens on the surface of an artificial globe, which was afterwards deposited in the Library at Alexandria. Hipparchus also made one of the most important discoveries in astronomy, the precession of the equinoxes: by comparing his own observations with those of Timocharis and Aristyllus, upwards of a century and a half before, he found that the stars always preserved the same relative positions with respect to each other; but that they had all a sensible motion in the order of the signs of the zodiac, which may have been about 48″ in a year. Thus was the *effect* detected; but it was left for the sagacity of Newton to discover the *cause*.

Such was Hipparchus! Considering his era and means, his services to practical astronomy are unequalled; and his immense labours laid the foundation on which the whole superstructure of the science was to be raised. Well therefore has Professor De Morgan said: "If Hipparchus had possessed the pendulum and telescope, fifty years might have enabled his successors to place astronomy in the state in which it stood at the birth of Newton." And the discerning Delambre placed him at the very head of those ancient philosophers, whose inquiries demand observation and geometry: "On trouve dans Hipparque un des hommes les plus étonnans de l'antiquité, et le plus grand de tous dans les sciences qui ne sont pas purement spéculatives, et qui demandent qu'aux connaissances géométriques on réunisse des connaissances de faits particuliers et de phénomènes dont l'observation exige beaucoup d'assiduité et des instrumens perfectionnés." With a very exalted regard, therefore, for the memory of this Reviser of the Science, I was greatly gratified with a gem bearing his likeness, in the possession of my worthy friend, the Rev. Charles Turnor, who kindly presented me the copy of it which decorates the title-page of this work. It is from the late Prince Poniatowski's collection, and is a very fine head; though I fear for its authenticity as the work of a cotemporary artist. Possibly it may have been copied from some original bust; but the existence of any ancient portrait in sculpture prior to Alexander, except, perhaps, those of the conquerors at the games, may be doubted *.

Between the days of Hipparchus and Ptolemy, astronomy languished in the "divine" school of Alexandria. But though there was no observer of eminence in that interval, there were various writers, whose works are valuable, as links in the chronological chain: for it must not be concluded that every opinion ascribed to any particular Greek astronomer, was actually maintained by him exclusively. Such were Hypsicles, Posidonius, Hyginus, Manilius, Seneca, Theon I., and Menelaus. About 70 B.C., Geminus, the Rhodian, published a systematic treatise

* Mr. Turnor's family now possess the estate at Woolsthorpe, the birthplace of Newton, and never could property so distinguished, have fallen into hands wherein it would be more duly appreciated. Mr. Turnor has spared neither time nor expense in collecting matters of interest relative to Newton and his scientific cotemporaries; and a rich harvest attests both his taste and his judgment. For a mention of Mr. Turnor's valuable MS. Almanac of A.D. 1340, see Vol. II. p. 525.

on astronomy, entitled *Uranologion*, which treated of the various cycles, and expounded the Hipparchian theories and their consequences: and Theodosius, of Bithynia, wrote an important work on Spherics. Julius Cæsar also rendered very great service to the science, by new modelling the Roman calendar, B.C. 46. It is true he invited Sosigenes, the Peripatetic, from Athens to Rome to assist him, but Cæsar himself appears to have been well versed in astronomy. He discovered that autumn occupied the proper place of the winter months in the calendar, and that winter encroached on the spring months; he therefore called upon Sosigenes to assist in correcting this disorder. They began by giving fourteen months to the current year, to re-establish the order of the seasons. They likewise determined that the year should consist of 365 days, 6 hours, in future; and this, though too long by 11^m 11^s, was coming very near the real length of the tropical year. This is still called the Julian year. Posidonius made a sagacious determination, which, like all those ancient notions. required demonstration; he found that the distances of the moon and sun from the earth were, respectively, two million stadia, and five hundred million stadia; and he moreover calculated the height of the atmosphere to be four hundred stadia—results which do not violently differ from those of the moderns. But one of the most remarkable opinions of those times, is the conjecture of Plutarch, (*De Facie in Orbe Lunæ*,) that the velocity of the moon's motion is the cause which prevents that body from falling to the earth, just as the motion of a stone or other weight in a sling, prevents it from falling to the ground.

There is a very unfounded opinion, that the paganism and ignorance of those ages were fostered by astronomy; but that noble science was ever pursued by the best men, and the contemplation of the skies was held in high estimation. The Royal Psalmist, considering the wonders of the heavens, and the Creator's glory as magnified by His works, thinks that man must be little lower than an angel; and Josephus calls astronomers the *sons of God.* Virgil entreats the muse to teach him the laws of the sun, moon, stars, and tides; and Ovid, Lucan, and even Lucretius, materialist as he was, are eloquent on the same theme. Seneca boldly predicted that posterity would despise the ignorance of his age as to comets, which he pronounced to be wandering planets: and Pliny considered the formation of a sidereal catalogue, to be rather a work pertaining to the Deity than to man. The taste, the skill, the perseverance, and the genius of ancient astronomers, deserve the fullest acknowledgment, though the discoveries actually made by them were but imperfect aids to physics, and their methods of philosophizing were necessarily defective. Serious reflections on that comparative little which they had discovered, ignorant as they were of the substantial harmony of the system, led them to the acknowledgment of a supreme Being: "When you behold," says Cicero, "a large and beautiful house, surely you would not believe it was built by mice and weasels;" and, in showing the impossibility of the creation's having resulted from a fortuitous concourse of atoms, he asks whether the beautiful world, its summer flowers and winter snows, or the lunar influence on the tides, could possibly subsist in such harmony without the continued aid of a Divine spirit. It is true that reason requires no proofs where everything displays the existence of an Almighty Creator; but, to use the words of the illustrious Laplace, "the progress of astronomy has been the constant triumph of philosophy over the illusions of the senses;" and there are such exhibitions of immensity of power and design in the starry heavens, that the mind is staggered, and feels its impotency in scanning the mysterious and awful infinity. Yet the modern astronomer, well aware of the existing concord of the spheres in balanced power, perfect adjustment, controlled motion, and undisturbed force, can only perorate with the acute Pagan: "In the heavens there is nothing fortuitous, unadvised, inconstant, or variable; all there is order, truth, reason, and constancy;" and he asserts, (*De Nat. Deorum*,) that "the creation is as plain a signal of the being of a God, as a globe, a clock, or other artificial machine, is of a man*." Plutarch also, (*De*

* The *luminous* polytheist, Hume, argues thus: "A great number of men join in building a house, or a ship; why may not several Deities combine in contriving and framing a world?" To this the uniformity observable in the vast operations, and the consummate wisdom of adjustments of the forces, is a conclusive reply. But he is severe upon Cicero's house simile, saying, "But surely you will not affirm that the universe bears such a resemblance to

Placit. Philos.,) observes, "that when men saw the harmony of the heavenly bodies, and the pulchritude around them, they acknowledged a God;" and this effect of studying the order of the heavenly spheres, is acknowledged even by the *atomic* Lucretius: they saw, he tells us, the constant and circling order of the heavenly bodies, and the relations of the heavens with the varied seasons; and ignorant of other cause, they cunningly ascribed all to the gods:

> Præterea, cœli rationes ordine certo
> Et varia annorum cernebant tempora vorti;
> Nec poterant quibus id fieret cognoscere caussis.
> Ergo perfugium sibi habebant omnia Divis
> Tradere, et illorum nutu facere omnia flecti.

To return. Ptolemy is entitled to great regard from astronomers, both as an observer, a discoverer, and a judicious compiler. In undertaking the delicate measurement of the zenith distance of the sun and the obliquity of the ecliptic, he used an instrument on the plan of the meridional armillæ of Eratosthenes; it consisted of two rings, one moveable upon the interior circumference of the other, in the same plane, the exterior circle being graduated, and the interior one bearing two small gnomons to form the line of sight. He also used a quadrant with a moveable alidad carrying sights; but distrusting the results of both these instruments, he invented another, which Theon II. designated the parallactic rods. With these, and other instruments, Ptolemy made some observations on objects previously examined by Hipparchus, and his comparisons led him to still further exertions. He has handed down to us in the *Megale Syntaxis*, or as it was subsequently called, the *Almagest*, the principal observations and theories of the ancients, together with his own researches, and the Catalogue of Hipparchus reduced to his own time, either by an assumed value for the precession, or corrected by new observations. He adopted the theory that supposes the earth placed in the centre of the universe, which has received

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a house, that we can with the same certainty infer a similar cause, or that the analogy is here entire and perfect." David, however, instead of deducing conclusions from principles, is very much in the habit of placing the cart before the horse.

his name; and which, most un-dynamically, assumes the planets to move uniformly in circles, the centres of which move also in regular circles round the earth. But as this system was somewhat countenanced by the angular motions of the planets, despite of the oscillations and librations which embarrassed the imaginary equant, it was universally adopted, and retained till the days of Copernicus, with all its imperfection and complexity. The alterations in the apparent planetary diameters, if at all observed, were not attributed to a change in their distances from the earth; and, notwithstanding the inaccuracies of the system, with its excentricity of the equant, semi-diameters of the epicycle, and other barbarisms, Ptolemy computed the eclipses which should occur in the six ensuing centuries; but what is remarkable, he makes no mention of comets. He discovered refraction, and made some tolerably correct experiments to determine its law; and he explained the apparent enlargement of the discs of the sun and moon when near the horizon. He extended the sphere of Hipparchus, and entered into the investigation of every point upon which that great man had touched. But Ptolemy's principal discovery is, that of the moon's second inequality, or evection, a change such as would be caused by an alternate increase and diminution of the excentricity of the moon's orbit.

Ptolemy studied several different sciences with a surprising versatility of talent, and besides his Uranian pursuits wrote also works on geography, mechanics, music, chronology, and, despite of kindly doubts, on judicial astrology as well. Now this visionary and pernicious art was so long in close relationship with astronomy, to the study of which it was a powerful incentive, that a word upon it must be dropped in passing, especially since such men as Aristotle, Manetho, Manilius, Censorinus, Julius Firmicus, Albumazar, and Tycho Brahé were its dupes. This *science* is of the highest antiquity in the East, and still flourishes wherever science is compelled to stoop before ignorance; but in those regions it certainly led to habits and means of watching celestial phenomena, and to the shadows of fancy, fear, hope, and destiny, added a considerable share of rational ideas of space, time, and numbers. The ancients were strangely infatuated with it as an art, which, together with magic, gave the artful such an irresistible sway over the ignorant and superstitious. Horace, though in a hot-bed of astrologers, wisely advises Leuconoë not to seek what term of life the gods had granted her, but patiently bear whatever shall happen:

> Tu ne quæsieris, scire nefas, quem mihi, quem tibi
> Finem Dî dederint, Leuconoë; nec Babylonios
> Tentaris numeros. Ut melius, quicquid erit, pati!

Kepler, who himself had a slight touch that way, and was driven by necessity to affect more, observes: "Astrology is the foolish daughter of a wise mother, and, for one hundred years past, this wise mother could not have lived without the help of her foolish daughter;" and he thought that the study of astronomy had been greatly neglected, ever since men ceased to apply themselves to astrology. Indeed, it was once a science so fully established in the judgment both of the learned and unlearned, that to disbelieve a connection of human dispositions with heavenly influences, would have been regarded as symptomatic of sheer blockishness. But though Kepler's remark would imply that the occupation was then gone, the names of Morin, Ashmole, Lilly, Heydon, Nostradamus, Gadbury, Goad, and others, prove that it still held way: and the story of Dryden's foretelling the drowning of his son is so notorious, that, as the man in the play says, it must be true. Even Bayer, the useful Greek letterist, might be added to the list, for in his first edition of the *Uranometria*, he has marked the various names of the constellations and single stars, together with the planets with which they were supposed to have astrological affinities. "Melancholy" Burton was a mathematician, an astronomer who gazed at Jupiter's satellites with his own 8-foot telescope, and so inveterate an astrologer, that having calculated his own nativity and predicted that he was to die in January, 1639, there was a whisper, according to Wood, "that rather than there should be a mistake in the calculation, he sent up his soul to heaven through a slip about his neck." The scheme or horoscope decorates his monument in the Cathedral of Christ Church, at Oxford; and in his *Anatomie* we gather that astrologers of note were well remunerated. In planning his Utopia, he says, "But

I will choose a site, whose latitude shall be forty-five degrees, (I respect not minutes,) in the midst of the temperate zone, or perhaps under the æquator, that paradise of the world, *ubi semper virens laurus*, &c., where there is a perpetual spring. The longitude, for some reasons, I will conceal. Yet *it be known to all men by these presents*, that if any honest gentleman will send so much money, as Cardan allows an astrologer for casting a nativity, he shall be a sharer." Simpson, the eminent mathematician, was obliged to quit Nuneaton, for frightening a young woman into violent fits, which threatened to terminate either in death or insanity, while endeavouring to raise the devil, in a barn; but he was loth to abandon astrology and its easily-earned emoluments.

Laplace shows how this moral solecism may have taken rise: "Equally deceived by the imperfections of his senses and the illusions of self-love, man long considered himself to be the centre of the movements of the stars. And his vanity has been punished by the terrors to which they have given rise. At length, ages of labour have removed the veil which concealed the system of the world from him. He then found himself placed on the surface of a planet, so small as to be scarcely perceptible in that solar system, which itself is but a point in the infinity of space." But in removing the veil a few shreds were left, which have obscured many an understanding of the eighteenth and even the nineteenth century. Germany, France, and Italy, have still writers of the black art; and even the great Napoleon himself confided in his lucky star, a bearing which probably induced Messier to publish, in 1808, the *Grande Comète qui a paru à la naissance de Napoléon le Grand*. England has produced a volume or two, very lately, on "aspectal prognostication;" and the present year shows Zadkiels, Raphaels, Weather Guides, and other trash, in such numbers, as to testify that the demand is still sufficiently large to remunerate the publishers. One of these works is entitled, *Phrenology and Astrology harmonized, showing that the compartments of the head, as divided for phrenological study, exactly agree with the astrological houses of Heaven, &c. &c.* Some of these boldly predict the fate of ministers, and meaner men; while others merely circulate exploded doctrines about the planetary influences on our atmosphere, and give sage directions when a gentleman is to carry his umbrella out, or when a lady may safely cut her corns. Now and then something most conclusive in the way of coincidence is thrown out, and the purchasers are aghast at the mysterious connection before them. Thus, a settler on the Malabar coast in latitude 18° 20′ north, just to the southward of Bombay, hears of the death of George III. This, of course, would be known to him from heavenly aspects. He would find that *a* Lyræ rose to him achronically on the 4th of June, his late Majesty's birthday, and that it set achronically on the 18th of January, the day appointed for celebrating the same birthday: it would then follow, that the figures which indicate the degree of latitude, mark also the year of the sovereign's death. Q. E. D. It is but a few years ago that the editors of the well-known *Moore's Almanac*, attempted to discard the monthly column containing the moon's supposed influence on the several members of the human body, as legs, arms, eyes, nose, &c.; and as an experiment, to ascertain the feeling of the public on the occasion, printed at first only one hundred thousand copies. But the omission was speedily detected, and nearly the whole edition was returned on their hands, whence they were obliged to reprint the favourite column. And yet we boast of the march of intellect!

From the death of Ptolemy to the time of the Arabians, no astronomer of the first order is to be found among the Greeks, the spirit of whose school had then evaporated. In this interval, however, there were useful compilations published, containing historical information with regard to the otherwise neglected science. Among these is the learned commentary on the *Syntaxis*, by Theon II. of Alexandria, (A.D. 385,) one book of which was written by his daughter Hypatia, the first female recorded for her attainments in science. This lady constructed some mathematical tables; but her extensive learning, ready elocution, graceful address, and elegant manners, could not suffice to save her from a tragical end, for she was brutally murdered in the streets of Alexandria, by the infamous partizans of Bishop Cyril (A.D. 415).

Shortly afterwards, Proclus attempted to establish the true figure of the universe as globular, from the circular movement of the sun as shown by his invariable apparent magnitude, and the complete circles daily formed by some of the stars about one fixed point. This was certainly a more obvious approximation than that of Cleomedes, who, about this time, proposed to ascertain the diameter of the sun, by making a horse run on a level plain from the moment the upper limb of the sun appears in the horizon till the whole disc is above it, and noticing the time and distance: Cleomedes, however, had some good notions of planetary movements, and the moon's borrowed light, although he insisted on the circular theory of the celestial bodies. Pappus and Simplicius were able commentators on the text books; and Martianus Capella, (A.D. 470,) left some astronomical views of planetary motions, which are reported to have been of great use to Copernicus. Several other works of much interest appeared; but the only observations recorded, in the above-mentioned interval, are six registers of lunar occultations and solstices by Thius of Athens (A.D. 500).

Such is ancient astronomy, with respect to which it is remarkable how much was achieved, how much remained unaccomplished, and how many true principles of science died, as it were, at their birth. Something like a correct idea of the solar system had been taught; and there were sagacious considerations respecting the stellar regions, which almost appeared to be anticipations of the revealments by the telescope. But the physical researches of the ancients are so intermixed with sound and chimerical opinions, and display such extravagance and gratuitous theorizing, that in their illogical deductions they only "guessed at truth." All that is truly precise and permanent in natural philosophy belongs to modern times. Still we must pay a tribute of admiration to the investigating spirit which, with observations and calculus so inferior to those now possessed, enabled them to account for so many of the phenomena of the heavens, and to offer such reasonable modes of accounting for the celestial movements.

Literary scandal delights in ascribing the fall of the Alexandrian school, (A.D. 642,) to Omar, the second Khaliph of the Saracens, and the first *Emir al mumenin*, or Commander of the

Faithful; but the evidence on which the charge is supported, can hardly be received. Be this, however, as it may, the world is greatly indebted to the Saracens for the attention which they devoted to astronomy, and the discoveries they made therein; and, but for them, that invaluable legacy of the ancients, the *Megale Syntaxis*, had been lost. War and fanatical factions interrupted the progress of science, until the family of the Abbassides, or *Hashemites*, obtained quiet possession of the khaliphate, about A.D. 750, when the torch of science blazed with extraordinary splendour. The Arabian school received a local habitation, a name, and a date for seniority, in the founding of Baghdad by the Khaliph Abu-Ja'far Al Mansur, the victorious, in the year 762. Under him translations of Aristotle, Hippocrates, Timocharis and Aristyllus, Euclid, Ptolemy, Menelaus, and other Greek writers, were begun; showing that speculative philosophy, medicine, mathematics, and astronomy, were ardently pursued: and it may be readily supposed that, placed so far in the East, the schools of Baghdad were not limited to the Greek sources of knowledge. The Hellenic springs, however, seem to have been preferred to the Hindu ones by the more exact astronomers; and with nearly the same instruments, and the same theory as Ptolemy, a career of four centuries began, during which many astronomical elements, and, in particular, the obliquity of the ecliptic, and the precession of the equinoxes, were more accurately examined.

Al Mansur was succeeded by his grandson, the celebrated Khaliph Harun al Rashid, the renowned hero of the *Arabian Nights*. His claim to the title of Rashid, the wise and good, may be questioned in his treatment of the Barmecides, and some other points; but the respect of the scientific is demanded by his love and encouragement of learning, whence his court became the resort of the most eminent literary characters of his time: of geniuses instead of genii. Although he died at the age of forty-seven, he reigned from A.D. 785 to 808, and was the richest and most potent sovereign of his era. He sent a splendid embassy to Charlemagne, his ally, which, among other presents, brought a water-clock, in the dial of which were twelve small doors, forming the division of the hours. Each of these doors opened at the time it marked, and let out little balls, which, falling on a bell of brass, struck the hours. The doors continued open till twelve o'clock, when twelve little knights, mounted on horseback, came out together, paraded round the dial, shut all the doors, and returned to their apartments. This must have been a wonderful effort for the time; and horology is too closely connected with astronomy for its mention to be uninteresting. After Harun, his eldest son, Al Amin, became khaliph, but drunkenness and misgovernment upset him, and his brother, Al Mamun, succeeded to the throne, which he held from 812 to 833. This sovereign was himself a diligent observer, an improver of astronomical instruments, and a great promoter of science. Under him, the translation of Ptolemy's *Syntaxis* was completed by Ishak Ibn Houain, and given to the world under the name of *Almagest*, about the year 827. Al Mamun also made and caused to be made, good observations which were worked into a body of astronomical science known as the *Mamunic Tables*, and *Al Mumtaḥan*, the proved by trial. Two observations of the obliquity of the ecliptic are recorded, which were either made by Al Mamun himself, or under his immediate auspices, one at Baghdad, and the other at Damascus; and the mean of the observations established a declination of about 23° 34′. This determination is important in the history of science; and it is moreover remarkable from having been followed by the measurement of a degree of the terrestrial meridian, in order, as it is expressly stated, to verify the former values; and this is the only instance of an attempt to emulate the ancient operations, during a long dark period of fourteen hundred years. The spot fixed upon was an extensive plain in Mesopotamia, between Palmyra and Rakkah, a district now principally inhabited by the Mowali Arabs: here one party was directed to travel north and the other south, till they had changed the situation of their zenith one degree from the place of their departure. The whole was well planned, but as we neither know how they determined their latitude, nor how they measured their distance, and are also ignorant of the measure employed, it is impossible to ascertain what degree of accuracy was attained. The statement, however, is, that one of these degrees was found to contain 56⅔ miles, and the other 56, each mile being 4000 royal cubits. But of the precise length of the cubit there have been such different opinions, that Al Mamun's degree may be considered as lost to the world. Those who leap to conclusions assume each *dhirá*, or cubit, to contain 27 inches; and the inch was equal to six grains of barley placed side by side: others reduce the royal cubit to 19⅓ inches.

The principal assistants in Al Mamun's views, were Yaḥya Ibn Abilmausor, Saïd ben Ali, Abbas ben Saïd, Khalid ben Abdil-melik, Abul-tayyib, and Ali ben Isa; but the flowers of his flock were Ahmed-Ibn-Kethir al-Ferghani and Thabit-Ibn-Korrah. The first, known as Alfraganus, surnamed the Calculator, was called Al Ferghâni, from the town of his birth: he is the author of an *Introduction to Astronomy*, in which he endeavoured to popularize the *Almagest*, and in its twentieth chapter, is a detail of the twenty-eight Lunar Mansions of the Arabians. Thabit was also a clever astronomer, and is said to have improved what Ferghâni prepared: he, however, is principally remarkable for having revived the old notion of a variation in the position of the ecliptic, as well as in the fixed stars, which has been called the *trepidation*. It was his opinion, founded on some erroneous observations, that the stars moved for some time according to the order of the signs; that they afterwards proceeded in a retrograde direction, and returned to their former places, after which they assumed a direct motion; and that they then had an irregular motion, which was rapid for a certain period, then became slower, and at last insensible. He maintained that the obliquity of the ecliptic was variable, under similar periods of increase and decrease; and his opinions prevailed for a considerable time.

The most distinguished practical astronomer of the Baghdad school was Albategnius, a corruption of Al Battâni, from his birthplace Battan, near Harran, in Mesopotamia. By the Arabians he is known as Mohammed Ibn Jaber Ibn Senan Abu-Abdallah al-Harrani. He computed new astronomical tables to supersede the imperfect ones of Ptolemy, and composed a work entitled *The Science of the Stars*, comprising all branches of astronomy, according to his own observations and those of Ptolemy, adding to the latter's results, as "he had added to those of Abarchis" (Hipparchus). He observed the autumnal equinox at Rakkah on September the 19th, one hour and fifteen minutes after midnight, A.D. 882; and he also observed, about 883, that the first star of Aries was 18° 02′ from the equinoctial point; he states the obliquity of the ecliptic at 23° 35′, and the motion of the sun's apogee, since Ptolemy's time, as well as the motion of the stars, at one degree in seventy years. He is the first who made use of sines (instead of chords) and versed sines; and he found the length of the year more accurately, making it only two minutes less than what it was stated to be by Dr. Halley, eight hundred years afterwards. The *Alphonsine Tables* of the moon's motions were founded on the observations of Albategnius. About this time flourished Albumazar, or Abú-Ma'ashar al-Balkhi, who was esteemed as one of the most learned astronomers of his age, although he was strongly tinged with astrology. His *Introductio in Astronomiam*, printed at Venice in 1489, is well known; and he is said to have observed a comet above the orb of Venus. It is not known when Alchabitus lived, but his introduction to the knowledge of the celestial influences, was translated and printed at Venice in 1491, under the title of *Isagoge ad Magisterium Judiciorum Astrorum.* He also wrote upon optics.

In the middle of the tenth century, a description of the sidereal heavens was written by Abdu-l-rahman Sufi, a dervish, who likewise rejoiced in the appellations Ibn Omar Ibn Mohammed Ibn Sahl Abul Hasan al-Rasi. Alfarabius, or Al-Farabi Abu-Nasr, who died A.D. 950, wrote upon optics and astronomy, and is somewhat remarkable as having been, perhaps, the first compiler of an *Encyclopædia;* for such one of his works may be called, as it gives a clear and comprehensive compendium of the arts and sciences: there is a manuscript copy of this book in the Escurial. He was followed by Ibn-Yunis, of Egypt, also a man of many names, who died in the year 1008. He flourished under the Fatimite dynasty, and was an observer and mathematician of great merit. He first noted the time of the beginning and end of an eclipse by taking the altitude of a star; and his *Hakemite Tables* display an increasing knowledge of trigonometry, he being the first who employed subsidiary angles. His cotemporaries were Ibn-al Alam, or Ali Ibn al-Hasan, of Osaila, whose works are unfortunately lost; and Abul-Wefá, who first formally used tangents, co-tangents, and secants, which Albategnius had overlooked. Abul-Wefá also knew and treated of the third inequality of the moon, or *variation*, the discovery of which delicate quantity is attributed to Tycho Brahé: the Arabian shows the cause of the equation, and states its amount to be about 45′. He named the anomaly *Muhazal.*

After the Arabs had conquered the greater part of Spain, about the year 1020, they built several observatories to continue their observations, and planted a love of science in their new dominions. Among those who have taken precedence among the Hispano-Moors, is the philosopher Al-Hazen; but the claim is doubtful, since it is only known that he was born at Basrah; in what year is uncertain; and his death took place at Cairo, 1038. He was a skilful geometrician, and a great improver of the science of optics, confirming his theory by experiment and observation. He was the first who applied the laws of refraction, to show how the heavenly bodies are sometimes seen as if above the horizon while still below it; and who, in the same way, explained the cause of the morning and evening twilight. In his optical treatise, he gives a tolerable description of the eye, maintaining that the crystalline humour is the most important organ for the purpose of sight, without considering it as a lens, asserting that vision is not completed till the ideas of external objects are conveyed by the optic nerves to the brain. Among other dioptric discoveries, he probably suggested the hints which led to the useful invention of spectacles; and it is in his writings, that we find the first distinct account of the magnifying power of glasses. Shortly after Al-Hazen, Arzachel, also a Spanish Moor, is supposed to have produced the *Tabulæ Toletanes*, calculated for the meridian of Toledo, where he probably was residing about the year 1080. These tables are of indifferent accuracy, but were not unuseful to the Alphonsine astronomers, who, says Delambre, "n'ont eu en vue que de les rendre un peu plus exactes." He also wrote a work entitled, *Observationes de Obliquitate Zodiaca.* About the same time, Geber, another

Spanish Moor, introduced the use of the co-sine, and made improvements in spherical trigonometry. He was a man of extensive attainments; but as he was addicted to the mystical jargon of the alchemists, Dr. Johnson is disposed to derive the word *gibberish*, which Camden writes *geberish*, from Geber. He exercised a very undue criticism upon Ptolemy's conclusions, but without any essential amendment: whence Delambre, after a strict investigation, sharply says, "Géber est donc inattentif et injuste; sa critique porte entièrement à faux." Abu-l Hasan, who flourished about 1200, and has left some improvements in dialling, and a Catalogue of 240 stars, is also claimed for Spain; but he seems to have been born in Morocco.

The middle ages produced some good astronomers among the Persians, and their Tables were translated by George Chrysococcas, a Greek physician, in the fourteenth century. They made many observations in order to discover the real length of the solar year, which they fixed at 365 days 6 hours; their method, therefore, of intercalating, was of surprising accuracy, however complicated it may have been. Two cotemporary labourers in this vineyard deserve especial mention. Kazwíní, or, to do him full justice, 'Omadu-d-dín Abu Yahya Zakariyá Ibn-Mahmúd Ansárí al-Kazwíní, who died in 1283, was the author of several useful works. Three of these are extant, and treat of history, geography, and cosmographic natural history, in the latter of which is the curious description of the constellations so largely made use of by Assemani, in his description of the celestial Cufic globe at Velletri. Kazwíní's *collaborateur* was the celebrated Nasír-Ed-dín, more properly Mohammed Ibn-Hasan El-Tusi, a native of Tus, in Khorasan, who published the Persian Tables A.D. 1270, under the patronage of Hulagu, grandson of Jengiz Khan, and conqueror of Persia. Nasír-Eddin was an admirable and learned man, and besides the *Ilkhanian Astronomical Tables*, said to be still used in Persia, he also published—with commentaries—the most esteemed Mohammedan editions of Euclid's *Elements*, and the *Spherics* of Theodosius and Menelaus. Indeed, he cultivated literature and the sciences with such success, that he was characterized as "the master who had acquired the highest reputation in all branches of knowledge." To this epoch are assigned the two Arabic Globes, so often referred to, one of which is in the Museum established by Cardinal Borgia at Velletri, and the other in the Mathematical Saloon at Dresden.

The last of the Oriental astronomers was the Mogul prince, Mohammed Taragaï Ibn Shah-rokh Ibn-Timur, known by the name of Ulugh Beigh, the great lord: he was a grandson of the famous conqueror Timur-len (Timor the lame), the Tamerlane of our stories, and was born in 1393. This prince not only encouraged the sciences as a sovereign, but was himself a practical astronomer, a mathematician, and one of the most learned men of his age. Among other institutions for the promotion of science, he established a gymnasium (*madratah*) at Samarcand, his capital; and he constructed an observatory which he furnished with the best instruments. Here he worked in person, with Salah-ed-din and his son Ali Kushi, and Musa Ibn-Gaïat Mohammed Jamshid, as his assistants. The latitude of this important spot he pronounced to be 39° 37′ 23″ north; and to determine this, he is said to have employed a quadrant, the radius of which was one hundred and eighty Roman feet: but most commentators suppose that this must have been a gnomon instead of a quadrant. To this fine spirit we are indebted for the *Zij*, or Tables of Ulugh Beigh, part of which is the well-known catalogue of stars for the year 1437, a re-examination of Ptolemy's stars, with the exception of twenty-seven which were too far south to be visible at Samarcand; and there were eight others which he could not find. This was the most perfect collection which had ever appeared, and will always be a valuable evidence in astronomical science. An unhappy difference now occurred between this learned sovereign and his eldest son, Abdallatif. Addicted, like other Orientals and astronomers of the time, to astrology, he calculated his son's nativity, and from the aspect of the horoscope, saw ground for preferring his younger son; so that the eldest, being slighted, rebelled against him, and by the event, cast a spurious air of truth over the astrological predictions. A civil war was the consequence, and in a bloody battle near Samarcand, the father was defeated, and compelled to seek safety in flight. In the hope that Abdallatif would compassionate him, Ulugh Beigh afterwards returned to Samarcand, and claimed protection; but the unnatural son issued an order for the execution of his father and brother, which tragical events took place in the year 1449. "Fuit rex justus, doctus, perfectus, sapiens, prudens, ac victoriosus," say the biographers of this martyr to astrology.

From this time astronomy declined throughout the East: the Emperor Akbar, indeed, liberally encouraged it, and the Jesuits endeavoured to spread it, but there is little left besides the craving to foretel future events from the aspects, positions, and influences of the heavenly bodies.

There is, however, a large debt due to the Arabians. Among the principal dictionaries of the Arabic language, the *Kámús*, ocean, of Fírúzábádí, may be cited as containing much illustration of stellar nomenclature in 1350; and the Catalogue of Tízíní is useful in Oriental researches. But the works of this school, in general, must be consulted with caution; although there is ground for supposing that many new points of astronomical history may follow a closer examination of the Arabian archives. Thus MM. Sédillot, father and son, have, indeed, already achieved much, and discovered, to use the words of Delambre, "des choses curieuses, et qui seront toutes nouvelles pour nous:" and in taking leave of the Arabs, it may be said, that by their energy, under enlightened and munificent rulers, the sacred light of science was preserved and nourished; "qui se serait éteint sans eux," says M. Bailly. They made numerous, and, for that age, accurate observations of the sun and fixed stars, to ascertain their apparent movements; and their uninterrupted application to the practice, enabled them to supply corrections for most of the elements. The length they found for the tropical year, and their determination of the sun's apogeum, are both within a few seconds of the truth; while their tables of planetary motions, when compared with those of recent construction, confirm the secular equation of the moon, and the great inequalities of Jupiter and Saturn. From a statement of Averroes, who perhaps mistook solar spots for planets crossing the sun's disc, it is clear that in his day it was held that Mercury and Venus were opaque, and that transits would result from the pòsitions of their orbits. In a word, it is to the Arabians that we are indebted for the sines and tangents of circular arcs, two new functions by which the formulæ of trigonometry are considerably simplified; as well as for the introduction of the neat Hindú notation by numeral digits*, for transporting from India the powers of algebra, and for the preservation of the astronomy of the Greeks through the western darkness of those ages; whilst among their discoveries may be mentioned, that of the motion of the solar apogee, and the third inequality of the moon, called its variation. Although Europe afterwards developed science to the fullest possible extent, her obligation to those "heathen savages," although they were greatly given to speculative theories, is shown by retaining their names of stars, and in the use of their words Almanac, Algebra, Algorithm, Azimuth, Zenith, Nadir, Alidad, Almacantar, and other terms. Mr. Edward Barnard, Savilian Professor at Oxford, in 1673, asserted that the Arabs made use of the pendulum for marking time: the passage may be quoted from the *Philosophical Transactions* for 1684: "Quam illi sollicite temporis minutias, per aquarum guttulas, immanibus Sciotheris, imo (mirabere) fili penduli vibrationibus, jampridem distinxerint et mesurarint."

During those times Europe was immersed in gross ignorance, the density of which was only occasionally pierced by the gleams of science, and that at long intervals, appearing as little in unison with the bent of the epoch, as an outcropping of granite would be in the chalk. At length, about the year 1230, the first translation of the *Almagest* was made under the auspices of the Emperor Frederic II. Shortly afterwards appeared the first European Tables; they were brought forward by Alphonso X., king of Castile, surnamed the Wise. (See No. CCCLVI., Vol. II., p. 214.) These Tables could hardly have answered the time or expense which were devoted to them, since they differ very little from those of Ptolemy; and the catalogue of fixed stars therein, seems to be a mere augmentation of the former longitudes, as shown in the Latin translation of the *Almagest*, by

* The use of the decimal and decuple number was not new, but the notation was. Plutarch says that it was common not only among the Greeks, but also among the Barbarians. The ten fingers probably gave rise to it.

17° 8′. A consciousness of this, together with a view of satirizing the perplexing maze of eccentric cycles and epicycles with which the system was then embarrassed, may have occasioned the noted exclamation of Alphonso, that "If he had been consulted when God created the world, he would have advised a less complex scheme;" a saying which, though branded with arrogance and impiety, can only be viewed as a sarcasm on some dispute among the system-makers of his age. About the same time, Roger Bacon, the "Doctor mirabilis" of the English, wrote on the phenomena of astronomy, in which he suggested various advances, both in perfecting instruments and in making observations: and it is beyond a doubt that his extraordinary mind *conceived* the telescope, though there is no proof that he gave it birth. He was the first to show, probably from his own observations, that the days of the equinoxes happened earlier, with respect to the calendar, than they did in the time of Ptolemy; and he concluded in his *Opus Majus*, that the anticipation was equal to one day in a hundred and twenty-five years, which is nearly correct. He thus foresaw the necessity of correcting the calendar three centuries before that correction was actually made. Delambre is perhaps travelling out of the record, when he pronounces this severe sentence: "On ne peut mettre Bacon au rang des promoteurs de l'astronomie." Bailly evidently thought otherwise.

Between the days of Roger Bacon and those of Copernicus, there were several writers of more merit than importance; but they severally assisted in diffusing a taste for astronomy, and in keeping up a knowledge of the science. Of these, two deserve special mention, albeit it cannot be said that they made any direct advances either in theory or observation. George Purbach, the eminent mathematician, wrote on gnomonics, with tables suited to the difference of climates and latitudes. This work was followed by a small tract *Concerning the Altitudes of the Sun*, with a table, and "astrolabic canons." He then constructed exact celestial globes, with Ptolemy's stars corrected to the middle of the fifteenth century; and made considerable improvements in trigonometry, with an extension of its tables. His *Theoricæ Novæ Planetarum*, which became a text-book in all the schools, is based on the theory of Ptolemy. At the request of Cardinal Bessarion, he commenced a Latin translation of the *Almagest*, but died in 1461, before it was completed. This task was executed by his friend and favourite pupil, John Müller, commonly known by the name of Regiomontanus, from his residence at Königsberg, a mathematician, astronomer, and inveterate anti-Copernican. Insensible to all argument but what was drawn from the assumed letter of the Scriptures, he persisted in giving fixity to the earth; and though he admitted that the planetary orbits were not material, he placed epicycle upon epicycle to account for and modify the irregularities of their motions. He executed various mechanical projects, and published a treatise on the true place and magnitude of comets. He also extended trigonometry: Purbach was the first who reduced the tables of sines to the decimal scale, and Müller perfected the project by carrying the sines to every minute, the radius being 600,000, as designed by Purbach, but he afterwards computed them to the radius of 1,000,000 for every minute of the quadrant. He likewise introduced tangents into trigonometry, and published the first almanacs which were worthy of the name. His cotemporary Cardinal Cusa, wrote on the correction of the calendar, and speculatively maintained the motion of the earth, in his work *De Doctâ Ignorantiâ:* he also thought he had demonstrated the quadrature of the circle, but in this he was refuted by Müller.

Various useful hints are thrown out in many writings of that epoch, which can even yet be available to the progress of knowledge; but the search into the original works demands both ability and patience, being often perplexing and bewildering, instead of simply instructing. There is, however, every excuse to be made for those authors. Numerous circumstances influenced their style and mode of communicating new notions and discoveries: in the mists of ignorance, it might be necessary to be tedious in illustrating truths now commonly received; and from the prejudices then current, it was necessary to combat errors with caution or with vigour, to a degree which would seem excessive or preposterous in the present day. The minds of the philosophers, also, felt the influence of the age in which they lived, whence they complied with its fashion, and so darkly communicated their inventions, that an air of mystery has overshadowed and obscured some of their most remarkable discoveries. Among the most popular of the works thus alluded to, was the treatise entitled *Homocentrica*, which is an exposition of planetary movements, by Fra Castorio, upon hypotheses long since abandoned.

Nicholas Copernick now rose, and made so great a figure in astronomy, that the true system he discovered, or rather restored, has been ever since called the Copernican system. This was the advent which divides old science from new; formal astronomy—or the relations of space and time, from physical astronomy—or the relations of force and matter. In studying the celestial mechanics, his understanding at once revolted against Ptolemy's scheme for the motions of our planetary system; but the subject required a combination of skill and caution. He was perplexed and embarrassed by the epicyclical theory, the combating with which incurred no great penalty: but the hypothesis of the earth's being the motionless centre of the universe, was implicitly received; it had been adopted by Plato and Aristotle, whose authority was considered paramount, and Joshua's command to the sun and moon irrefragably confirmed it. To attack this system, therefore, incurred the imputation of heresy; yet, nothing daunted, Copernicus went boldly to work, improving his views by a long series of observations, between 1507 and 1530, and by a close attention to the writings of ancient authors. In these he found that the Egyptians taught the revolution of Mercury and Venus about the sun; that Apollonius Pergæus had assigned the same motion to Mars, Jupiter, and Saturn; that Pythagoras, whose learning was derived from the Egyptians, asserted the earth's motion round its own axis; and that Aristarchus and Philolaus went still further, and maintained that our globe did not only move about its axis, but employed twelve months in revolving round the sun. On these foundations Copernicus reared his structure, of which his intense and sagacious study furnished him with the most correct mathematical evidence. Advancing on the *festina lente* principle, he improved the lunar tables, and gave, to a considerable extent, an explanation of celestial phenomena upon the revived basis. In 1530, he had finished his tables of the planets, and his great work, *De Revolutionibus Orbium Cœlestium;* but he did not venture to launch it into the learned world before 1543, when he received a copy of it only a few hours previous to his death, and consequently never read it in print. It contains the old philosophy interspersed with his own original and acute conceptions, and was received under very considerable opposition.

This reception was somewhat justified by the hesitation with which it was brought forward. By making the earth to revolve round the sun, and its orbit to become a great epicycle, he adequately accounted for what are called the second inequalities; and it became immediately obvious, with the help of a diagram, why a planet must sometimes appear retrograde and sometimes stationary. By this hypothesis he was enabled, with the aid of geometry, to assign the rates subsisting between the distances of the planets from the sun, and to account for the variations of the planet's latitudes; yet he failed in explaining the lunar theory, and the first inequalities of the planets. These were objections among the scientific class, many of whom, however, saw great cause for admiration in the labours of Copernicus; but his substitution of the diurnal and annual motions of the earth, for the apparent diurnal revolution of the heavens, and his making the whole terrestrial orbit shrink into a mere point, as compared with the distance of the fixed stars, was too violent a contradiction to the evidence of the senses, and the prevalent opinions, to obtain any extensive credit. All the mechanical objections to the system, however, and they were neither few nor light, have now been removed; and it has been firmly established by new arguments and demonstrations brought forward by Kepler, Galileo, and Newton. Still it must be distinctly understood, that the discoveries of the last mentioned philosophers were so decidedly novel, that the planetary system as promulgated by Copernicus, was very far removed from that which is at present distinguished by his name.

Ignatius Danti, the Perugian mathematician, applied himself assiduously to the improvement of instruments, and left at Florence, as monuments of his skill, a marble quadrant, and an equinoctial and meridional oval line. Observations had been made with the gnomon from the earliest ages, and Danti wished to perpetuate its use. In 1575, he made a grand one in the church of St. Petronius, at Bologna, which has received deserved praise. It consists of a meridian line, traced along the pavement, with an aperture in the wall through which the solar rays are transmitted. Cassini restored this line in 1653, which, becoming again deranged by the sinking of the pavement, was finally restored by Zanotti in the year 1776. I may add, that it was with peculiar pleasure that Baron de Zach and I inspected this relic on the morning of the 7th September, 1820, just before observing the annular eclipse which happened on that day.

Between the deaths of Copernicus and Tycho Brahé, there were several astronomers of considerable note, who greatly advanced the science by improving the means of observation, and by printing astronomical works. Such were Reinhold, who formed the *Pruthenic Tables;* Recorde, of *Castle of Knowledge* notoriety, the first English Copernican, and the introducer of algebra into this country; Gemma, surnamed Frisius, a proficient in mathematics and astronomy; Rheticus, editor of the *Opus Palatinum;* Maurolico, of Messina, the restorer of the Vth book of *Apollonius;* Piero Nuñez, inventor of an improved method of subdividing the units in reading an angle, by a sliding scale called Nonius, his Latinized name, which anticipated Vernier's application; Hood, the inventor of an astronomical staff which went by his name; Mœstlin, the author of *Ephemerides*, and *Epitome Astronomiæ;* Thomas Digges, who assisted such as would fly or climb to science, by his *Alæ sive Scalæ Mathematicæ;* and Bishop Wilkins, who sought other habitable worlds on Copernican principles. There is, nevertheless, a gross misrepresentation as to the state of English knowledge at this epoch. The above cited Hood, in 1590, published *The Use of the Celestial Globe in Plano*, the first English work noted by Lalande in his *Bibliographie Astronomique;* and he naïvely remarks, "L'astronomie commençait à percer en Angleterre." But Urania had already found her way into England, and in the book which he cites, he might have seen that there was then a considerable demand for the aids to knowledge already disseminated; for Hood distinctly says, "Our globes, and spheres, and celestiall draughts, which heere we have, will witness the falsehood of that exception, wherein eche severall starre is so truelye prickt that they misse not an haire of their naturall place." We will say nothing of Wilfred of Ripon, who flourished about 690; Adelm, who died at Malmsbury in the year 709; the venerable Bede in 735, and his pupil Alcuin in 804; Adelbold, the correspondent of Pope Sylvester II. in 1000; and John Garland, the Devonshire alchemist in 1081 ; because they knew neither Euclid, nor Ptolemy, as we are told by Professor De Morgan, who, in showing that this country held a conspicuous rank in the philosophy of the middle ages, gives a list of no fewer than ninety-six English mathematical and astronomical writers between 1068 and 1599, remarking that he had no doubt but that it might still be enlarged. Half a hundred of these names may be selected in illustration; and we shall soon see that England has contributed her full quota to the series of philosophical and zealous inquirers who have so largely opened the human intellect.

1060. Oliver of Malmsbury. *Astrological writings.*
1095. Herbert Lozing. *Astrology and Tables.*
1130. Adelard of Bath. *Translation of Euclid, &c.*
1132. Richard of York. *On the Tables of Arzachel.*
1160. John of Hexham. *On comets.*
1164. Simeon of Durham. *Ditto.*
1170. Roger of Hereford. *A theoretical work on astronomy.*
—— Clement Langton. *On astronomy.*
1190. Daniel Morley. *Principia Mathematices.*
1210. Gilbert Legley. *A compendium of astronomy.*
1224. Ægidius of St. Alban's. *On astronomy.*
1253. Robert Greathead. *Compendium Sphæræ, &c.*
1255. Roger Bacon. *Investigator of phenomena.*
1256. Sacrobosco (John Holywood). *De Sphæra Mundi, &c.*
1260. John Peccam. *On optics (perspective).*
1290. Michael Scot. *Translated Aristotle from the Arabic.*
1304. Duns Scotus. *Meteorology and physics.*
1316. Walter Evesham. *On the planets and on the sphere.*
1320. John Baconthorp. *On the sphere.*
1326. Richard Wallingford. *A writer on astronomy and an observer.*
1330. Walter Catton. *Against astrology.*
1340. Robert Holcoth. *On the motions of the stars.*
1342. John Maudith. *Tables of the fixed stars.*
1349. Thomas de Bradwardyn. *On optics, and geometria speculativa.*
1350. William Grizaunt. *On the magnitude of the sun, &c.*
1360. John Killingworth. *On astronomy and astrology.*

1360. Louis of Caerleon. *Calculations of eclipses.*
1370. Richard Lavingham. *On the distances of the planets.*
—— Simon Bredon. *On the equations of the planets.*
—— Nicholas of Lynn. *Astronomical Tables.*
1385. William Rede. *Planetary Tables.*
1390. John Somer. *The Oxford Ephemeris.*
—— Walter Bryte. *On the sphere and the theory of the planets.*
1400. Geoffrey Chaucer. *A treatise on the astrolabe.*
1410. John Walter. *Astronomical Tables.*
—— William Batecumb. *On astronomical instruments.*
1489. Thomas Kent. *Astronomical Tables.*
1530. John Robins. *Astronomical Tables.*
1540. Andrew Boorde. *Principles of astronomy.*
1552. Anthony Askham. *A lytel Treatyse of Astronomy.*
1555. Richard Eden. *On navigation and surveying.*
1556. John Field. *An Ephemeris for* 1557.
1557. Robert Norman. *On navigation.*
1558. Robert Recorde. *On geometry, astronomy, algebra, &c.*
1559. William Cunningham. *The Cosmographicall Glasse.*
1572. John Dee. *A translation of Euclid.*
1585. John Blagrave. *The Mathematical Jewel.*
1590. Thomas Hood. *On the Celestial Globe.*
1595. Leonard and Thomas Digges. *On spherical trigonometry, parallaxes, &c.*
1599. Edward Wright. *Navigation and magnetism. Inventor of the projection called Mercator's.*

The first observer who made any important additions to the phenomena of the heavens as received from the Arabians, was Tycho Brahé, a Danish nobleman, who, in 1576, constructed a splendid observatory named Uraniburg, at Huen, an island near Copenhagen, at an expense of £40,000, half of which was paid by his sovereign. Here he made a catalogue of the fixed stars, more accurate than any preceding one; gave the first table of refractions; rediscovered the lunar inequality called the variation; noticed the inclination of the lunar orbit; discarded the *trepidation* of the precession; and greatly improved and enlarged the instruments in use, as well as all the methods of observation. His numerous works prove that he was a man of extraordinary abilities; and it is to be regretted that he sacrificed his talents, and perhaps his inward conviction, to superstitious considerations, and rejected the true solar system. His errors and weaknesses ought certainly to be forgiven, in return for the observations and discoveries with which he so substantially enriched astronomy; and it is to be regretted that we know so much about his nose, his low-born wife, his insane companion, his attention to omens, his researches in alchemy, and his devotion to astrology*. A very singular fatality has, however, attended the noble Dane's fame with the million, among whom he is more usually quoted as the schemer of an un-dynamic order of planetary rotations, than as he who made more astronomical observations than any man before him. Less happy in systematizing than in observing, and averse to the Copernican theory, he substituted for it one of his own, usually known by the name of the Tychonic system; also, from its being a sort of medium between the views of Ptolemy and Copernicus, the Semi-Ptolemaic. In this retrograde step, Tycho placed the earth motionless in the centre of the universe, round which he asserted the annual motion of the sun, and the menstrual motion of the moon. The geocentric system was certain of a favourable reception, since texts from Scripture had been very unwarrantably dragged forward against the heresies with which Copernicus had shocked prejudice; and, indeed, the savans had advanced objections which were then deemed irrefragable; the earth, they contended, was too large and ponderous for motion, and the idea of its diurnal movement they held to be ridiculous, inasmuch as the centrifugal force would throw off all bodies, animate and inanimate, from its surface. His system, however, involved too many inconsistencies and improbabilities to gain supporters of note; so that it led to another called the Semi-Tychonic, in which some of the absurdities of the former are removed, by conceiving the earth to revolve round its axis every twenty-four hours, with the moon as its satellite. The other planets were considered as performing their revolutions relatively about the sun; and the whole of this system, together with that of the firmament, or orb of the fixed stars, was supposed to be carried by the diurnal motion round one of the smallest

* Tycho's first catalogue, the *Astronomiæ Instaurate Progymnasmata*, contained exactly 777 stars; a number which was probably determined on from the mystic importance of the seven, which, Hermes Trismegistus says, refers to the accomplishment of all things; in this Dr. Slop would perhaps have agreed. There were seven wise men of Greece, seven champions of Christendom, seven wonders of the world, seven branches of the golden candlestick, seven altars, seven planets, and seven heavens.

planets. As this scheme, however embarrassed and perplexed with different centres, explains all sensible appearances pretty well, it became popular, and prevailed among the anti-Copernicans for nearly a century, till it was entirely exploded by the discoveries of Newton.

Among the earliest disciples of Copernicus, the unfortunate Giordano Bruno of Nola must be named. He quickly embraced the heliocentric opinions, and connected a plurality of worlds therewith. In 1591 he published his book *De Innumerabilis Mundis*, in which he maintains that each star is a sun, about which planets revolve; and he may have been instrumental in introducing these views into England, on his visit thither a few years before. These notions, no doubt, coloured the other heresies of the poor Dominican, for which he was brought to the stake at Rome, and burnt in 1600.

Cotemporary with Tycho there flourished several eminent astronomers, among whom was the famous Kepler, who saw that the attractive influence of the moon was the means of raising tides in the ocean; and he had a strong perception, as Newton admitted, of the principle of gravitation. In 1609, this great man published his extraordinary commentary, *De Motibus Stellæ Martis*, in which he established, from Tycho Brahé's observations, his rst and second laws, viz. that the form of the orbit is an ellipse about the focus, and that the areas are proportionate to the times. This investigation is truly remarkable, as a perfect example of legitimate connexion between theory and experiment under mutual suggestion; it required a large expenditure of time, labour and sagacity, to arrive at the truth, that the orbit of Mars was not a circle, but a curve interior to a circle; and a curious light is thrown on the inquiry, by finding that the elliptical law was based on the presumption, that an observer so exact as Tycho could not have been in error to the amount of eight minutes in his observations*. In 1618, Kepler announced his third law,—that the squares of the periodic times

* Copernicus laughed at Rheticus, when he was disturbed about single minutes; saying, that if he could be sure to ten minutes of space, he should be as much delighted as Pythagoras was when he discovered the property of the right angle.

of the planets are in proportion to the cubes of their distances from the sun; and this discovery is partly ascribed to his confidence in the mystical powers of numbers. He also laboured upon refractions, first noticed the zodiacal light, published the unrequited Rudolphine Tables, discovered the fourth inequality or annual equation of the moon, and was incessantly engaged in various scientific works, in the midst of pecuniary difficulties. Copernicus had failed in explaining several parts of his system, from his idea that it was a law of nature that uniform motion should be in perfect circles, as well as from his excessive deference for Ptolemy. Kepler, however, was displeased with the complication of epicyles; and presumed to suspect that the author of the *Syntaxis*, instead of deducing his theory from observations, had sometimes corrected the observations to suit his theory, and this sagacity led to the demolition of the circles and deferents. His own approaches were not made with the greatest precision in the first instance; yet he was no sooner baffled on one tack, than he trimmed sharp upon the other. No disappointment was sufficient to check the ardour of his researches, and nothing ever dismayed him; his patience and perseverance were inexhaustible; but his patience and perseverance were not those of a mere mathematical plodder,—he was daring, sagacious, inventive, and fanciful. He made no fewer than nineteen hypotheses with regard to the motion of Mars, and calculated the results of each, before he pronounced the path to be an ellipse; and prepared "the tabular prisms and equated excentric fetters for the vanquished planet." To sum up his services, it may be stated, that to him we owe the true figure of the planetary orbits, and the formal proportions of the motions and distances of the various bodies which compose the solar system: indeed, THE THREE GREAT LAWS of Kepler may be said to be the foundation of astronomy as an exact science in mechanical philosophy. But the proof of this was awaiting the higher generalizations of the mighty Newton, who was the first to appreciate duly, and reveal satisfactorily to others, the secrets which Kepler had extorted from nature. Kepler's idea, that a planet must exist between the orbits of Mars and Jupiter, too small for the naked eye to perceive,—and his opinion that the sun performed a revolution on its axis,—preceded the actual knowledge of those facts.

Meantime Galileo was rendering services of the highest importance to the philosophy of nature, in showing the laws by which material bodies act mechanically on each other, and by the theory of the composition of forces, which determines the result or equivalent of forces acting upon bodies in the same or in different directions. In thus restoring, in a clear and geometrical manner, the long-neglected doctrine of motion, which Maclaurin says, has been justly called the Key of Nature, he demonstrated the important problem, that the spaces described by heavy bodies from the beginning of their descent are as the squares of the times. Having made a telescope from a general description of a magnifying instrument by one Jansen, in Holland, he applied it to the examination of the heavens, and with it caught a view of some wonderful spectacles announced in 1610, in his *Nuncius Sidereus.* Thus armed, he made many useful and valuable discoveries, as the lunar mountains, the component stars of the Via Lactea, the satellites of Jupiter, the *ansæ* of Saturn, the phases of Venus, and the spots on the sun: the last, however, had been already observed by Harriot, in England, and were also seen by Christopher Scheiner, the active anti-Copernican, in 1611. Among other important pursuits, Galileo made experiments on the gravity of the air; invented the geometrical cycloid; discovered the isochronous motion of pendulums; and acquired an extensive knowledge of agriculture, drawing, painting, poetry, music, and architecture. By his observations and sound dynamical reasonings, the objections to the system of Copernicus were satisfactorily answered, and it acquired a probability almost equivalent to demonstration; although that demonstration was conclusively given afterwards, by Bradley's discovery of the aberration of light, which furnished the direct and unanswerable proof of the earth's motion. The judgment and sagacity, however, of Galileo, led him to exact results, and though he veiled his discoveries under anagrams, he sturdily divulged and maintained his opinions. By openly espousing these heretical doctrines, the philosopher, in his seventieth year, drew down upon himself the notice, perhaps reluctant, of the Inquisition at Rome, which condemned him to pass the rest of his days in a dungeon; but he was liberated after the expiration of a year, on condition that he should never more teach or hold up the Copernican as the true system of astronomy. So unconquerably imbued, however, was he with the truth which he had taught, that, rising from his compulsory recantation, he whispered to a bystander, "E gira nondimeno," or, as others insist, "E pur si muove." The exhibition was humiliating on both sides.

One of Galileo's discoveries deserves especial mention, since it is mixed up with a notable story about Copernicus. It runs thus: "If the earth move round the sun," said the *paper philosophers*, who objected to the new system, "the moon must also bear company in the annual revolutions of both; moreover, if the planets Venus and Mercury also revolve round the sun, in orbits comprised within that of the earth, they must sometimes appear horned, and have the same phases as the moon, in their apsides or approach towards the earth." "All these will be proved in the course of time," answered Copernicus, with great sagacity, "Venus will be horned, at present our sight is not perfect enough to see those changes." This imputed prediction was verified by the application of the telescope; and, in a Latin metaphor, Galileo announced that the *mater amorum* and *Cynthia* exhibited similar forms. The astronomers of all systems had been sorely foiled, in assuming that Venus was four times as large when near her perigee, as when near her apogee; but it is now seen, that though her visible diameter might countenance the assertion, she does not appear four times as large when she is four times as near, because the bright portion of her disc is not then four times as large.

In 1603, Bayer "leaped into fame" by the publication of his very useful *Uranometria*, in which the principal stars are first designated by the letters of the Greek alphabet, the brightest star in each constellation being α, the next in degree of brightness β, and so on*. Baron Napier contributed largely to the

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* Delambre thinks Bayer gained immortality at a cheap rate, by affixing the Greek and Roman letters, each to a star; but Professor De Morgan has

practical progress of the science, by the publication of his *Tables of Logarithms* in 1614: "an admirable artifice," says Laplace, "which, by reducing to a few days the labour of many months, doubles the life of the astronomer, and spares him the errors and disgust inseparable from long calculations." Seventeen years afterwards, Gassendi, a French philosopher, saw the planet Mercury on the sun's disc, which was the first observation of the kind. A little after this, the youthful Jeremiah Horrox, of Liverpool, discovered that Venus would pass over the disc of the sun on the 24th November, 1639. This event he mentioned but to one friend, Mr. Crabtree; and these two men were the only persons in the world who observed this phenomenon, which was the first transit of Venus that had ever been viewed by human eyes. Horrox wrote in defence of Copernicus and Kepler, ascertained the diameter of Venus, and proposed an improvement in the lunar theory of Bullialdus, which consisted in making the earth always occupy the lower focus of the moon's orbit, and in giving to the centre of the ellipse a movement in the circumference of a small circle described about its mean place, by which the distance of the earth from the apsides of the orbit was made variable, and the corresponding variations in the lunar motions were more correctly exhibited. This theory was esteemed so ingenious as to attract the attention of Sir Isaac Newton, who spoke of Horrox as a mathematical genius of the highest order. Assisted by Crabtree, he procured good instruments, and diligently made many promising observations; but the hopes of astronomers, from the abilities of this extraordinary young man, were soon blasted, for he died in the beginning of the year 1641, when only twenty-three years old. He had just finished his *Venus in Sole visa*, a treatise which shows him to have been

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shown, that he had been preceded by Piccolomini, who was born at Sienna, 1508, and died there 1578. Gaffarell, who wrote about 1650, assures us, that the stars were very anciently ranged in the heavens, by the Hebrews, in the form of letters. This seems to be founded on a legend in *Razael, or Divine Secrets*, a book held to be of at least eighteen hundred years standing; it is there shown, that the Omnipotent dropped the mystic seal, *Emét*, on which all knowledge is founded. This seal was inscribed with three letters; *aleph*, the leader of the Jewish alphabet; *mim*, the centre; and *tau*, the last letter of the alphabet—אמת. This *Emét*, truth, was held as the stamp of universal harmony.

more intimately acquainted with the extent of the solar system than his learned editor, Hevelius.

About this time, English science suffered another irreparable loss in William Gascoyne, the inventor of the micrometer, and the first who applied the telescope to the quadrant: he was killed, while fighting for Charles I., at Marston Moor, 2nd of July, 1644.

The above allusion to Hevelius, must not be understood in the light of a disparagement of that scientific burgomaster, to whom we owe so much. He founded an observatory at Dantzic, and furnished it with a great many excellent instruments, some of which were divided so minutely as to 5′, which was, at that time, esteemed a triumph of art. He constructed telescopes himself, and when he had completed his course of observations, and prepared a great number of fine engravings upon copper with his own hands, published, in 1647, his *Selenographia*, in which the moon's libration in longitude is announced, and wherein we find the first accurate description of the lunar surface. The observations of eclipses had formed the principal study of the early astronomers; but it was Kepler who first showed the practical advantages which may be derived from them, by giving an example of the method of calculating a difference of meridians from an eclipse of the sun. The observations of Hevelius on the spots of the sun, and on the nature of comets, are very numerous; and his Catalogue of 1564 stars, observed by himself, was esteemed for its accuracy, although, from the greater precision given to instruments through the application of the telescope, it cannot now be compared with the more modern ones. And hereby hangs a tale. In 1668, he published his *Cometographia;* and having sent copies of this work to several members of the Royal Society of London, the present gave rise to a controversy with the ingenious but irascible Dr. Robert Hooke, as to the question whether distances and altitudes could be most accurately ascertained by means of plain or telescopic sights, Hevelius recommending the former, and Hooke the latter. In 1673, Hevelius published the first part of his *Machina Cœlestis*, as a specimen of the accuracy of his instruments and observations. The next year Hooke, who was ever ready to break a lance, published some observations on the *Machina Cœlestis*, in which he treated the author with great illiberality. Such was the interest taken in the controversy, that Halley was deputed by the Royal Society to repair to Dantzic, and investigate the subject of dispute. Halley arrived at the house of Hevelius on the 26th of May, 1679, and remained with him till the 17th of July following. On the evening of his arrival, the two astronomers commenced observing, Halley with the telescope and Hevelius with plain sights (*nudis oculis*), to ascertain, from a comparison of the observations, which of the two methods gave the most correct results; and such was the dexterity which Hevelius had acquired, aided by a most excellent eye-sight, that the difference of their readings seldom amounted to more than a few seconds, and in no case to so much as a minute. Halley therefore decided against our countryman, but succeeding astronomers have not confirmed the verdict; and the dispute between Hevelius and Hooke was carried on with improper animosity and rancour on both sides, till death parted the combatants, by carrying off the Prussian on the 28th of January, 1687, the very day on which he completed his seventy-sixth year. Eight years before this event, he had published the second part of the *Machina Cœlestis*, which is peculiarly valuable from its scarcity, owing to most of the copies having been destroyed by a fire, which consumed the author's house at Dantzic, and ruined his observatory and astronomical apparatus. This work is a record of his observations for a period of forty years, comprehending about twenty thousand distances, of all kinds. He made upwards of two thousand observations of the moon; observed more than one entire revolution of Saturn; observed Jupiter about two thousand five hundred times; Mars during eleven revolutions; Venus about two thousand times; and Mercury—dodger as he is—about 1100 times: whilst the observations of the distances of the fixed stars alone, amount to upwards of seven thousand.

Meantime René Des Cartes, a soldier and mathematician, had promulgated a dreamy system of philosophy, which obtained a great degree of credit, especially in France and England. Following the steps of the Epicureans, he assumed that the particles of matter were originally endowed with motions in every direction, and that, by their collision, they acquired circular movements about an infinite number of centres; thus constituting vortices or whirlpools of matter, in the centres of which the sun and stars formed themselves: in a word, that the planets were kept in their courses by means of a fluid matter, which continually circulating carried those bodies along with it. But this ungeometrical theory was demolished by the demonstration of Newton, who showed, that the periodical times of all bodies which swim in a vortex, must be directly as the squares of their distances from the centre of the vortex: whereas the planets, in revolving about the sun, observe quite another law; for the squares of their periodical times are always as the cubes of their distances. It was also objected that planets and comets, while in the same region or part of the heavens, are seen to move with different velocities, and in different directions; and if they are both carried round by vortices, there must be one direction and velocity to allow for the motion of planets, and another to account for the motion of comets. But though the Cartesian doctrine evaporated, the admirable qualities and acquirements of its founder have been greatly applauded. "As to dioptrics," says Halley, "though some of the ancients mention refraction as a natural effect of transparent media, yet Des Cartes was the first who, in this age, has discovered the laws of refraction, and brought dioptrics into a science." He is, however, thought to have borrowed much of his algebra from Harriot, when he visited England about 1631, and is positively averred to have derived even the law of refraction from Willebrord Snell's manuscript papers. Indeed, the originality of his larger views on nature's horror of a vacuum (*fuga vacui*), may be questioned, since that air admits no void, has probably been a general belief through longer periods than history can trace: thus Shakspeare remarks, when Antony sat alone,

> Whistling to the air; which, but for vacancy,
> Had gone to gaze on Cleopatra too,
> And made a gap in nature.

The improvement of the telescope continued to lay open new sources of discovery. The celebrated Huyghens constructed two of these machines, one of twelve feet in length, and the other of twenty-four, with which he completed the discovery of Saturn's ring, and found the fourth satellite of that planet. These discoveries, which gained him a high rank among the astronomers of his time, he communicated to the world in his *Systema Saturninum*, 1659. Huyghens discovered the laws by which a body descends and ascends along the arc of a cycloid, and measured the intensity of terrestrial attraction by the vibrations of pendulums; constructed the first pendulum clock, made *portative* watches, and improved the micrometer. But he unfortunately committed himself when he discovered that satellite of Saturn now termed the fourth, in rashly asserting that there remained no more planetary satellites to find, because their number was, then, exactly equal to the number of primary planets.

In 1663, James Gregory, one of the most eminent mathematicians of the seventeenth century, announced his invention of the reflecting telescope; and the announcement immediately attracted the notice of astronomers, both at home and abroad. In July, 1665, Eustace Divini saw some spots on Jupiter's disc, with a telescope of his own making, and published a description of them at Rome. On the 13th of October in the same year, Mr. William Ball, and his brother Dr. Ball, of Minehead in Devonshire, first saw Saturn's ring double. Auzout and Picard now applied the telescope to the mural quadrant, without knowing that Gascoyne had preceded them; and that he had anticipated the application of the micrometer to the telescope by the former. Dominic Cassini, director of the observatory at Paris, was unwearied in watching the heavens with instruments of a more perfect construction than had ever been known before. With these means he discovered the first, second, third, and fifth satellites of Saturn; and observed that the disc of Jupiter is not circular, being in a sensible degree compressed at the poles, as was soon afterwards proved by the measures of Pound and Short, in England. He also found that the planets Jupiter, Mars, and Venus, turned round their axes in a manner similar to the earth, and determined their time of rotation; he also detected the inclination of the lunar equator, and the coincidence of its nodes with those of its orbit. These discoveries contributed materially to establish the opinion, that all the solar system is subject to one law of action. In 1689, the greatly-gifted Danish astronomer, Olaus Römer, who had already immortalized his name by his fine discovery of the velocity of light by means of Jupiter's satellites, first used the transit instrument; that is, he fixed a telescope in the meridian for the purpose of observing the passages of the heavenly bodies. Besides the essential element which Römer gave, by proving the successive propagation of light, he greatly promoted the diffusion of practical astronomy, by shewing that instruments did not require to be fixed on high towers.

Maraldi, the gifted nephew of Cassini, observed an eclipse of the fourth satellite of Jupiter, in the upper part of his circle; from which he was led to the conclusion, that its inclination is three minutes less than was established by Cassini. This induced further inquiry. By recurring to an observation made B.C. 300, he determined the position of the ascending node of Jupiter's orbit, and comparing it with the position of the same node observed 1934 years afterwards, he found that, in the interval, it had advanced 12½ degrees with respect to the equinoctial points; but these having, in the same time, retrograded 27 degrees, it was evident that the node must have retrograded, with respect to the fixed stars, as much as 14½ degrees. Maraldi, and his cousin James Cassini, suspected also, that the aphelia of the orbits of Jupiter and Saturn had each a progressive motion in space, because, in the course of ages, they appeared to have advanced more than the equinoctial points had retrograded; but want of precision in the observations precluded a positive conclusion. The remarkable fact, however, that the mean motion of Jupiter was then more rapid, and that of Saturn less so than it had formerly been, was detected. This anomalous phenomenon, which is now so well known to be caused by the mutual perturbations of those planets on each other, was a startling difficulty; but Cassini investigated the conditions, and boldly conjectured that the time would arrive, when those effects would be of a contrary nature. His happy prediction has been beautifully verified.

The sciences of that epoch were greatly furthered by the writings of Riccioli, although to comply with the prejudices of the

Church, he expressed himself ambiguously; Ismael Bouillaud, who suggested the laws of planetary attractions; Du Hamel; La Hire, the channel surveyor; and Cotes, the valued friend of Newton, cut off too soon; all promoted the same end. The almost universal genius, Leibnitz, had a large school of admirers, and in most points fully deserved it. But it was fated that he should knock his head against a wall; for he certainly came off second best in his lengthy disputes on mathematics and free will, with Newton and Dr. Samuel Clarke. He was the contriver of the *calculus differentialis*, after having received hints of Newton's method of *fluxions*, on his first visit to England. His philosophy is a system formed, partly in emendation of the Cartesian, and partly in opposition to the Newtonian doctrines. He admits of the circulation of ether with Des Cartes, and of gravity with Newton; but he never explained how these principles could be reconciled and adjusted together, so as to account for the planetary revolutions in their respective orbits. The choleric Dr. Hooke was a man of undoubted talents; and though in 1674 he assigned no law or connecting facts to his revival of the ancient idea of attraction, it was well received as the suggestion of a powerful mind: it is wrong, however, to conclude, that in suggesting that the motion of the planets resulted from a projectile force, combined with the attractive powers of the sun, he was anticipating Newton, since Newton's office was to *prove*. When the *Principia* appeared, Hooke, with his habitual warmth and jealousy, claimed priority concerning the force and action of gravity; but his pretensions were most satisfactorily refuted. Newton, who was candour itself, admitted his claim, but showed at the same time that Hooke's notion of gravitation was different from his own, and that it did not coincide with the phenomena. Newton's merit consisted, not in ascribing the planetary motions to gravitation, but in determining the law which gravitation follows, and clearly showing the dependence of the forms of the orbits on that law of attraction. Taken "bye-and-large," however, Hooke was an extraordinary man: he made helioscopes, pendulum-watches, and other instruments; he was the inventor of the zenith-sector, wherewith to determine whether or not the earth's orbit afforded any sensible parallax; and he gave one of the first hints of making a quadrant for the purpose of measuring angles by reflexion. Cotemporary with Hooke was the illustrious Flamsteed, the first Astronomer Royal, who explained the equation of time, gave the law of the moon's annual equation, and crowned his numerous labours with the *Historia Cœlestis Britannica*, and his unrivalled catalogue of stars. As it is undeniable that he was a man of very extensive practical science and indefatigable zeal, it is most lamentable that he was both unjustly and harshly treated by Halley and Newton.

That important element, the refraction of the heavenly bodies in altitude, had long been known, and is described with tolerable precision in the optics of Ptolemy: the honour of introducing corrections on account of variation of density in the atmosphere, as indicated by the barometer and thermometer, is undoubtedly due to Mr. Lowthorpe, who, in 1698, proved, in presence of the Royal Society, that the refractive power of air is directly proportional to its density.

Flamsteed died in 1719, and was succeeded by Dr. Halley, the greatest astronomer, says M. de la Lande, in England; and Dr. Long adds, "I believe he might have said in the whole world." He had already passed a most active scientific life. In his twentieth year he was selected to observe and tabulate the stars of the southern hemisphere, which he executed during a residence of two years on the island of St. Helena, in a manner which procured him the name of the Southern Tycho. His means consisted of a pendulum clock, a brass sextant of 5½ feet radius, a telescope of 24 feet, and some minor instruments; and the number of stars he observed was 341. We have seen that he was sent on a visit to Hevelius in 1679; and in 1680, on his way between Calais and Paris, he had, the first of any one, a sight of the remarkable comet of that year, as it appeared for the second time in its return from the sun. This suggested to him the idea of writing a treatise on the subject of comets, in which he investigates the orbits of those wandering bodies, and predicted the return of that of 1758, which was the first prediction of its order that was ever verified. To carry on his inquiries into magnetical variations, King William commissioned him to the command of the Paramour, a pink of ten guns, in 1698. Having crossed the line, his men grew sickly, and the first lieutenant with some others openly mutinied; he thereupon returned home, got his lieutenant tried and cashiered, and set sail again, with a fresh batch of officers, in September, 1699. Captain Halley now traversed the vast Atlantic Ocean in both hemispheres, and completed the necessary observations for his magnetic chart. He was next employed on a survey of the British Channel; and in 1703, he was engaged by the Emperor of Germany to survey the coast of Dalmatia. Among other obligations, we are certainly indebted to him for prevailing on Newton to publish the *Principia*. After a course of successful researches into every branch of knowledge, he died in January, 1742, aged eighty-six years, and was buried at the church of Lee in Kent. The inscription states that, with his dearest wife, there reposes by far the chief astronomer of his age,—*astronomorum sui sæculi facilè princeps;* and adds, "That you may know, reader, what kind of, and how great a man he was, read the multifarious writings with which he has illustrated, adorned, and amplified nearly all the arts and sciences." This tomb was recently opened to receive the corpse of Mr. Pond, the late astronomer royal. Halley, who retained his half-pay as a captain in the navy to the last, was succeeded by Dr. Bradley, to whom we are indebted for two of the most beautiful discoveries of which the science can boast—the aberration of light, and the nutation of the earth's axis. Aberration was a valuable accession as well to physics as to practical astronomy; and it was the last link wanting in the chain of evidence relating to the Copernican system, by changing an apparent anomaly into a normal fact, as will presently be shown.

This remarkable epoch, which gave to science and philosophy a new existence and a new form, was crowned by the incomparable achievements of Sir Isaac Newton, truly the *Princeps Philosophorum.* By the diligent exercise of the sagacious penetration, inventive genius, and profundity of thought, which this magnate of the intellectual world brought to bear upon the elements gradually accumulated during a long series of ages, the laws by which the material universe is held in equilibrium were revealed; and an advance to perfection in mechanics, mathematics, and physics, was the consequence. The solidity of his knowledge was animated by a vivid imagination, so that his inquiries were as bold as various. His sublimest discovery was that all the long-prevalent and vague notions of attraction, resolved themselves into the all-pervading influence of gravitation; an influence by the application of which he was enabled to account satisfactorily for all the visible occurrences in the universe: and to the illustrious Laplace belongs the high honour of having completed the development of this theory, by shewing that there remains not a single phenomenon, in what has since been denominated physical astronomy, which that principle is not capable of explaining. Still this grand discovery was nearly lost to the world, from the great philosopher's doubting its conformity to fact, and therefore feeling inclined to lay it aside. The incident is interesting in the history of the human mind. At first, Newton had considered the bodies attracting and attracted as mere points; but he next showed, that the particles of matter composing the great bodies of the solar system are held together by an attractive power similar to that which is in action between the bodies themselves. Hence he inferred that bodies are attracted with forces which are directly as their mutual masses; decreasing from the centre of any gravitating body, in the ratio of the squares of the distance from that centre: and to demonstrate this, it was necessary to determine the identity of the force of terrestrial gravity, with that which retains the moon in her orbit. But when Newton first attempted to verify this hypothesis, the proportion between the radius of the earth and that of the lunar orbit was not exactly known; and a slight discordance between the result of the calculation and that proportion, induced him for a time to abandon his great discovery. Ten years afterwards, happening, at one of the evening meetings of the Royal Society, accidentally to hear of Picard's measurement of a degree of the meridian in France, he was tempted to go over his calculations again, and the result verified his law. It is recorded that, towards the end of the investigation, his agitation was so great, that he was under the necessity of requesting a friend to assist him in finishing it. This determined the question definitely. From the power by which planets act upon their satellites, and cause the movements observed in the latter, he was enabled to determine the quantities of matter, and the densities, of those planets which are attended by satellites. In applying the principle to our globe, he taught, that the centrifugal force arising from the diurnal rotation, causes the particles in the equatorial regions to recede from the centre, thus producing an inflation there, and a proportional flatness or oblateness at the poles, in a ratio as 229 to 230. At the surface, the centrifugal force diminishes that of gravity, by the product of the centrifugal force at the equator multiplied by the square of the co-sine of the latitude. Now, since it is necessary for the maintenance of the equilibrium, that the column, by its length, should compensate the diminution of its weight, it ought to surpass the polar column by one-twentieth of its length, multiplied by the square of the above co-sine. That such is the fact has been beautifully proved *à posteriori*, from the oscillations of pendulums being slower and smaller—owing to diminished weight—in the equatorial than in the polar parts of the globe; whence it is evident, that the equatorial regions are more removed from the influence of the central attractions than the polar ones. These results immediately afforded to the penetrating mind of Newton, a solution of the phenomenon of the precession; he had made a slight mistake, it is true, from the want of correct data, but, as his candid commentator, the learned Daniel Bernouilli, acknowledged, " he saw through a veil, what others could hardly discover with a microscope in the light of a meridian sun."

Newton, however, was not permitted to walk the course in peace. Objections were raised against his universal principle, as an occult and preternatural scheme, and a mere begging of the question; while not a few, unable to discriminate between assigning causes, and proving their effects, declaimed against its originality. The latter class brought forward the hint contained in Kepler's introduction to his remarkable work on Mars, as well as Bacon's suspicion of the existence of such a cause, the singular observations on gravity in old Eden's *Arte of Navigation*, and the casual allusions scattered in older writers; yet so very obscure were the notions of even the most enlightened philosophers on this subject of gravitation, that it had never been successfully applied to the explanation of a single astronomical phenomenon. It was, in fact, a faint gleam of knowledge of a power in nature, but no perception of the means by which that power produces the phenomena of the earth and the heavenly bodies: thus the account which Lucretius gives, (lib. II. *v.* 225—242,) is sufficiently *Newtonian* as to an effect of gravity on descending bodies, but silent as to its cause. "Attentively peruse the *Face of the Moon* of Plutarch," says Voltaire, "and you will find, if you look for it, the doctrine of gravitation; but the true author of a system is he who demonstrates it." Others have seen a direct allusion to the theory of gravitation in Ovid's opening hexameters:

> Circumfuso pendebat in aere Tellus
> Ponderibus librata suis.

The progress of that knowledge, which, by observation and experiment, expels indistinctness and conjecture, is necessarily slow and gradual; whence, even in the hands of Kepler, Galileo, Hooke, and Bullialdus, the principle of attraction remained fruitless, and the materials were waiting till the mist then obscuring it should be dispelled by a transcendant intellect. The geometry of the Greeks undoubtedly contributed to the discovery of the planetary laws of Kepler; and these, with the sound dynamic principles of Galileo, gave birth to Newton's sublime doctrine of universal gravitation, which affords universal demonstration, and satisfies the conditions both of mechanics and geometry*. By his supreme invention of the fluxionary calculus, he led the way to sublime soaring, and enabled a galaxy of profound mathematicians to pursue his physical researches, and develope the most abstract and abstruse effects of the simple cause which he had advanced. Among other labours we may proudly quote the

* While this sheet is in the press, I have received a letter from the Rev. C. Turnor, which may please the reader: "Knowing the interest which you take in everything connected with Newton, I am sure you will take the trouble of presenting, in my name, to the Royal Society, the Solar Dial, cut in stone, *with his own hand*, when a boy, which has been recently taken out of the wall of the manor-house at Woolsthorpe, in which he was born. You are aware that the house has been the property of our family for more than a century, and is now in the possession of my nephew, who kindly consented to its removal, when I mentioned that it would be presented to the Royal Society, over which Newton presided for so many years." *See* p. 17.

investigation of the planetary perturbations, or the refined doctrine of their reciprocal influences, by which every inequality of motion is ultimately redressed, and the permanence and stability of the solar system incontestibly established on an immoveable basis. This result stamps the pre-eminence of modern science, and, indeed, forms its *experimentum crucis*. Newton himself had not only discovered the cause and principle which maintains the frame of the universe, but, by the balance of an exalted geometry, ascertained its law and intensity. His principle being then assumed by other philosophers, the calculated phenomena of nature were found to agree with observation, by which a conquest far above the circle of mere geometrical truths was obtained, and the justness of the hypothesis from which they were derived established beyond dispute. Still the retardation of planetary motions sorely perplexed the astronomical world; and the knowledge requisite for their development was of tardy growth. But the veil is at length withdrawn, and the Newtonian theory of the mysterious influence of gravitation and attraction is successfully carried to an extent beyond the warmest anticipation of its discoverer. "These inequalities," says Laplace, the most gifted follower of Newton, in treating of the reciprocal attraction of the planets, "seemed formerly inexplicable by the law of gravitation; but they are now one of its most striking proofs. Such has been the fate of this brilliant discovery, that every difficulty which has arisen, became for it the subject of a new triumph; which is the most certain characteristic of the true system of nature. "Tel a été le sort de cette brillante découverte, que chaque difficulté qui s'est élevée, est devenue pour elle, un nouveau sujet de triomphe; ce qui est le plus sûr caractère du vrai système de la nature." This is the justification *à posteriori* of the English portion of Pope's hybrid epitaph:

> Nature, and nature's laws, lay hid in night:
> God said, LET NEWTON BE! and all was light.

In whatever degree of national exultation we may indulge, at having produced one whose genius soared supremely over that of the greatest philosophers of his own, and of ancient times, the world at large has warmly united with us in venerating him; and in France especially, the noblest estimate of his transcendental merit has been made, albeit it led to the demolishment of their own Cartesians. Bailly, whose glowing portrait of the *Princeps Philosophorum* is stamped with skill and dignity, remarked, that "as the empire of Alexander was divided among his successors; so the sceptre of Newton passed into the hands of Clairaut, Euler, and D'Alembert." The labours of these great mathematicians, together with those of Lagrange and Laplace, have consolidated the empire of their illustrious founder, and reared an imperishable trophy to his fame. In thus abandoning the airy and hypothetical notions of Des Cartes, and perpetuating the immutable truths of one whom Halley considered a near approach to the divine intelligence, the names of the continental geometers must for ever be associated with that of their illustrious prototype, in the history of physical astronomy. Yet the services thus rendered to science by the disciples, eminent as they are, cannot be placed in competition with those which emanated from the vast genius of their master; whose mind, superior to common barriers, and equally distinguished for extent and accuracy of intellect, not only discovered the existence of a solid principle, but even created the calculus, by which alone it could be demonstrated, and all its difficulties vanquished. "Yet," says Voltaire, "if Newton had been in Portugal, and any Dominican had discovered a heresy in his inverse ratio of the squares of the distances, he would without hesitation have been clothed in a *san benito*, and burnt as a sacrifice acceptable to God at an *auto-da-fé*."

The Newtonian philosophy, that pure and transcendental knowledge which reveals the unfathomable sublimity of the heavens by which we are surrounded, is grounded on physics and mathematics; the first treat of those laws of matter and motion which regulate and govern the various phenomena of the creation, and the last by expressing the effects of those laws in terms which can be employed in calculation, raise new fabrics on a known basis; while the union of the two condenses the whole mass of facts and deductions into one common and useful series; opening to the contemplative philosopher, an intensely interesting glance into the means employed by Omnipotence for perpetuating this admirable structure. The leading quantities requisite for the mathematical analysis of the heavens, are simple in their conditions; for all the supposed deviations from a fixed order of recurrence, are but modifications of the governing principle which extends through the velocities, directions, and other motions of the celestial bodies, and those deviations are duly corrected in definite secular periods. These modifications, however, are numerous and vast; and without hard study, and a knowledge of algebra beyond simple equations, the complete doctrine of the reciprocal influences must for ever remain a sealed truth. Though the same plan and government are readily evident to the tyro, still the abstract view of the principles of celestial mechanism is not to be gained by any royal road: human knowledge is generally slow in its progress, and especially that which is founded on the various applications of mathematical calculation. The very language of the calculus, by which alone these great truths can be positively demonstrated, is not to be acquired without a more intense assiduity than many are able to devote to the attainment of science. Now, as this condition must especially be the case with the readers whom I am addressing, it is a great consolation to add, that the Astronomer Royal —albeit one of the most accurate and comprehensive geometers of the age—has published a work on gravitation, wherein an elementary explanation of the principal perturbations in the solar system is given, without the introduction of any algebraic symbols. This valuable book, together with the admirable *Treatise on Astronomy* by Sir John Herschel, would be amply sufficient to convey a fair insight into the curious, complicated, and beautiful structure of the universe, to all who can take a geometrical view of the subject.

A few words must be said here, in the hope of checking the scientific heresy which has of late obtained, in quarters where results ought to have been ascertained before theories were hatched. It being much easier to please the imagination than to satisfy reason, numbers have left the path of genuine science, and plunged into unsubstantial labyrinths, in quest of the meteor which destroyed Cardan, and Albertus Magnus—the ape of Aristotle. Although the increasing accuracy of the planetary tables palpably evinces the truth of the fundamental assertion, the Newtonian philosophy is still arraigned by some of the fanciful; and as so many, even in this age of intellect, still cling to the empiricisms by which conclusions can be leaped at, there are not a few who *study* the demonstrations of St. Pierre, Sir Richard Philips*, Captains Forman and Woodley, Lieutenant Brothers, and other anti-Newtonians, whose works are circulated with exemplary industry among the less-instructed classes. These geocentric sectarians maintain, and pretty violently too, the immobility of our globe as the veritable *centrum mundi*, under the trite axiom, that as no angle can be perceived respecting the fixed stars on a base of a hundred and ninety millions of miles, therefore the earth must be stationary. To this, the prodigious distance of those bodies, as compared even with the major axis of the earth's annual orbit, is a sufficient answer; but it may be added, that the powerful aid of trigonometry, which has enabled us to determine the diameter and orbits of the planets of our own system, is insufficient for the remoteness of the stellar host, and recourse has been had to investigating their parallax by improved instruments and able observation. In watching the diurnal progress of all the celestial bodies, it is obvious that there must be a general cause for the motion; and for argument's sake we will admit, that this cause may exist either in the immobility of the earth and the daily revolution of the heavens around it,—or in the heavens being at rest and the earth revolving round its own axis every twenty-four hours. In either case, the rising and setting of the sun and stars will be presented to a certain degree, in the same order; yet the revolution of our globe on its own axis, is much more consonant with the comparison of appearances within our reach, and with the established laws of motion, than the revolving of the whole

* This pseudo-mathematical knight once called upon me, at Bedford, without any previous acquaintance, to discuss those *errors* of Newton which he "almost blushed to name," and which were inserted in the *Principia* "to puzzle the vulgar." He sneered with sovereign contempt at the "Trinity of gravitating force, projectile force, and void space;" and proved that *all change of place is occasioned by motion!* He then exemplified the condition by placing some pieces of paper on a table, and slapping his hand down close to them, thus making them fly off, which he termed applying the momentum. All motion, he said, is in the direction of the forces; and atoms seek the centre by "terrestrial centripetation," a property which causes universal pressure,—but in what these attributes of pushing and pulling differ from gravitation and attraction, was not expounded. Many of his "truths" were as mystified as the conundrums of Rabelais; so nothing was made of the motion.

heavens. One of the strongest proofs of rotation is the oblate-spheroidal figure of the earth, its polar diameter being considerably less than its equatorial one, a fact in which the deductions of profound theory have been proved by actual measurement. In round numbers we may estimate the terrestrial circumference at twenty-five thousand miles; the space which every point of its equator must pass through, if the earth revolves on its axis, is about seventeen miles per minute; a velocity nearly equal to that of a cannon-ball, on its first leaving the mouth of the gun. But the apparent velocity becomes absolutely insignificant compared with what the stellar bodies would have to fly at, on the other supposition; the sun would have to proceed twenty thousand times quicker than a cannon-ball, and the daily motion of Uranus must be twenty times greater than the sun's, because it is about twenty times further distant from the earth than that luminary. These velocities are astounding, but they are snail-tracks in proportion to the rapidity with which the fixed stars must move to accomplish the same task: for if their distance be roundly assumed at two hundred thousand times that of the sun from us, they must move over the space of 1,400,000,000 miles per second, in order to complete a revolution round the earth in twenty-four hours. This is a *pauler* to the geocentrics: but let us, in addition, consider the bulk of these different bodies, and a new question arises as to the extraordinary powers that would be necessary to retain them in their orbits, and counterbalance the amazing centrifugal force which they must possess. Whilst, on the contrary, the observed rotatory motions of other planets, and various analogies, support the conclusion, that the earth revolves daily upon its axis; while its annual motion is incontestibly established by the exactness of the sidereal year, by the periodical synodic aspects of the planetary spheres, and, above all, by the aberration of light*.

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* The aberration of light being the most direct proof of the earth's annual motion, the reader may be reminded, that during the time which light takes to pass over the semi-diameter of the earth's orbit, which is 8′ 13″, the earth ought to move 20″·5 in its orbit; and this is found by observation to be actually the case.

Many still stigmatize the heliocentric system as rank impiety, and mercilessly drag in, to sustain hypotheses equally repugnant to mathematical and religious knowledge, scraps and texts twisted from Scripture. The Holy Writ, the guide of religion and morality, was not given to instruct men in astronomy: yet there is a large class who wish, like Mohammedans with their Korán, to regulate the progress of intellect, by their own literal conceptions of abstruse passages in the sacred text. The fixity of the earth is their *Pons Asinorum.* "How," they triumphantly demand, "how could ships sail on the ocean, if the globe had axical motion at the rate of nine hundred geographical miles an hour?" But *quick* and *slow* motions are comparative terms; and the circuit which occupies months or years may be called slow. The earth in its diurnal motion requires twenty-four hours to complete one revolution round its axis; it therefore has not the absolute velocity which our reckoning by miles would make us fancy. But these sages are not aware, in objecting to axical motion "like a rolling barrel," of the incomparably greater centrifugal velocity which they necessarily assign to the millions of splendid orbs which bespangle the heavens. The objection to the world's moving around its "noiseless axis," has been a favourite position with the persecutors of astronomy, and deficiency of argument has generally been made up by acrimony of invective. In the sentence pronounced by the seven recondite cardinals on Galileo, it was dogmatically observed: "The proposition that the sun is the centre of the world, and immoveable, is absurd, false in philosophy, and specifically heretical; for it is expressly contrary to the Holy Scriptures." Many of the members of the Roman church knew better than this, and saw the imprudence of endeavouring to extinguish the torch of science by mistaken expositions of religious authorities, a practice which Kepler thus condemned: "By striking the edge of your axe upon iron, it becomes of no avail even against wood." And in the middle of the eighteenth century, the two learned commentators upon Newton, in publishing their work at Rome, were obliged to make this degrading admission: "Newton, in his third book, adopts the hypothesis of the motion of the earth: we could not explain his propositions without making the same hypothesis. Hence we are compelled to take a character different from our own; for we profess obedience to the decrees promulgated by the popes against the motion of the earth." "Ceterum latis a summis pontificibus contra telluris motum Decretis nos obsequi profitemur." Yet the Newtonian doctrines, softened by the term *hypothesis* instead of *theory*, had been taught in the Roman Catholic universities of Europe; until at length, in 1818, the voice of truth was so prevailing, that Pius VII. repealed the edicts against the Copernican system, and thus, in the emphatic words of Cardinal Toriozzi, "wiped off this scandal from the church." But while this pope, with whom I had the honour of being personally acquainted, was wiping off the scandal, various publications still adhered to the earth's immobility, as the actual *dictum* of the book of Genesis.

Among the antagonists of Newton, few have more temerariously assailed him than Captain Forman, who asserts that the paragon of philosophers is "continually committing the grossest blunders, in consequence of neglecting the rules of geometry;" and that, for his monstrous proposition on the gravity of a body resting on the earth's surface, he "richly deserves to be decorated with the cap and bells." This, as well as the other effusions of the Geocentrics, might have been passed over, but that they are lauded, *ad astra*, by many who deserve a better mental pabulum, and have led numbers of good seamen rashly to despise the tidal doctrines. It is surprising that a navigator, of all others, should not have satisfied himself that the tides follow periodically the course of the sun and moon, especially as old pilots, albeit unacquainted with theories, predict the times of high water, with considerable truth, by the mere compass-bearing of our satellite. The Newtonian theory of tides was put to practical test in the late war, which ought to have worked conviction in the minds of naval officers. The blockade of the Texel was successfully managed on a system at once economical in anxiety and labour. The ports of Holland admit of the ingress and egress of large ships only during spring-tides; two days before which, our squadron regularly took its station off the Texel, and remained there only as many days after the full and change of the moon, so that the Dutch lost all the advantages of high tides, and their heavy ships were effectually detained within their harbours. This amusingly countenanced the well-known assertion of M. Le Prieur, that tides were attached to the ocean to facilitate the entry of ships into their respective ports, a conclusion which Voltaire held to be equivalent to contending that legs were made to wear boots. Those who reason upon subjects which they do not understand, must advance arguments not worth refuting in form; but their reckless assurance may be noticed. The symptoms of the anti-Newtonian disease are, a feverish anxiety to square the circle, trisect an angle, duplicate the cube, detect perpetual motion, and the like paralogisms: the capacity of the patients for finding the longitude is not disputed.

It had long been suspected that the ebb and flow were produced by solar and lunar influences, as may be gleaned from Manilius, Plutarch (*De Iside et Osiride*), Macrobius, Pliny, Ptolemy, and other ancient writers; but Kepler was the first who formed fair conjectures respecting the true mode in which they act, stating distinctly, that the attractive virtue of the moon is evident from its enticing up the waters of the earth. What Kepler, however, only touched *extremis digitis*, was developed and demonstrated by Sir Isaac Newton. His sublime mind, urged by an ardour at once inextinguishable and comprehensive, not only supplied the principles for extending human knowledge, but also advanced far towards the solution of its most abstruse problems: still some were necessarily left more or less obscure, till completely determined by the multiplied experiments and accurate observations of many subsequent years. Thus has Newton's theory of the tides awaited the labours of Bernouilli, Maclaurin, Euler, Laplace, Poisson, Airy, Lubbock, Whewell, Chazallon, Monnier, and various other able and laborious inquirers, to be pronounced incontrovertible: yet has it been noisily assailed by jejune dabblers, who never suspect, that were the globe entirely covered with water of an uniform depth; its flux and reflux might be still more accurately computed and predicted. But when it is considered how greatly the attracting forces are modified by the rotation of the earth, and the irregularities of straits, continents, and islands, with other embarrassments, it is idle to expect that any general theory can assign with minute accuracy all their precise effects, and residual phenomena. Still a clear practical deduction is easily available, in illustration of this hydrodynamic law, the most striking result of attraction which is presented to the evidence of the senses, although it admits of various exceptions, from local and other circumstances*. The forces of the moon's and sun's attraction are to each other as 51 to 10; the sum and differences of these numbers are 61 and 41; therefore the spring tides caused by the moon and sun will be to the neap tides in the same proportion, or as 6 to 4; that is, the first are better than one-third greater than the last; consequently, if the sun can raise the tide 1 foot 11 inches, the moon will raise it 9 feet 11 inches, and both together, during the spring tides, about 11½ feet, but in neaps only about 7½ feet. Here another proof is afforded of the figure of the earth; not only does the centrifugal zone considerably raise the waters in the region of the equator, by the motion of the diurnal rotation, but they are moreover elevated about 25 feet, twice a day, by the tides: the lands about the line should then be perfectly inundated. But they are not so; therefore the region of the equator must be much more elevated, in proportion, than the rest of the earth: whence the earth is a spheroid, or flattened at the poles. It has also been demonstrated, that the tides increase as the cubes of the distance decrease, so that the moon, at half her present distance, would produce a tide eight times greater:

> Attractive Power! whose mighty sway
> The ocean's swelling waves obey,
> And mounting upward, seem to raise
> A liquid altar to thy praise.

The interval between the death of Newton and the epoch of this Cycle presents so brilliant a display of the fruits of

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* From local examination, I hardly think Sir Isaac was fortunate in his selection of the mouth of the Avon, for forming his estimate of the respective powers of the sun and moon in influencing the tides. In many cases, the rise of the water owes its elevation to rains, and to freshes from the interior; in addition to which, the water is known to pool there, which would seriously affect the exactness of a spring and neap comparison.

intellect, in observation, analysis, methodical deduction, and extended views, that numerous gaps left by theory are now nearly filled up, and celestial mechanics are rescued from the uncertainties of hypothesis. Among these fruits may be instanced the transcendental labours, which have demonstrated and established the stability of the system; the expeditions to observe the transit of Venus over the sun's disc; the operations for determining the figure of the earth; and the late stupendous discoveries in the heavens. These, however, are so universally and familiarly known, that having thus brought the reader from the earliest epoch of the science down to the death of Newton, since whose time "all is light," it may now be sufficient merely to submit a muster-roll of the leading astronomers, mathematicians, navigators, opticians, engineers, and mechanicians, whose united labours have achieved such magnificent results. In this list, the names are placed in chronological order, from the year of each person's death, and to each is appended a slight note upon their leading scientific pursuit: it must, however, necessarily be defective in numbers, since no branch of human knowledge has had a greater host of cultivators and admirers than astronomy.

1729. Maraldi, J. P. *French arc of the meridian. Parallax of Mars. Jupiter and his satellites.*

—— Bianchini. *Rotation of Venus. Reform of the Calendar. Eclipses.*

1731. Taylor. *Centre of oscillations. Perspective. Infinite series.*

1732. Louville. *Solar Tables. Obliquity of the ecliptic. Inquiries in physical astronomy.*

1735. Carbone. *Eclipses and occultations.*

—— Derham. *Eclipses. Solar spots. Nebulous stars.*

1739. Manfredi. *Lunar transits. Ephemerides motuum cœlestium.*

1740. Kirch. *On comets, occultations, and new stars.*

1741. Sharp. *On geometry. An improver of astronomical instruments.*

1742. Halley. *Zealous pursuit of astronomy, both in theory and practice.*

1744. Hadley. *Improver of telescopes. Inventor of the reflecting quadrant.*

1746. Maclaurin. *Algebra. Fluxions. On Newton's discoveries.*

1749. Châstelet (Mad. la Marquise du). *Translator of the Principia into French, and commentator upon Newton.*

1751. Graham. *Invented the mercurial pendulum, and zenith sector.*

1752. Whiston. *Theory of the earth. Longitude at sea. Newtonian philosophy.*

1754. De Moivre. *Mathematics. Transits of Venus and Mercury. Infinitesimal equations.*

1755. Weidler. *Transit of Mercury in 1736. Explicatio Jovilabii Cassiniani Historiæ Astronomiæ.*

1755. Marinoni. *Geodesy. Founder of a Specula domestica.*
1756. Cassini II. (James). *Figure of the earth. Planetary elements. Inclination of orbit of Saturn's fifth satellite. Elements of the planets. Saturn's ring.*
1757. Fontenelle. *Elements of geometry. On the plurality of worlds.*
1758. Bougier. *Figure of the earth. Arc in Peru. Invents a two-object glass micrometer.*
1759. Maupertuis. *Measure of a degree in Lapland. On variable stars.*
1760. Hodgson. *The eclipses of Jupiter's satellites.*
—— Godin. *Degree in Peru. On scientific inventions and machines.*
1761. Poleni. *Solar and lunar eclipses. De vortibus Cœlestibus.*
—— Simpson, T. *Trigonometry. Fluxions. On Chances. Speculative and mixed mathematics.*
—— Dollond. *Discoveries in optics. Achromatic telescopes. Invents the double-object glass micrometer.*
1762. Bradley. *Practical astronomy. Comet of* 1737. *Discoverer of aberration and nutation.*
—— Gersten. *Transit of Mercury,* 1743. *Eclipses and occultations.*
—— La Caille. *Solar Tables. Uranography of the southern hemisphere. Arc of the meridian in Caffraria.*
—— Mayer. *Theory of librations. Equations of condition. Repeating circle. Catalogue of* 998 *zodiacal stars. Solar and lunar Tables.*
—— Manfredi, G. *Transit of Mercury in* 1736. *Solar maculæ. Solar and lunar eclipses.*
1764. Bliss. *Transit of Venus,* 1761. *Practical astronomy.*
—— Horrebow. *Mathematics. Refractions. Clavis Astronomiæ. Copernicus triumphans.*
1765. Sisson. *Improvements in dividing and fitting mural quadrants.*
—— Chevalier. *Eclipses, and general observations.*
—— Clairaut. *Lunar Tables. Researches in the planetary theory. Cometary perturbations.*
1767. Dunthorne. *On comets. Satellites of Jupiter. Lunar Tables.*
1768. De l'Isle. *Transit of Mercury,* 1723. *Parallaxes.*
—— Short. *Improvements in telescopes. Eclipses. Transits of Venus.*
—— Camus. *Inquiries in mathematics and mechanics.*
1769. Chappe. *Transit of Venus in* 1761 *at Tobolsk. Ditto in* 1769 *at California. Meridian passage of Mercury. On the zodiacal light. Halley's solar and lunar Tables.*
1770. Long. *History of astronomy. Made the gigantic astronomical machine at Cambridge.*
1771. Pemberton. *On eclipses. Lunar parallax. Newton's philosophy.*
—— Fontaine. *Theory of differential equations.*
1774. La Condamine. *Conic sections. Pendulum vibrations. Arc of meridian in Peru.*
1775. Lyons. *Nautical astronomy. On fluxions.*
1776. Harrison. *Inventor of the marine time-keeper, and the compound or grid-iron pendulum.*
—— Bird. *Improver of astronomical graduated instruments.*

1776. Pezenas. *Fluxions. Optics. Nautical astronomy.*

—— Ferguson. *Astronomical principles, precepts, and tables.*

1777. Dixon. *Transit of Venus in* 1761, *at the Cape of Good Hope; and that of* 1769 *at Hammerfest. Arc of meridian in America.*

—— Lambert. *On comets. Photometry. Tables of eclipses. On the construction of the universe.*

1779. Cook. *Nautical astronomy. Transit of Venus in* 1769 *at Otaheite.*

1781. Beccaria. *Arc of the meridian in Piedmont.*

1782. Bernouilli, D. *Researches in the tidal theory.*

—— Costard. *Researches in ancient astronomy and chronology.*

—— Zanotti. *Bologna ephemerides. Catalogue of* 414 *zodiacal stars.*

1783. Wargentin. *Transits of Venus in* 1761 *and* 1769 *in Sweden. Tables of Jupiter's satellites.*

—— Lexell. *Solar parallax. Lunar occultations. Cometary orbits. On the great comet of* 1770.

—— Mayer, C. *Transits of Venus in* 1761 *and* 1769, *at Schwesingen.*

—— D'Alembert. *Planetary theory. Figure of the earth. Precession of the equinoxes.*

—— Euler. *Analytical treatment of the planetary motions. Theory of the moon. Solar and lunar Tables.*

1784. Frisi. *On gravity, hydraulics, mechanics, and electricity.*

—— Cassini III. (De Thury). *The French arc of meridian. Refractions.*

1786. Ludlam. *Occultations and eclipses. Transit of Venus in* 1769.

—— Ximenes. *Transit of Venus in* 1761. *History of Tuscan astronomy.*

1787. Boscovich. *Optics. Degree of the meridian at Rimini. Invents a prismatic micrometer.*

—— Mason. *Degree of the meridian in North America. Lunar Tables. Transit of Venus in* 1761 *at the Cape of Good Hope.*

1788. Fouchy. *On the lunar atmosphere. Transits of Mercury.*

—— Maraldi II., J. D. *Theory of Jupiter's satellites.*

—— Lapaute, Madame. *Planetary Tables. Parallactic angles. On the cometary theory.*

1789. Roy. *Geodesy. Trigonometrical survey of England.*

—— Dagelet. *Sidereal observations. Astronomer to La Pérouse.*

1790. Favre. *Mathematical and astronomical inquiries.*

1792. Le Gentil. *Refractions. Transit of Venus in* 1769 *in India.*

—— Hell. *Solar parallax. Transit of Venus in* 1769 *in Lapland.*

—— Smeaton. *Improvements in various astronomical instruments. Adapts an equatoreal micrometer and clock.*

—— Dunn. *Probability of a lunar atmosphere. On comets. Transit of Venus in* 1761.

1793. Bailly. *History of astronomy. Theory of Jupiter's satellites. On the zodiacal stars.*

—— Mudge. *Improvements in reflecting telescopes and chronometers.*

1794. Saron. *Orbit of Uranus. Cometary orbits.*

—— Condorcet. *On analysis and integral calculations.*

—— Du Séjour. *Inquiry into parallaxes. Irradiations. Inflections. Celestial motions.*

1796. Pingré. *Transit of Venus in 1761 at Rodrigues; and that of 1769 at St. Domingo. On chronometers.*

1797. Maraldi III., J. P. *Astronomical observations at Perinaldo.*

1798. Wales. *Astronomer to Cook. Transit of Venus in 1769 at Hudson's Bay. On ad-fected equations.*

1799. Borda. *An improved reflecting circle. On navigation.*

—— Le Monnier. *Solar and lunar Tables. Zodiacal charts.*

—— Montucla. *History of mathematics. Observations at Cayenne.*

—— Liesganig. *An arc of the meridian in Hungary.*

1800. Ramsden. *Numerous improvements in the construction of astronomical instruments.*

—— Cousin. *Differential and integral calculus. Physical astronomy.*

—— Bandini. *Commentary on Aratus.*

1801. Bory. *Nautical astronomy, and its instruments.*

1802. Swanberg. *Measure of an arc in Lapland.*

1803. Fontana. *Integral calculus. Indefinite equations.*

—— Jeaurat. *Tables of Jupiter. Chart of his sixty-four stars of the Pleiades. On dissecting the angle.*

1804. Méchain. *Grand arc of the meridian. Comets. Cometary orbits.*

1805. Robinson. *On light. The orbit of Uranus.*

1806. Horsley. *Solar atmosphere and parallax.*

—— Coulomb. *General mathematics and physics. Magnetism.*

1807. Berthoud. *Improvements in horology, and marine chronometers.*

—— Lalande, J. *Planetary tables. Lunar librations and parallax.*

—— Atwood. *Theory of motion. Rotation of bodies.*

1809. Cavallo. *Atmospheric electricity. On micrometers.*

—— Dupuis. *Researches into ancient astronomy.*

1810. Cavendish. *Density of the earth. Prismatic micrometer.*

—— Hornsby. *On solar parallax. Transit of Venus in 1769.*

1811. Maskelyne. *On local attraction. Establishes the Nautical Almanac. The Greenwich stars.*

—— Nouet. *Tables of Uranus. A meridional arc in Egypt.*

—— Bougainville. *Integral calculus. Nautical astronomy.*

1813. Lagrange. *On the propagation of sound. Gravitation of the planets. Analytical functions. On libration. Jupiter's satellites. Attraction of spheroids. Variations of the elliptic elements.*

1814. Flinders. *Nautical astronomy. Local magnetism.*

1815. Wollaston, F. *Transit of Venus in 1769. Stellar zones. Catalogue of circumpolar stars.*

1817. Messier. *Catalogue of clusters and nebulæ. Comets and eclipses.*

1818. Cagnoli. *Conic sections. Occultations. Catalogue of stars.*

1819. Playfair. *Mathematical and astronomical disquisitions.*

1821. Vince. *On fluxions. Infinite series. System of astronomy.*

—— Mudge, General. *The great English arc of the meridian. Geodetical operations.*

1822. Herschel, Sir W. *Extensive telescopic discoveries in planets, nebulæ, double stars, &c. Improver of metallic mirrors, telescopes, micrometers, and every means of observation.*

1822. Delambre. *Tables of Jupiter, Saturn, and Uranus. Grand French arc of the meridian. On refractions. Solar tables. An elaborate history of astronomy.*

1823. Lambton. *Grand arc of the meridian in India.*

—— Hutton. *On the mean density of the earth.*

1825. Burckhardt. *Tables of the moon. Cometary theory. Orbits of the new planets.*

1826. Bode. *Celestial maps, and index of* 17,240 *stars. Gradations of the planetary distances.*

—— Frauenhofer. *Researches in physical optics. Optical improvements.*

—— Piazzi. *Discovery of Ceres. Catalogue of* 7646 *stars.*

1827. Woodhouse. *On the transit instrument. System af astronomy.*

—— Calandrelli. *On stellar parallax. Opusculi Astronomici.*

—— Laplace. *Analytical investigations. Secular inequalities of the solar system. Theory of Saturn's ring. Orbit of Uranus. Theory of the tides. Méchanique céleste.*

1828. Wollaston, W. *Invents the goniometer and dip-sector. Various experiments on light. On horizontal refractions. Finite extent of atmosphere.*

1829. Young. *Vision, light, colours. Physical optics. Nautical astronomy.*

1831. Fallows. *Catalogue of* 275 *southern stars.*

—— Pons. *Cometary observations.*

—— Forster. *Observations on refraction. Pendulum experiments*.*

1832. Zach. *Solar tables. Catalogue of* 1830 *zodiacal stars. Tables of aberration and nutation. On local attraction.*

—— Oriani. *Perturbations of Mercury and Ceres. The lunar theory.*

—— Groombridge. *Tables of refraction. Catalogue of* 4243 *circum-polar stars.*

—— Le Gendre. *On the integral calculus. Method of least squares. Elliptic numbers. Various geodetical operations.*

1833. Harding. *Discovered the planet Juno. Compiled a Celestial Atlas.*

—— Brioschi. *Practical astronomy and geodetical operations.*

—— Caturegli. *Places of the four new planets. Table of zodiacal stars, with constants. Bologna ephemerides.*

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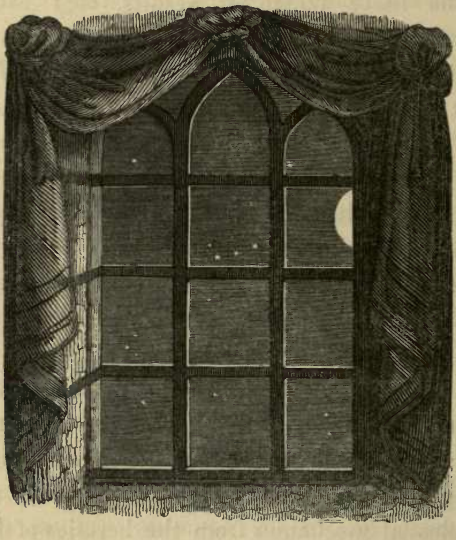
* In recording the untimely death of my zealous and scientific friend, Captain Forster, who was drowned from a canoe in the River Chagres, Isthmus of Darien, I cannot but regret the being unable also to state the period of demise of another seaman, the skilful Spanish astronomer, Don José Joaquin de Ferrar. This gentleman was a bright ornament of that powerful navy, which, in our own times, has passed away; and he must be placed in the very foremost rank of maritime savans. Proofs of his scientific talents may be seen in the *Memoirs of the Royal Astronomical Society of London*, where his papers on cometary orbits and solar parallax exhibit an intimate acquaintance with the subject; and his process for obtaining the longitude of the Havannah in Vol. IV. is so truly admirable, that I cannot but recommend it to the reader's attention. His able discussion of the transit of Venus in 1769, in Vol. V., is dated from Cadiz, so late as 29th December, 1815.

1834. Soldner. *Astronomical and geodetical operations. Astronomische Beobachtungen.*
—— Burg. *Lunar tables. Ephemerides of Vienna.*
1835. Brinkley. *Tables of refraction. Stellar parallax.*
—— Troughton. *Numerous improvements in the structure and graduation of astronomical and geodetical instruments.*
—— Kater. *Convertible pendulum. Floating collimators.*
1836. Pond. *Mural circle observations, by direct and reflected vision.*
—— Gambart. *Cometary orbits, and general phenomena.*
—— Ramage. *Improvements in reflecting telescopes.*
1837. Colebrooke. *Researches in Hindu astronomy.*
—— Tiarks. *Nautical astronomy. Chronometric measures.*
1838. Bowditch. *Translator and commentator of the Méchanique Céleste.*
1839. Lalande, Le Français. *Horary tables. Catalogue of* 50,000 *stars.*
—— Rigaud. *Life of Bradley. Critical views on astronomical history.*
1840. Olbers. *Cometary orbits. Discoverer of Pallas and Vesta.*
—— Gregory, O. *Various useful works on mechanics, mathematics, geometry, and astronomy.*
—— Poisson. *Planetary perturbations. Attraction of the spheroids. On the precession of the equinoxes.*
—— Littrow. *Various researches in physical astronomy. On comets.*

From this hasty sketch it results, that astronomy has advanced from its infancy to full maturity by successive stages, every one of which is an honour to the age of its advent. But the last and present century have witnessed its most rapid approach to perfection. The mechanical improvements which have been introduced into the construction of instruments, within that period, have induced a corresponding accuracy of observation, and given a fresh energy to observers, by the gratification which the assurance of working securely confers. Every link in the great chain has been ably overhauled, and all the details proved to be in admirable connection: the altitude of the pole, the obliquity of the ecliptic, the declination of the stars, their right ascension, the longitude of the sun, and the elements of refraction, have a mutual and harmonious dependence on each other. The amazing extension that has been given to analysis, has raised the celestial mechanics from the heresies of hypothesis to a rivalry with the most complete of the abstract sciences, showing the vast progression between the heliacal risings of old, and those astonishing modern discoveries by which future centuries are anticipated. In a word, so important have the labours of the last hundred years been, that, independent of the surprising discoveries which have resulted, a complete system of the planetary motions might be deduced from the observations made during this period; and, as Bowditch remarks, "If all the previous observations, even from the most remote antiquity, were lost, the effect on the tables of the sun, planets, and satellites, would hardly be perceived, since the great accuracy of modern observations more than compensates for the shortness of the epoch." And independent of utilitarian bearings, astronomy has the highest claims upon reason: "Though it should not," says Fontenelle, "be absolutely necessary for the purposes of geography, navigation, and even for the cultivation of divinity, yet it is highly worthy of the attention of every rational being, for the noble and sublime spectacle which it presents to the mind."



Chapter II.

A GLIMPSE OF THE SOLAR SYSTEM.

> **Survey this midnight scene:**
> **What are earth's kingdoms to yon boundless orbs,**
> **Of human souls, one day, the destined range!**

Although the Cycle is strictly a sidereal one, its contemplated use will be materially enhanced if introduced by a few preliminary words on the Solar System, or that assemblage of celestial bodies which consists of the sun, the planets which revolve round him, their satellites, and the numerous comets which traverse space, and mark the wondrous extent of the sun's influence. This group so strongly manifests the intelligent design of an Omnipotent Being, who is at once the Creator and Maintainer, and furnishes such an index to other visible systems, that it could not be omitted in a work like this. And indeed it is both right and necessary to show our colours, since the irregular cruisers already alluded to, despising alike the aids of deduction and induction, will not allow us to abandon what is evidently unsearchable, and reason upon what may be really discernible, without direct charges of impiety. But their interpretation of the creation is guided by their own degree of knowledge: and they lose sight of the necessity of proportioning a miracle to its end. The opening of the book of Genesis is a description of the creation of the earth, not the universe, so revealed as to accommodate the ineffable ideas of the Creator to the limited understanding of the creature: and the doctrine of a plurality of worlds, rolling in silent grandeur in the remote and unexplorable dominions of the boundless empire, is rational, as irresistibly manifesting the power and grandeur of the all-glorious Ens Entium. Much must ever remain above our comprehension, but we are not therefore to limit the powers of the Creator; and until the anti-Newtonians can better handle the argument, we are likely to continue under the delusion of viewing

> This world
> Pois'd in the crystal air, with all its seas,
> Mountains, and plains, majestically rolling
> Around its noiseless axis.

The mind must be deficient in culture, which is not filled with the utmost exultation on contemplating matters of certainty, and not of speculation. The worlds which compose the solar system, from revolving in complex and intricate paths, seem, at a first view, to be subject to strange anomalies and irregularities; nevertheless, all these apparent discrepancies have been resolved, after many ages, into the most beautiful order, and for every deviation yet detected by observation, a proper compensation has been found to exist.

That branch of science which relates strictly to our own system, and compares the laws of motion as observed in the heavens, with its known laws on the surface of the earth, is usually termed Physical Astronomy: it treats of the planetary orbits, or the curves which the planets describe around the sun; of their rotation about their own axes, and also of their figures, which, as well as their motions, are modified by gravitation. This sublime study may be said to have arisen in the seventeenth century, when Newton rejected all the complex machinery which had hitherto been adopted; and it was accompanied by the invention of logarithms, the fluxionary calculus, the science of dynamics, the theory of central forces, and the great law of gravity. When to these brilliant developments are added the discovery of the telescope, the microscope, barometer, and thermometer, and the application of the pendulum to time-keepers, the claim of that age to intellectual superiority must be fully admitted. It was the art of printing, however, which by leaping at once into maturity, like Pallas from the brain of Jupiter, had paved the way for this by facilitating the intercourse of minds; and there is a near connection between the extended emulation it occasioned, and the accelerated progress of knowledge. It drew the speculative world from wild and visionary theories to rational inquiry, and made the productions of the human mind imperishable.

By duly recognising the powerful influence of gravitation, the orbits of the planets are capable of being determined with singular precision, because by reason of the great distances of these bodies from one another, and the near approach of their figure to that of a sphere, they are such, that their mutual actions are nearly the same as if their masses were collected at their respective centres of gravity; so that they may be regarded as so many material points gravitating towards one another according to a given law. But the computation of the effects of gravity on the rotatory motion of the planets, cannot be accomplished with the same precision, from our being, as yet, imperfectly acquainted with the law by which their densities vary from their centres towards their surfaces, and also from our ignorance of the actual figure of their surfaces.

Newton accounted for the movements observed in the solar system, from the principles of gravitation combined with the laws of matter and motion, deduced from observations on terrestrial matter. Hence he saw that the sun, situated in the midst of the planets, attracts them all towards himself, while they also attract the sun; but from the greater mass of the latter, the effect of the planets is comparatively small. Had no other impulse been given to each of these bodies, they would have come together in consequence of their mutual attraction. But a proper impulse was given to each planet in a direction perpendicular, or nearly so, to a line joining the sun and planet. These impulses must have been given at the creation; for they required, to use the words of Newton, "the Divine Arm to impress them according to the tangents of their orbits." And surely none but the OMNIPOTENT CREATOR who framed the universe, could have so beautifully proportioned, as well as originated, the adverse centripetal and centrifugal forces, thus wonderfully called into action. The celestial motions exhibit at once the existence of a power acting under different circumstances; a power originally impressed upon the bodies, and a power continually acting upon them. And the motive forces indicate an external cause; for no internal powers of a material body can give it motion, or when in motion alter its state.

To arrive at a comprehensive view of the systematic order of the solar system, from our excentric station in it, we must reject many of the fallacies and prejudices dictated by the mere senses. The distinction between supposition and demonstration consists both in object and degree; the former rests frequently on little or no reality, and is therefore altogether unlimited in its compounds; but the end of the latter being perfect congruity, it is necessarily restrained to matter-of-fact. It is thus that, on examining the apparent revolutions of the inferior planets, notwithstanding their approximation to regularity of appearance, it becomes evident that no strictly regular and constant motion can be deduced from these appearances, which could be referred to the earth as a centre. Still less could the greater changes of the superior ones be thus explained, for it is evident that, in consequence of the earth's revolving around the sun within their orbits, they will appear successively in every point of the ecliptic. Their apparent revolutions are subject to all the changes of direct and retrograde motions observed in Mercury and Venus; but the discovery of the real cause was made when the motion of the earth itself had been assumed, instead of adhering to the ancient absurdity of assigning to the whole universe, a diurnal rotation of inconceivable rapidity around us. It is true, that Philolaus is asserted to have taught the annual motion of the earth round the sun, and Hicetas, of Syracuse, the diurnal rotation on her own axis*; yet it is clear that neither of these conclusions was adopted, for the system of Ptolemy was the generally received one for many ages. Philosophers were, therefore, sadly perplexed with the apparently inexplicable epicycloidal maze; and the erudite Riccioli, a constrained maintainer of terrestrial immobility, distracted by the puzzling combinations required to keep the earth in the centre, dexterously cites the Rabbinical opinion, which allots to each planet an intelligence, or a *conning*

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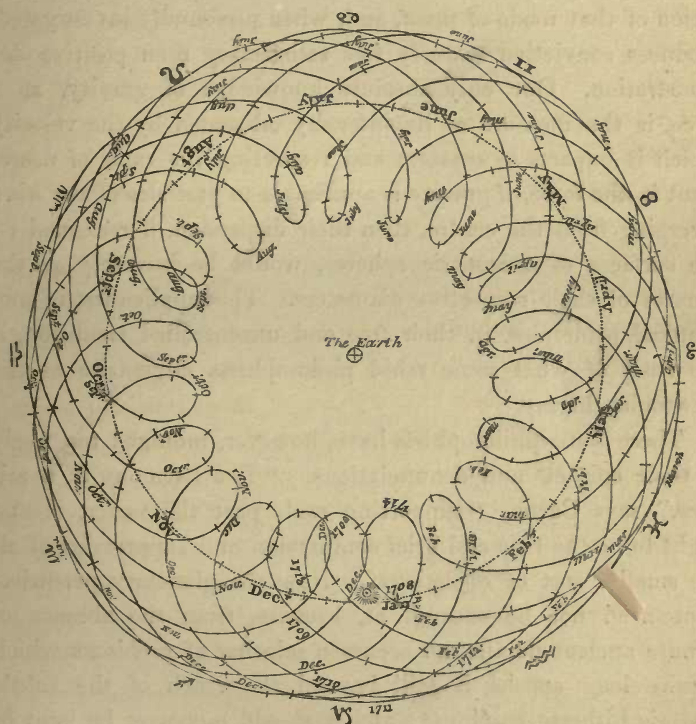
* Hicetas, or Nicetas, who seems to have flourished three or four hundred years before our era, is expressly mentioned by Cicero—*Acad. Quæst.* lib. II.—as a maintainer of this doctrine. The passage is: "Nicetas, according to Theophrastus, considers that neither the sun, the moon, nor the stars are at all in motion; but that the earth, by rolling round its axis (*circum axem*), produces the same apparent effect as if it were immovably at rest, and the firmament itself in motion." See likewise *Diogenes Laertius*, lib. VIII., c. 7.

angel, to direct its arbitrary course. These difficulties were cleared off by the Copernican theory, it is true; yet the apparent movements and *stations* of them are curious, and very difficult to calculate, even when limited to the elliptic motion. Cassini treated them very ably in an essay, *Du mouvement apparent des Planètes à l'égard de la Terre;* which is inserted in the *Mémoires de l'Académie Royale des Sciences*, for 1709, with large plates illustrating the involutions performed by Mercury, Venus, Mars, Jupiter, and Saturn. A careful reduction of the first of these—shewing the meandering movements of Mercury with respect to the earth, between the years 1708 and 1715—will explain the tenour of this argument:



Such was the perplexity of astronomers, when the mechanical application of gravitation threw its powerful light over the question, and reduced the spiral loops and complicated curves to order and harmony. It is true that all the salient cosmical phenomena may be accounted for by other laws, as well as by that of universal gravity; but no other supposition possesses the simplicity of the Newtonian theory, or proves satisfactory in the remoter consequences—the mutual planetary perturbations. Of motive powers inherent in matter, the reciprocal attraction or tendency towards each other of every particle of such matter, is allowed to be universal; and to be the most regular, and at the same time the most comprehensive in its effects, and the most incomprehensible in its cause, of all the powers or qualities of matter. It may be urged, and with propriety, that astronomical truth does not admit of that species of evidence which belongs to experimental science, because many of its conclusions rest on analogical argument; but it is the purest and most simple application of that mode of proof, and, when profoundly investigated, produces conviction scarcely less satisfactory than positive demonstration. Our only absolute knowledge of gravity, as a force, is the measure of its intensity estimated by the velocity which it imparts to matter: and respecting the ratio of decrement in the force, if gravity is applicable to particles of any kind diverging from the centre, then their dispersion, if reckoned on the surfaces of concentric spheres, would be inversely as the squares of their respective diameters. This application of mechanical principles, in their free and uncontrolled condition, is the basis of what some rabid philosophists stigmatize as the Newtonian heresy.

These same philosophists have, however, indulged too freely in their epithets and denunciations. "The harmony of a science," says Bacon, "supporting each part the other, is and ought to be the true and brief confutation and suppression of all the smaller sort of objections." Now the planetary perturbations need not be sneered at, because, from the absence of minute ancient details, an accurate solution of problems which require long epochs is still beyond the reach of the subtle analysis hitherto employed; and it should moreover be kept in view, that those which depend on the variation of orbital elements, and are called secular, are so named merely for the convenience of the term,—for the centenary periods are no more connected with these influences, than is the course of a ship with the log-line by which its course is measured; or the wonderful succession of distinct vicissitudes which occur in a dream, with the momentary instant of time in which they are presented to the imagination, by the mysterious and unfathomable powers of the mind. But though a certain assumption of some of the less perceptible elements is thus necessarily made, such has been the advancement of the exact sciences, that a single second of time, and even a fraction of one, now claims the zealous astronomer's attention. Nay, more: a second in arc, a quantity entirely microscopic to the human eye, provides data for the inductive process, of which the recent disputes between the late Bishop of Cloyne and the late astronomer royal, as to whether such an observed difference in a star's place were referable to parallax or to southern motion, afford an example in point. But improved means and methods of observation and reduction, promise, ere long, to bring all difficulties to an issue: in the interim, we can but register phenomena with the utmost precision, and by allowing for the influences which we are acquainted with, reduce them to that state in which the result may be compared with observation, to test its truth or fallacy; or, by the regularity of the deviation, indicate some new modification of the influences, and thus lead us more closely to the desired object. Yet the intervals may be of such surprising extent, that hundreds, thousands, even millions of years, become familiar to the conception of philosophers, however humiliating to beings of threescore years and ten!

In conducting the reader, by an unencumbered path, through the planetary system, among what old Philip de Thaun calls, *Des estoiles reials*, it may be necessary to call to his recollection, that the planets all move round the sun from west to east, and almost in the same plane as that in which the earth revolves; and that the satellites are similarly circumstanced with respect to their primary planets, with the single exception of those of Uranus, on the outer verge of our system, which, contrary to analogy, move from east to west, or,—as Sir J. Herschel expressed it to me, when he caught sight of two of them,—"go backwards." This general movement Laplace considers as too extraordinary to be the effect of chance—"Un phénomène aussi extraordinaire n'est point l'effet du hazard;" and he thinks that it indicates a general cause, which has determined all these motions. "Whatsoever may be the nature of this cause," he continues, in his *Exposition du Système du Monde*, "since it has produced or directed the movements of the planets, it must have embraced all those bodies; and seeing the prodigious distance which separates them, it cannot be other than a fluid of immense extent. To have given them, in the same order, a movement nearly circular round the sun, this fluid must have environed this sun as an atmosphere. The consideration of the planetary movements leads us then to think, that in consequence of an excessive heat, the atmosphere of the sun primitively extended itself beyond the orbs of all the planets, and that it was afterwards gradually contracted to within its actual limits." While acceding, however, to this philosopher's supposition of so vast a spread of solar fluid, we are not obliged also to concur in the whole question as to its contraction.

In performing their revolutions round the sun, as the centre of motion, the planets follow the fundamental laws so happily discovered by Kepler; those revolving at a less distance from the sun than the earth does, being called the *inferior*, those at a greater distance, the *superior* ones. The extremity of the major axis of the ellipse, nearest the sun, is called the point of *perihelion;* the opposite extremity is the point of *aphelion;* and the line which joins these two points, is the line of the *apsides.* The *anomaly* of a planet is its distance in degrees from the place of the perihelion; and the *radius vector* is a line supposed to be drawn from the centre of the sun to the centre of the planet, in any part of its orbit. The *motion* of a planet is always most rapid when in its perihelion. This velocity diminishes as the radius vector increases, till the planet arrives at its aphelion, when its motion is the slowest. But *velocity* is any given uniform movement, however it may differ in degree, and by parity may be regarded as a measure of time.

§ 1. The Sun ⊙.

The sun, that mighty ruler and animating principle of our system, by exhibiting various magnitudes according to his altitude above the visible horizon, affords a notable lesson on the futility of consulting the "evidence of the senses," instead of the deductions of reason; and such inconclusive evidence ought always to be suspected by the cautious inquirer. The elements of this fountain of light, heat, and vegetation, upon which our astronomical creed is founded, shall now be given. By means of the most profound computations, it has been found that the sun's mean distance from the earth is 11,992 times the earth's diameter, or nearly ninety-five millions of miles, a distance to be reached by a cannon ball, retaining its full incipient force, only in twenty-two years, though light is transmitted to us from the sun in eight minutes and thirteen seconds. The other principal conditions, as established for the commencement of the present century's epoch, or the moment of mean noon at Greenwich on 1st of January, 1801, reckoning from the mean equinox*, are:

Mean longitude - - - -	280° 39′ 10″·2
Longitude of perigee - - -	279° 30′ 05″·0
Greatest equation of the centre - - -	1° 55′ 27″·3
Secular diminution of ditto - - -	17″·2
Inclination of axis (82½°) - - -	7° 30′ 00″
Motion in a mean solar day - -	59′ 08″·3
Motion of perigee in one year, or 365 days - -	1′ 01″·9
Apparent semi-diameter - - -	16′ 00″·9
Mean horizontal parallax - - -	8″·6
Rotation on its axis, in sidereal days - -	25·01154
Time in passing over one degree of mean longitude -	24h 20m 58s·14
Ex-centricity of orbit - - -	·01685318
Volume, earth as unity - - - -	1,384,472
Mass, earth as unity - - -	354,936
Mean distance (95,000,000 miles) semi-diameters of earth -	23,984
Density, or ratio of mass to volume - -	0·2543
True diameter (883,000 miles) in diameters of earth -	111·454

The apparent diameter of the sun requires distinct mention. From the ellipticity of our annual course, this quantity undergoes a periodical change amounting to 64″·6, its mean being = 32′ 02″·9. When in its perihelion, the earth is 3,202,104 miles nearer to the sun, than when at the opposite point of its orbit; the maximum in perihelion = 32′ 35″·6, and the minimum in aphelion = 31′ 31″, respectively taking place at intervals of six months, after a movement of 180° in longitude. From the oblique impact of the solar rays, the greater proximity of the sun at the winter solstice has so little effect in raising our tempera-

* The planetary elements in this "glimpse," are mostly taken from Mr. Baily's privately printed volume of *Astronomical Tables and Formulæ.* 1827.

ture, that it is imperceptible, even in the tropical regions; while, from the ellipticity of the earth's path, and the sun's place in it, we are seven days longer in passing through the northern than through the southern signs, notwithstanding we go at a quicker pace through the perihelion.

The quantities here tabulated afford an overpowering view of magnitude, as they show the circumference of the sun to be 2,766,000 miles; or above five hundred times larger than that of all our planetary bodies taken together, vast as some of them also are: nor is it violently repugnant to reason to suppose the existence of mountains of 17,000,—50,000,—or even 100,000 miles in height, on a body whose diameter is nearly four times larger than the vast interval that separates the moon from the earth! A body of one pound at the terrestrial equator would, if removed to the sun, weigh 27·9 pounds; and bodies would fall there with a velocity of 334·65 feet in the first second of time. Besides its axial motion, the sun has a slow movement about the centre of gravity of the system; its apparent annual movement round our globe being merely an optical illusion, arising from the real motion of the earth on its axis, and in its orbit. The sun has been usually considered as a planet, but should rather be numbered amongst the stars, because he agrees with them in the continual emission of light, and in apparently retaining his relative situation with very little variation. His radiant orb is in figure a spheroid, surrounded by an atmosphere of extreme tenuity and great extent. The sun constantly emits streams of light, which, being reflected by the planets they fall upon, can be ascertained to extend with inconceivable swiftness into space nearly two thousand millions of miles,—how far beyond the regions of Uranus, is left to conjecture, as well as the further effects of their impingement upon planetary surfaces, and what eventually becomes of this wonderful traversing emanation. Must it not reach, at least, as far as the aphelia of comets?

The solar rays, thus transmitted through space in every direction, must affect the several heavenly bodies very differently, on account of the varieties in their atmospheres, and because the intensity of both light and heat diminishes as the square of the distance increases. The appearance of the sun is that of an intensely brilliant ball, far too dazzling for the unprotected eye. This light is so ardently strong, that the most vivid flames which human art can produce, when held before the sun, disappear; and intensely ignited solids become dark spots on the solar disc when seen between it and the eye. "The ball of ignited quick-lime," says Sir John Herschel, "in Lieutenant Drummond's oxy-hydrogen lamp, gives the nearest imitation to the solar splendour which has yet been produced. The appearance of this against the sun was however as described, (*viz. a dark spot*,) in an imperfect trial at which I was present." The direct light of the sun has been estimated to be equal to that of 5570 wax candles of moderate size, supposed to be placed at the distance of one foot from the object. That of the moon is probably only equal to the light of one candle at the distance of twelve feet. Consequently the light of the sun is more than 300,000 times greater than that of the moon*.

A singular phenomenon accompanies the sun, which led Sir William Herschel to suppose that it must appear nebulous as viewed from the other stars: this is a peculiar brightness occasionally perceptible in the heavens, which cannot be mistaken for any atmospheric meteor or aurora borealis, and which may be the same with that called *trabes* by Pliny. This glow is now designated the Zodiacal Light, because it issues from the *via solis*, where it exhibits a pyramidal figure, lying obliquely in the zodiac, within which its summit and axis are inclosed. It was first regularly treated of by Descartes about the year 1630, and by Childrey in 1659; yet their hypotheses did not attract particular notice till it was described by Cassini the elder in 1683: the writings of Fatio, Kirch, Einmart, Derham, and Mairan followed soon afterwards. On the whole, it may be collected, that this curious light is attributable to the solar atmosphere, and that its form is connected with the rotation of the sun on its axis; while my friend, M. Arago, is disposed to regard it as somehow identified with the advent of the November meteors.

* So great is the power of the solar rays, that, as the late Mr. Whidbey informed me, some of the men employed in the Plymouth Breakwater had their caps burnt in a diving bell thirty feet under water, from inadvertently sitting under the focal point of the convex glasses in the upper part of the machine.

In this climate the zodiacal light may be perceived any very clear evening soon after sunset, in the spring months, and before sunrise at the opposite season: but the cone, however luminous, is not distinctly visible in these latitudes, except at the equinoxes, from the long twilights of the summer months, and the great obliquity of the sun's path in winter,—owing to which, besides many disappointments of catching it at all, it never reminded me here of the singular object I had so constantly watched in the tropics. At first it seems a faint whitish zone of light, less intense than the Milky Way, with ill-defined borders, scarcely to be distinguished from the twilight; being then but little elevated, and its figure nearly agreeing with that of a spheroid seen in profile. As it rises above the horizon, it becomes brighter and larger, till it resembles a lenticular beam of light, somewhat analogous to the tail of a comet, rounded at the vertex, with its base towards the sun, and its axis in the direction of the zodiac, or rather, in the course of the sun's equator. But though this phenomenon is pronounced to be occasioned by the solar atmosphere, yet it is necessary to make the latter extend beyond the orbit of Mercury, and even to that of Venus, to reconcile the idea of its being a section thereof,—a position discountenanced by the researches of Laplace. Sir John Herschel thinks this phenomenon may be "no other than the denser part of that medium, which, as we have reason to believe, resists the motions of comets; loaded, perhaps, with the actual materials of the tails of millions of those bodies, of which they have been stripped in their perihelion passages, and which may be slowly subsiding into the sun."

When viewed with a telescope and coloured glasses, the sun is observed to have large black spots upon it, surrounded with a band or border less completely dark, called a penumbra. This penumbra is partially luminous, and terminated by distinct edges, presenting no apparent gradations of luminosity: it is mostly of a shape nearly corresponding to that of the spot it surrounds, but occasionally occupying a considerable space, and including several spots. Though the sun's radiant disc is sometimes clear, it very frequently, indeed generally, exhibits these *maculæ;* they are of various magnitudes,—some of them I have myself found, by careful measurement, to be several times larger than the earth. These solar spots are usually confined within 35° of his equator, and in a zone parallel to it; but I have often seen them much nearer to the polar regions. By observing that their apparent progress across the solar disc, occupies 13 days and nearly 16 hours, during a proportionate advance of the earth in its orbit from west to east, it has thence been found that the period of the sun's rotation on his axis is about 25 days and 10½ hours. But this revolution, though accurate to a certain limit, is not yet actually ascertained to the requisite nicety which such a problem, involving also the consequent probability of a motion of translation in space, demands; for the extreme difficulty of watching such changes with the telescope, in the sun's brilliant glare, is a very serious obstacle to minute scrutiny. Nor is it wholly without danger; the illustrious Sir William Herschel lost an eye in this service; and I myself had a narrow escape from a similar disaster, by neglecting to reduce the aperture of the instrument. The easiest way of examining and delineating the solar spots, is perhaps by a lens of some twenty-feet focus, in a hole in a window shutter with a metallic reflector, in a dark room: perhaps a good looking-glass might do, but it would possibly give false penumbræ to the maculæ: in either case, much of the sharp definition which direct vision by a telescope affords, must be lost.

Priority in the first discovery of these interesting phenomena was warmly contested by Galileo, Fabricius, and Scheiner, who all and severally seem to have seen them in 1611; but our countryman, Harriott, had unquestionably examined them a full year earlier. Scheiner, who wrote eight hundred mortal pages upon them, at first thought the spots to be small planets revolving about the sun, an idea which Tardé maintained by naming them *Astra Borbonia;* while C. Malapert, being of the same opinion, called them *Sydera Austriaca.* But I am inclined to ascribe the first notice of them to a much earlier date. Plutarch tells us, that in the first year of the reign of Augustus, the sun's light was so greatly diminished, that one could look at it with the naked eye: might not this be as well owing to a temporary accumulation of spots, as to any other supposed cause?

Kepler mentions a similar occurrence which took place in 1547, when the sun appeared reddish, as when viewed through a thick mist, and the stars were seen at mid-day, a phenomenon which he imputed to the conjunction of some cometary opaque body with the sun. Averroes, the Spanish Moor, in his commentary on the *Almagest*, affirms that he saw two dark spots on the sun at times when, by computation, Mercury and Venus (1161?) were to be in conjunction with that luminary: it is, however, more probable that instead of the planets, what he saw were extensive displacements of the luminous ether. But an instance in point, is that which is recorded in Hakluyt, (ii., p. 618,) where he gives the second voyage of James Welsh to Benin, in 1590. Early in December of that year, the good ship, *Richard of Arundel*, had arrived off the coast of Guinea, and thus saith her log: "The 7th, at sunset, we saw a great black spot on the sun; and on the 8th, both at rising and setting we saw the like, the spot appearing about the size of a shilling." And on the 16th they again saw it.

There is an opinion that Cassini first started the idea of watching these spots in order to detect the sun's motion on his axis; but among the MS. correspondence preserved in the archives of the Royal Society, I find a very angry letter from Flamsteed to Mr. Oldenberg, the secretary of that body, making a reclamation in favour of Halley. This document is dated 30th November, 1676, and Flamsteed affirms that he had communicated also with Paris on the subject. "I received," he says, "the intimation from Mr. Halley, whose zeal for these things carries him to the Indies. In the mean time, I think he ought not to be a loser by his absence. I had long agone, ever since our first discourse of it, thought of the several varieties of the spot's motions, which might be caused by the rotation of the sun about his inclined axis; and have this morning sent Sir Jonas Moore a draft of the principal, whereby you will see, that theory was no news to me. Only I waited the return of the spot, that I may be more certain of my measures."

As the further investigation of the solar spots offers employment to the *amateur* astronomer, a word or two more may be acceptable. From their generally preserving the same position *inter se*, and continuing visible during equal times, it is held that they are component parts of the sun's solid body, seen through vast accidental openings in the luminous substance which encompasses that immense orb. Hence the variability of the maculæ, which in some cases are seen to contract, dilate, and disappear, at short intervals, in a manner only compatible with the atmospheric or gaseous state of matter. While Halley was making the observations recorded in the *Philosophical Transactions* for 1676, the spot which had the largest diameter was broken into several portions. Every new spot is preceded by a brilliant indication called a *facula*, whence the conjecture that the visibility of the maculæ is in consequence of an ascending current of empyreal gas, which breaks the resplendent envelope of the focal orb. By some, the dark spots are supposed to be scoriæ floating on the abyss of combustion, and the faculæ to be owing to volcanic eruptions from the fused mass. That view, however, which best explains these appearances, and therefore obtains among astronomers, regards the sun as a black solid nucleus surrounded by two atmospheres, the one obscure, the other luminous. In the instance of a spot, the penumbra is the extremity of the inner and dark atmosphere, a fissure exposing the bare nucleus, but not so wide as that in the outer luminous medium above. Dr. Wilson, of Glasgow, suggested this curious speculation, in a well-known essay read to the Royal Society, in 1773, and substituted material splendour instead of the transient and perishable fire, smoke and grosser exhalations which constituted the hypothesis of the day. Shortly afterwards, Sir William Herschel was led to suppose, that the difference which we had been accustomed to imagine between the sun and the rest of the planets, is in a very considerable degree unfounded. Under these circumstances, he remarks,

> The sun appears to be nothing else than a very eminent, large, and lucid planet, evidently the first, or rather the only primary one of our system, all the rest being truly secondary to it. Its similarity to the other globes of the solar system, with regard to its solidity, its atmosphere, and its diversified surface, lead us to suppose that it is most probably also inhabited, like the rest of the planets, by beings whose organs are adapted to the peculiar circumstances of that vast globe.

He answers the objection to which his theory is liable, as to intense heat, by substantial proofs, drawn from natural philosophy, showing that heat is produced by the sun's rays, only when they act upon a calorific medium; and he estimated the luminous atmosphere as extending to about two thousand five hundred miles from the solar orb. In order to render these inquiries more exact, this diligent astronomer discarded the terms by which the spots were formerly known, and substituted those of openings, shallows, ridges, nodules, corrugations, indentations, and pores; but it is to be regretted that his excellent example has, as yet, produced but little further investigation in this important department.

From comparisons of the duration of the sun's transit over the meridian, with the difference of zenith distance of his upper and lower limbs, his figure is concluded to be that of a prolate spheroid; but respecting his constitution, there is a conflicting uncertainty, insomuch that the Rev. Mr. Swinden's "seats of darkness," and Mr. Palmer's heliographical "body of ice," have gained as many admirers as Kircher's and Scheiner's solar volcanoes and fountains of fire, or the blissful regions supposed by Whiston and King. Many are glad to join in the opinion, that the sun is not a globe of fire, from unwillingness to believe that a mass containing so vast a portion of the matter of the whole system cannot be habitable and inhabited. That belief is strengthened by the production of heat and fire in many ways besides through the power of the sun; and even in those cases in which heat is supposed to be received from the sun, the matter may be only extricated, as it were, by his influence, from substances in which it previously existed. The strong light we derive from that orb, may proceed from the density and refulgence of its photosphere, and possibly the attrition of the sun's beams with the surface of the earth in its rotation, may be as great a cause of the heat we experience from the grand luminary, as the quality of its rays. But the most delicate experiments have failed in detecting whether those rays, flying with the enormous velocity of 200,000 miles in a second, or 1,550,000 times quicker than a cannon ball, have any appreciable impulsive force. Experiments, however, prove that the edges of the sun possess a light as intense as the centre; and, strange as it may appear, there is strong reason to infer, that the incandescent substance cannot be either a sòlid or a liquid, but necessarily a gas. "It is an established fact," says M. Arago, "that rays of light, issuing from an incandescent sphere, whether liquid or solid, possess the properties of polarization, whilst those emanating from incandescent gases are devoid of them:" and it is the application of this principle, to experiments made on solar light, which led to the above conclusion. Indeed, it is unquestionable, that the discovery of the orders and properties of gases has enlarged our perception of the conditions of the whole material creation; the transitions from solidity to fluidity, and and from fluidity again to solidity, being thus unveiled.

But whatever may be the constituent parts of the sun, his preponderating mass, as compared with that of all the planets taken together, is of itself sufficient to account for his pre-eminent quality of containing, causing, and communicating heat. The close connection between solar light and heat is a fact capable of experimental proof; and assuming that within ordinary limits the heating effect is precisely as the number of impinging rays, we may estimate, with sufficient accuracy, the relative proportions of light absorbed, from observing the quantities reflected. The law of the mutual influence of the celestial bodies upon each other, in regard to this quality, is sufficiently simple. As in respect to gravity, so with heat; different bodies, or portions of matter, act mutually upon each other in the direct ratio of their masses, and inversely as the square of their distance. With heat at a certain degree of intensity, which is here exactly analogous to density in matter, light is always found united; and from proportional laws, the heat of the sun, when assumed to be in a direct ratio of his mass, is inferred to exceed that of incandescence, or fire, about two hundred times. The elder Herschel, from his observations on the solar phenomena, deduced that the shining matter of the sun was not a fluid, but rather a mass of luminous or phosphoric clouds, which evolved light and heat; and that the opaque body which is occasionally seen by their dispersion is habitable. This deduction, of course, is too arbitrary for a science which admits only of demonstrative facts; but the over-scrupulous objectors to this supposition are also rather gratuitous in their reasonings; for all wire-drawn analogy, as to whether animal life could exist there or not, must prove more speculative than useful, and end in degrading OMNIPOTENCE to our own confined notions. Dr. Young holds that the sun could not be inhabited under Herschel's theory, on account of the rapid transmission of intense heat from the phosphoric clouds to the surface. "Besides," he adds, "if every other circumstance permitted human beings to reside in it, their own weight would present an insuperable difficulty, since it would become nearly thirty times as great as upon the surface of the earth, and a man of moderate size would weigh above two tons." But that mysterious WORD which formed the Laplander and the Negro, the condor and the whale, the mosquito and the elephant, for the several portions of one and a small globe, is surely not to be limited to the fashioning of creatures of our constitution or conception. The inhabitants of every world will be formed of the material suited to that world, and also for that world; and it matters little whether they are six inches high, as in Lilliput, or as tall as the inhabitants of Sirius, who, according to Micromegas, stand nine miles high in their shoes; whether they crawl like beetles, or leap fifty yards high. The bountiful Creator, in His infinite power and resources, never fails to accommodate His productions to the circumstances and conditions of their existence: even in the tropical regions of our own globe, are there not, at different elevations, every variety of climate and temperature, under the same influence of the same solar heat? Moreover, we have not only plants and animals suited to those various temperatures, but also fishes and sea-weeds adapted to various depths of water.

It is certainly true, that with an abyss before us so utterly unknown, the prudent part of reason is silence; yet, constituted as we are, it is utterly impossible to adhere invariably to the staid severity of experimental science. "If any one shall gravely tell me," says Huyghens, in his *Conjectures concerning the Planetary Worlds*, "that I have spent my time idly in a vain and fruitless inquiry, after what I can never become sure of; the answer is, that at this rate, he would put down all natural philosophy, as far as it concerns itself in searching into the nature of such things. In such noble and sublime studies as these, 'tis a glory to arrive at probability, and the search itself rewards the pains. But there are many degrees of probable, some nearer to the truth than others, in the determining of which lies the chief exercise of our judgment. But besides the nobleness and pleasure of the studies, may we not be so bold as to say, they are no small help to the advancement of wisdom and morality?" And Huyghens is right. In the whole circle of physical investigations none exerts a stronger charm on the imagination, than the analogical question of the modification of the other planets, and the inferences deducible therefrom. This taste has crept upon some who have not been remarkable for dealing only in conjectures, from Anaximander and Pythagoras to Galileo and Newton': and really when we remark, that the higher cultivation our intellect receives, and the deeper we carry our researches, the more we perceive a regular recurrence of epochs of countless variety, and a provident care pervading every part of this sublime creation, far exceeding our utmost efforts of conception; rational minds can only be inspired with profound humility, and by so much the more enlarge their views of OMNIPOTENCE, and feel a gratification in being permitted even to imagine such an attribute. For, every degree that we rise in knowledge, is like an additional step in ascending a mountain, proportionably expanding our horizon, and spreading before us a succession of objects apparently bounded, only because our senses are limited. Judging from analogy, the planets may exhibit the same admirable varieties of animate and inanimate organization which we behold on this earth; for the striking similarity of mathematical relations necessarily leads to the supposition of a corresponding similarity in their physical condition. There is no positive argument against the conjecture that those wondrous orbs —orbs revolving on axes inclined to the sun, and furnished with atmospheres and moons—are inhabited by rational witnesses of the Creator's power and grandeur: indeed, the provident care for living beings is so obvious, that this idea is intimately blended with our sublimest conceptions of the DEITY's wisdom and beneficence. "Not to contemplate the works of God in the creation," says Vince, "is to rob Him of a great share of the honour and glory which are justly due to Him." Can it be supposed that the sun, a body hundreds of times more vast than all the planets together, was created only to preserve the periodic motion, and give light and heat to the planets? Science declines giving a direct answer to this question, but supplies a convincing body of circumstantial evidence, by proving that those orbs receive, in common with us, such substantial benefits from the glorious centre, that, like us, they also enjoy the happy vicissitudes of day and night, by turning every part of their surfaces successively to the sun: nor are the alternations of light and darkness, in the several planets, remotely dissimilar.

Kircher, in his noted *Ecstatic Journey*, declares that the planets can produce nothing that hath either life or sense, and that they are placed aloft solely for the advantage of the inferior world, and to govern the mind of man by their various influences; but Kircher also declares that the earth has no motion. Other sages advance the utter impossibility of sentient beings' dwelling on Mercury, on account of the fierce heat, or on Uranus from cold and darkness; but, it must be repeated, that though these resplendent globes may not be exactly adapted for inhabitants organized as we are, that is no proof that they may not be peopled with intelligent agents, endued with bodily constitutions suitable to the nature and economy of the planet for which they are designed. "God's tender mercies are over all his works;" and "Heaven and earth are full of the majesty of his glory."

Having acknowledged our sun as a centre, we will now consider the bodies which revolve around him. Here everything is magnificent and orderly, the whole being amenable to the following well-known Keplerian laws. I. The orbit of each planet is an ellipse, of which the sun occupies one of the foci. II. The areas described about the sun by the radius vector of the planet, are proportionate to the times employed in describing them. III. The squares of the times of the sidereal revolutions of the planets, are to each other as the cubes of their mean distances. Upon these distinct terms hangs the certainty of astronomical demonstration; and upon them, and the seven principal elements of elliptical motions, are grounded the most satisfactory geometrical evidence of the beauty and correctness of the Copernican principles.

§ 2. Mercury ☿.

Mercury being the smallest of the primary planets, and, as far as we know, the nearest to the sun, performs his orbit in the shortest period according to the third law before mentioned, at the mean distance of 36½ millions of miles from the sun; though in a manner which appears somewhat complicated. At the epoch assumed as the commencement of the present century, viz. the moment of mean noon at Greenwich on January 1, 1801, reckoning from the mean equinox, the elements were thus registered:

Mean sidereal revolution	$87^{d}\ 23^{h}\ 15^{m}\ 43^{s}\cdot9$
Mean longitude	166° 00′ 48″·6
Longitude of perihelion	74° 21′ 46″·9
Annual motion of line of apsides	5″·8
Ditto, referred to the ecliptic	55″·9
Longitude of ascending node	45° 57′ 30″·9
Motion of ditto, W. per annum	7″·8
Ditto, E. referred to the ecliptic	42″·3
Mean orbital motion in a solar day	4° 05′ 32″·6
Inclination of orbit	7° 00′ 10″·0
Ex-centricity of orbit, half maj. axis as unity	0·210,551,494
Secular decrease of ditto	0·000,003,866
Greatest equation of centre	23° 39′ 51″·0
Secular increase of ditto	1″·6
Axical rotation	$24^{h}\ 05^{m}\ 28^{s}\cdot3$
Mean apparent diameter	6″·9
True diameter (3140 miles) earth as unity	0·398
Minimum elongation, or angular distance	16° 12′ 00″
Maximum ditto	28° 48′ 00″
Volume, earth as unity	0·063
Mass, sun as unity	0·0000004936
Mean distance (36,000,000 miles) earth as unity	0·3870981

The quantity of matter in spherical bodies being as their volumes and densities conjointly, it is easy to get at the several masses for comparing the force of attraction on the planetary surfaces. By this process it follows, that a body of one pound at our equator, would weigh 1·106 pound if removed to that of Mercury, the most compact planet of our system, and a heavy body would fall there, at the rate of 17·7 feet per second. The light and heat there received are about 6·68 times greater than those on the earth, the sun being seen from thence nearly seven times as large as from our globe. Whether there is any change of season can only be inferred, till improved observations may ascertain the inclination of the axis of the planet to its orbit; but inference leads to the assumption of there being very quick mutations, for the orbital revolution proves its year to be somewhat less than a quarter of ours; and if the seasons follow in the same proportion, they will each consist of only three of our weeks. To the Mercurian spectator, the solar spots will appear to traverse the disc of the sun in a right line from east to west, at times, but at others elliptically; while Venus and the earth will afford him a very glorious light, if any can be wanting in those tracts where all is dazzling glare, and where water, it is thought, must be continually boiling. Yet heat and cold are mere relative terms resulting from various conditions, and the Mercurian regions may be as frosty as we, in our ignorance of its constitution, fancy them burning: even as the snowy summits of the Himálayas are nearer to the sun, than the parched and scorching plains of Hindústan.

Although Mercury is never in *opposition* to the earth, he was, when in the house of Mars, always viewed by astrologers as a most malignant planet, and one full of evil influences. The sages stigmatized him as a false deceitful star (*sidus dolosum*), the eternal torment of astronomers, eluding them as much as the terrestrial mercury did the alchemists; and Goad, who, in 1686, published a whole folio volume full of astro-meteorological aphorisms, unveiling the choicest secrets of nature, contemptuously calls Mercury a "squirting lacquey of the sun, who seldom shows his head in these parts, as if he was in debt." His extreme mobility is so striking, that chemists adopted his symbol to denote quicksilver.

From the proximity of Mercury to the sun, and the difficulty of watching him, under a race of more than a hundred thousand miles an hour, the inclination of his axis is a quantity not yet ultimately settled; still we are aware that it is inclined to the plane of his orbit at a much greater angle than any of the other planets. The proper times for viewing him are about an hour and three quarters before sunrise in autumn, and after sunset in spring; and even then it requires keen gazing, for this planet is small and remote, is peculiar in scintillating and twinkling to the eye like a star, and never occupies a dark portion of the heavens. Hence it follows, that Corpernicus is not the only astronomer who never saw Mercury; yet at the extremes of his oscillations from one side of the sun to the other, he is a brilliant gem to the tutored naked eye. I have watched him in the telescope through all his various aspects, from the full gibbous to the thin crescent; but he was always far too dazzling for the detection of any *penumbræ* or *luculi:* of the supposed dense atmosphere, therefore, or the truncated horn of his crescent, or the mountains, or their probable height and effect in modifying the intensity of heat, I can offer nothing from personal observation. My large instrument was not the best adapted for the work; since though achromatics are most convenient from their reduced focal length, they are decidedly disadvantageous in those cases where it is necessary to command distinctness of vision under low magnifying powers. This telescope has an aperture of $5\frac{9}{10}$ inches to $8\frac{1}{2}$ feet focal length; but another, which helped to prove this point, and was presented to me by our esteemed late treasurer of the Royal Astronomical Society, has 10 feet, or more exactly 118·3 inches focus, to an object glass of $3\frac{3}{4}$ inches*.

When this planet is at his greatest distance from the sun, his illuminated portion has nearly the form of a half circle, more or less according to the earth's position. But when he is passing round on the opposite side of the sun to that at which the earth is situated, the bright portion becomes more than a semicircle, and assumes that form which is called gibbous. When he emerges from the sun he is again semicircular, but as he proceeds in his orbit and approaches the earth, the phase diminishes to a crescent, which attains its smallest dimensions when Mercury is either exactly over or exactly under the sun,—when but few of the solar rays, reflected from the planet's surface, can reach the earth. This affords satisfactory evidence, that the planet does not shine by any inherent light of its own; which fact is further corroborated by the opaque body presented, in its transit over the solar disc. By the same evidence its form is shown to be spherical†.

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* This is the instrument with which the experiments described by Dr. Pearson, in his elaborate essay on telescopes, in Rees's *Cyclopædia*, were made.

† Although we date the proof of the planet's opacity from so recent a period, it must not be overlooked, that Averroes, by mistaking probably solar spots for Mercury and Venus, shows that the opinion of planets being opaque bodies seems to have been current in the twelfth century.

From what has been advanced, it is clear that Mercury never appears at any great distance from the sun, either in the morning or the evening. The orbit he describes is much more ex-centric or elongated than that of any other of the larger planets; and he is remarkable for the great variations of his distance from the sun at different seasons of his year, for the obliquity of his path through space, and for the great changes of the temperature of his seasons. His elongation, or angular distance, varies from 16° 12′ to 28° 48′. When his course appears retrograde, the arc described varies from 9° 22′ to 15° 44′; the duration in the former case being twenty-three days and a half, and in the latter two days less. This retrogradation commences when the planet is distant from the sun from 15° 24′ to 18° 39′; and it terminates at a distance which varies from 14° 49′ to 20° 51′. When the planet begins to be visible in the evenings of spring, he is with difficulty distinguished in the crepusculum; but he gradually disengages himself till he arrives at about 22° 30′ from the sun, when he returns again, successively assuming the direct, stationary, and retrograde appearances, till lost in the solar beams, or, to use an old word, becomes combust. After continuing some time invisible, he reappears in the autumnal mornings, emerging from the beams of the grand luminary with a continued retrograde march as far as 18° 39′, when he becomes stationary, then resumes his direct motion to 22° 30′, when he once more returns, disappears, and afterwards becomes an evening star. The duration of each such oscillation is from 106 to 130 days; and the time of the planet's passing the meridian in any place, is limited to an interval of from about a quarter past ten to three quarters past one in the day.

Such being the conditions of Mercury, and the difficulties of observing him, it redounds not a little to the credit of the ancients that they recognised this body to be a planet, and approximated nearly to his period. The regularity of his phenomena, and the limited deviation from the sun, appear to have been noticed in the earliest times: Pythagoras was the first to make them known to the Greeks, but he learned the facts in Egypt. Pliny, in his *Encyclopædia*, though he errs greatly in the time of revolution, is not so far out in the mean angle of elongation; and Cicero, in his admirable treatise, *De Natura Deorum*, cites the period of Mercury's circuit of the zodiac in the course of about a year, adding, that it is "never further distant from the sun than the space of one sign, sometimes preceding, sometimes coming after him*." Indeed, we cannot but be struck with the near approach which some of those elders made to the present system; but the adoption of unproved hypotheses, and adhering to the *ipse dixit* of this or that sage, were the causes of their keeping to leeward of the point they were working to. The inquiry, however, is deeply interesting, as exhibiting the gradual advance of knowledge; and it will be recollected, that Newton himself, in his old age, regretted that he had not sufficiently investigated the former state of knowledge.

There are certain periods when this planet, being in conjunction with the sun, actually passes between that orb of splendour and the eye of the observer, as a dark round spot on the solar disc. These phenomena are called transits of Mercury. The centre of the earth being always in the plane of the ecliptic, as well as the centre of the sun, it is evident that this effect cannot occur unless Mercury also be at the time of his conjunction in that plane, or unless he be then at one of his nodes. If the planes of the two orbits coincided, it would follow that Mercury, when at his shortest distance from the earth, would be exactly between the centres of the sun and the earth; but this not being the case, the determination of the circumstance, whether or not the planet will appear on the face of the sun, depends on the position of the line in which the two planes intersect each other, or the line of the nodes. Now, the nodes of Mercury's orbit are, and for ages to come will be, in that part of the ecliptic which the sun passes through in the months of May and November; and in order that a transit may occur, Mercury must be in conjunction with the sun in those months. If the line of intersection of the two planes just alluded to, will not pass through the centres of the earth, Mercury, and the sun, then Mercury will

* Here are the *ipsissima verba:* ". . . . quæ (sc. stella) anno fere vertente signiferum lustrat orbem, neque a sole longius unquam unius signi intervallo discedit, tum antevertens, tum subsequens."

be a little above or a little below the centre of the sun, or more probably, exterior to the disc of the sun altogether, and therefore invisible. This circumstance, together with the smallness of the planet, its distance from the earth, and its contiguity to the sun, frequently prevents us from witnessing those useful and interesting transits, repeated observations of which would lead to further conclusions on the physical constitution of Mercury.

Mercury was first seen crossing the solar disc by Gassendi, on the 6th of November, 1631 (28th Oct. *styl. vet.*), and James Gregory entertained hopes, that the recurrence of the phenomenon would enable us to establish the sun's distance to a nicety; but though so important an object, as we shall presently see, is not altogether to be accomplished by the transits of Mercury, these phenomena are always events of great interest to observers. Thus Schakerlaus made a voyage, in 1651, to Surat, purposely to see one there; and thus that of the 8th of November, 1802, afforded delight to the closing days of Lalande: "The passage of Mercury over the sun's disc," he says, "was observed this morning for the nineteenth time. The weather was exceedingly favourable, and astronomers enjoyed in the completest manner the sight of this curious phenomenon. I was the more anxious to have a view of it, as I shall never see it more." The gratification this scientific veteran experienced arose from finding that his tables, the result of forty years' labour, had reached the utmost attainable point of perfection*. In common with several of my friends, I was greatly disappointed by the weather on the 5th of May, 1832, when some especial arrangements were made for detecting symptoms of the planet's assigned atmosphere, during his passage across the sun; but mists and clouds nearly precluded the phenomenon's being seen at all. The next one, visible in England, will occur on the 8th of May, 1845, when, it is hoped, that many of my readers will be on the look-out, and embrace the opportunity of witness-

* Lalande wisely confined himself to his astronomical duties during the heat of the French Revolution; and when he had consequently escaped the fury of those times, he jocosely remarked, that he might "thank his stars for it." He, however, was a supporter of *Liberalism*.

ing it. 'Tis true, they may not be provided with extensive or powerful means; but much service may be rendered by carefully noting the instant of the planet's appulse, and of its departure from the solar disc; the points of entry and exit: the altitude of the sun; indications of the barometer and thermometer; and particulars of the height and circumstances of the locality where observed. This may sharpen their tools for that which will occur on the 9th of November, 1848.

Although Mercury very properly gave way to Venus, in the great question of solar parallax, yet he is too intimately concerned in the leading conditions of the case, to be slighted in the story of that inquiry. Sir Isaac Newton, in demonstrating the law discovered by Kepler, proved that the periodic times of the six primary planets about the sun, are in the sesquiplicate proportion of their mean distances from the sun; the relative distances of the planets from the sun are known; consequently, if the real distance of any one of the planets could be found in any known measure, the distances of all, together with the dimensions of our whole solar system, would be known by analogy. But this was a problem the solution of which appeared to be so hopeless, that it was classed among the unattainable desiderata. Accident, however, discovered what learning and perseverance had toiled after in vain. On the 7th of November, 1677, Halley, then at the island of St. Helena, had the pleasure of seeing Mercury pass over the sun's disc; and found, that the duration of these transits might be observed to the exactness of one second of time. This casual observation strengthened the idea just mentioned, that the parallax of the sun, and consequently his distance from the earth, might be detected by close observations during a transit of Venus over his disc. Accordingly, in 1716, Halley drew up the paper printed in No. 348 of the *Philosophical Transactions*, which led to the public-spirited resolutions respecting the famous transit of June, 1761. That part of it which principally relates to Mercury, is thus expressed:

About forty years ago, while at the island of St. Helena, I was attending to the constellations which revolve round the south pole, it happened that I observed, with all possible care, Mercury passing over the sun's disc; and succeeding beyond my expectation, I obtained accurately, by means of an excellent

24-foot telescope, the moment when Mercury, in his immersion, appeared to touch the inner limb of the sun; and also the moment of his touching the limb at emersion, forming the angle of interior contact: whence I found the interval of time during which Mercury then appeared within the solar disc, even without an error of one small second of time ("etiam absque errore unius secundi temporis"). For a thread of solar light, intercepted between the dark limb of the planet and the bright one of the sun, appeared, however fine, to meet the eye; and in striking the eye, the denticle made on the solar limb by Mercury's entrance was seen to vanish; and also that made by his emersion seems to begin in an instant. When I perceived this, it immediately came into my mind, that the sun's parallax might be accurately deduced from observations of this kind, if Mercury were but nearer to the earth, and had a greater parallax from the sun: but this difference of parallaxes is so small, that it is always less than the solar one which we are seeking; and therefore Mercury, though frequently to be seen on the sun, is hardly to be considered suitable to this operation.

A reclamation, however, must be made here, for Halley needs no borrowed plumes. The use of the transits of the inferior planets over the sun's disc for determining the solar parallax was first pointed out by James Gregory in his *Optica Promota*, published in London in 1663, that is, fourteen years before the date of Halley's observation. Gregory's book is an important one in the history of optical discovery, inasmuch as it contains the first description of the reflecting telescope (his invention); and it is impossible to suppose Halley had not seen it. Halley does not mention Gregory, and he has generally had the credit of being the first who suggested the method, as well as that (to which he is unquestionably entitled) of having in 1716 called the attention of astronomers to the importance of the pheuomena in question. Gregory's claim is mentioned by Hutton, but Maskelyne seems not to have been aware of it. His words are perfectly clear and explicit: "Hoc problema pulcherrimum habet usum, sed forsan laboriosum, in observationibus Veneris vel Mercurii particulam solis obscurantis; *ex talibus enim solis parallaxis investigari poterit.*" *Scholium* (*Optica Promota*, p. 130).

Many endeavours have been made to ascertain whether Mercury has a satellite, yet none has ever been discovered; but the question is too difficult for us to rest satisfied, that therefore these admirable attendants have only been given to the superior planets. Nor can science pronounce, that no planet exists in the thirty-seven millions of miles between Mercury and the sun, though it may for ever remain lost to us in the solar rays. The density of Mercury is concluded to be fourteen times that of water, or more than equal to that of lead; so that a ball of lead 3140 miles in diameter, weighed in the capacious scales of Libra, would not balance the planet. Yet mighty as this may appear, should the centrifugal force be suspended and it thus fall upon the sun, with a velocity continually increasing as the square of the distance diminishes, it would not make its crash under fifteen days and a half*.

§ 3. Venus ♀.

Venus, the planet which follows Mercury in the order of our system, at the mean distance of sixty-eight millions of miles from the sun, is easily distinguished from the other solar satellites by greater lustre, her light being of a brilliant white colour, and so powerful when nearing the earth, as to occasion a sensible shadow. Owing to this lovely superiority, she was the first planet that attracted notice; and though it is usual to quote only Hesiod and Homer on the occasion, she is certainly mentioned by Isaiah as a morning star 2600 years before our time. Venus offers phenomena similar to those of Mercury, with this difference, that her phases are much more sensible, the oscillations more extensive, and their period more considerable: it is, therefore, from these two planets that an irrefragable proof of the falsity of Ptolemy's hypothesis is obtained. All observations agree, that Venus and Mercury are sometimes on this side of the sun, and sometimes on the other; but the earth has never been detected between them and the sun, a case which yet must have

* The tyro may be here reminded, that these dynamical results admit of ready proof. Mathematically speaking, the velocity with which a bullet falls to the earth, despite of their almost inconceivable disparity, depends on the sum of the masses of the earth and the bullet. The fall of a planet towards the grand centre is also determined by the sum of the masses of the sun and such planet: and the connection of such sums becomes so evident in mechanics, that the hypothesis may be adopted without material error.

frequently happened, if the orbits of all the planets encompassed our globe as a centre. A tale has obtained credit, about its being objected to Copernicus, that if his theory were true, and that Mercury and Venus actually revolved round the sun in paths comprised within ours, they must sometimes appear horned, and, in their apsides, bear the same phases as the moon. That intelligent philosopher is said to have admitted the validity of this reasoning, and to have predicted that this resemblance would one day be discovered. "Se non è vero, è ben trovato!" The invention of the telescope, soon afterwards, enabled Galileo to remove the objection, if ever it had been advanced, and show indisputably that planets are in their own nature opaque bodies, and that Venus necessarily moves round the sun. In a letter dated at Florence, the 1st of January, 1611, that illustrious astronomer informs his friend William di Medici, of his happy discovery, saying, "About three weeks ago, when Venus became visible in the evening, I began to observe her more attentively with my telescope, hoping to see with my eyes, what my understanding was long since convinced of. At first the planet appeared perfectly round, neat, and distinctly terminated, but very small; which figure she retained, though continually increasing in apparent magnitude, to her greatest elongation from the sun." It was a memorable incident.

As Venus is never elongated from the sun more than from 45° to 47° 12′, it follows that her orbit includes that of Mercury, but is included in ours. From their inferior situation they cannot be seen on the meridian, except in the rare case of their passing over the solar disc, an event of unfrequent occurrence. Venus, however, under very favourable circumstances, is occasionally caught up in the day, but neither she nor Mercury can ever be seen by us at midnight; which is a striking difference between them and the superior planets, and an additional proof of our exterior situation. From this cause, Venus cannot exhibit a perfectly round disc to us, except under the condition cited; for in her superior conjunction, when her whole enlightened face is towards us, the solar rays interfere with our seeing her absolutely full: I have, however, more than once, caught her within two or three degrees of the sun's limb. When she is to the west of the sun, which is from her inferior to her superior conjunction, she is seen before the rising of that luminary, affording, in a fine silver crescent, an elegant telescopic object: when she is to the east of the sun, that is, during her progress from the superior to the inferior conjunction, she is visible after sunset. In the former of these situations she has been successively named by the Greeks, Romans, and Moderns—Phosphorus, Lucifer, and the Morning Star; and when in the latter, Hesperus, Vesper, and the Evening Star. The morning and evening stars were, in Ogygian ages, supposed to be different bodies; and it must have required sagacity and a long period of observation to prove the contrary. From her uncommon splendour, Venus attracted great regard; she was deemed the cause of health, tranquillity, and love, and was lauded as "Veneris salubre sidus," with a sort of perpetual presidency over the sea.

In this latter dignity, Venus has lately been put upon maritime duty. From knowing where to look, I have frequently seen her with the naked eye nearly at noonday; and this visibility in full sunshine has only recently been made subservient to the purposes of navigation. Under most circumstances she is readily discovered with the slightest optical assistance; for, if the reflected rays fall upon the eye when it is not overpowered by the solar beams, it cannot but see a planet of such brilliance. A similar remark is also applicable to Jupiter, though he is not so easily visible; and there are times when Mars bears a large proportion of daylight: in fact, Venus, Mars, Jupiter, and Saturn, soon become visible towards the evening, and continue long so in the morning. I was happy in tendering my evidence to this effect, when they were impressed into the service in 1834, and duly appeared in the improved *Nautical Almanac*. For lunar distances, the rapid motion of Venus, estimated at no less than seventy thousand miles an hour, renders that magnificent orb extremely valuable to the seaman; and meridian altitudes of Venus can often be taken, when unfavourable circumstances may have prevented an observation of the sun.

At her greatest elongation, Venus appears stationary with respect to the sun, for some time; after this, her easterly motion becomes slower than the sun's, and she approaches that primary. At a certain point she appears stationary with respect to the fixed stars, and then her motion becomes retrograde, in an arc varying from 14° 35′ to 17° 12′, the duration in the former case being $40^d\ 21^h$, and in the latter $43^d\ 12^h$; and the retrogradation commences, or finishes, when she is from 27° 40′ to 29° 41′ from the sun. The general elements of this planet, at the epoch already given for Mercury, are:

Mean sidereal revolution	$224^d\ 16^h\ 49^m\ 08^s{\cdot}0$
Mean synodical ditto, in solar days	583·920
Mean longitude	11° 33′ 03″·0
Mean diurnal orbital motion	1° 36′ 07″·8
Longitude of perihelion	128° 43′ 53″·1
W. motion of apsides per annum	2″·7
E. ditto, as referred to the ecliptic	47″·4
Inclination of orbit	3° 23′ 28″·5
Annual decrease of ditto	0″·5
Longitude of ascending node	74° 54′ 12″·9
W. motion of ditto, per annum	17″·6
E. motion of ditto, referred to the ecliptic	32″·5
Ex-centricity of orbit, half maj. axis as unity	0·00686074
Secular decrease of ditto	0·000062711
Greatest equation of centre	47′ 15″·0
Annual decrease of ditto	0″·25
Rotation on axis	$23^h\ 21^m\ 07^s{\cdot}2$
Mean apparent diameter	16″·9
Diameter at superior conjunction	9″·6
Ditto, inferior, at times	1′ 01″·2
True diameter (7700 miles), earth as unity	0·975
Volume, earth as unity	0·927
Mass*, sun as unity	0·0000024638
Mean distance (68,000,000 miles), earth as unity	0·7233316

In her progress she exhibits moon-like phases, from the fine thin crescent to the semicircular, gibbous, and an enlightened sphere; and the illuminated part being constantly turned to the sun, the horns are towards the east in the morning star,

* The masses of Mercury and Venus are still subject to discussion, since the question is surrounded by every difficulty, as neither of them has a satellite. But the most remarkable circumstance connected with the theory of the motion of Venus, is the recent discovery of an inequality, depending upon the mutual attractions of the earth and Venus, the numerical results of which, are in the longitude of the earth 2″·06, in that of Venus 2″·95, and the period is 240 years. However small such an inequality may appear, it is sensible in the motions of the sun. This important improvement of the planetary tables, is owing to the skill, patience, perseverance, and sagacity of our present Astronomer Royal; and it forms a curious case, wherein prediction awaits the seal of observation.

and towards the west when it becomes the evening one. During these changes, there are remarkable alterations of the planet's diameter and brilliance, nor is she brightest when most of her face is seen. A still greater apparent anomaly, is that of Venus's appearing to keep on the same side of the sun for two hundred and ninety days together, although this is a longer period than she takes for her entire circuit; but this is owing to the earth's going at the same time round the sun, though at a slower pace; and she must continue to appear on the same side with the earth, till the excess of her daily motion above ours amounts to 179°, which, at the diurnal rate of 37′, will be in about two hundred and ninety days.

Various impediments have hitherto prevented the inclination of the axis of Venus to that of the ecliptic from being exactly ascertained; but being surrounded by an atmosphere, the refractive powers of which vary very little from ours, a constant change of seasons, under moderated solar rays, may reasonably enough be inferred. Her axis seems to be inclined at least 75° to her orbit, her tropics are 15° from her poles, and her polar circles at the same distance from her equator: she therefore seldom has a forenoon and afternoon of equal length, and the variation of her seasons is so frequent, that she has four, two summers and two winters, in each of her annual revolutions: such vicissitudes may produce a corresponding diminution of the atmospheric temperature. A body weighing one pound at our equator, would decrease to 0·98 if removed to that of Venus, from her possessing less gravity. The proportion of light and heat which she receives from the sun, is nearly double, or about 1·91 times greater than that received here; to her inhabitants, therefore, the orb of day will appear nearly twice as large as to us, and their eyes no doubt are fashioned accordingly. Among the surprising and apparently anomalous facts relative to Venus, is that of her annual revolution being only nine and a quarter of her days, reckoning by the sun's rising and setting to her, owing to which, the sun must appear to pass through a whole sign in little more than three quarters of her natural day; and the declination is so varied, that he cannot shine vertically upon the same part for two days together, so that the heated places have time to cool. Nor is this all: the variety occasioned by these motions, offers several other extraordinary astronomical appearances; and from the difference of the solar amplitude at its rising and at setting, means are afforded to the geographers on Venus, of finding their longitude with greater facility than that which attends our Tellurian latitudes.

In gazing at Venus, during her enlarged diameter, and often under no common advantages, I have been unable to detect the slightest appearance of spots or inequalities on her phosphorescent radiance; but her whole surface is so intensely brilliant, as to render observation difficult. In steadily watching this brightness, I have been satisfied that its nearly uniform whiteness is more dazzling upon her convexity, than on that part which separates the enlightened from the dark part of her disc; a fact also noted by Sir William Herschel, and by him reasonably attributed to the reflecting and refractive powers of a dense atmosphere. Yet as the elder Cassini perceived spots on the planet's face, and by them deduced her diurnal motion to within a minute of what Schroeter established it a hundred and twenty years afterwards, and as Bianchini distinctly saw permanent inequalities for hours together, it may be conjectured that her atmosphere has undergone a material change since the middle of the seventeenth century. It should be observed, that the cusps extend considerably more than a semicircle, occasioned, no doubt, by the atmosphere's being more luminous than the planet. Her southern horn is observed to vary its appearance, being alternately blunt and sharp, changes attributed to the shadow of a high mountain, which, by rotation, periodically intercepts the light she reflects, and thus gives the horn a truncated form. This furnished the indefatigable Schroeter with his opportunity of confirming the disputed point of the rotation established by Cassini, by watching the interval elapsing between two successive appearances of the observed truncature. A further examination of the same horn, in 1790, by that astronomer, together with calculations founded on the laws of the degradation of light, led to the discovery of the crepuscular light by which the planet is affected, and established the fact, that her illuminated portion is larger than it would be, were it not for refraction. Schroeter also determined, by measurement, the heights of four mountains on her surface to be no less than from ten or eleven, to nearly twenty-two miles! But on this point we know nothing positively.

The question as to whether Venus has a satellite or not, has been warmly and widely contested: no such attendant seems to have been undeniably detected, but to the present moment it cannot be demonstrated that it is not in existence. The satellite of an inferior planet, especially if it were very small, would be extremely difficult to find, for when the primary is nearest to the earth, and circumstances are most favourable for its discovery in other respects, the dark side would be turned toward us. Besides Baudouin, Rodkier, and other astronomers, Cassini and Short, two exact observers, were positive as to having perceived a satellite; and, from the published details, Lambert has given a very consistent theory of its action. But it has been pronounced, and that rather dogmatically, that the observers must have been deceived by stray light, ghosts, false images, or other optical illusions of imperfect telescopes; and that opinion is grounded upon the fact, of no secondary body being seen when Venus traversed the solar disc. Yet this, though a strong point, is not admitted by Lambert, and even if it were, would be scarcely conclusive: for in different countries, and with different eyes and means, that optical illusion must have been truly marvellous which could pervade the minutely detailed observations of Cassini in 1672 and 1686, of Short in 1740, and M. Montaigne in 1761*. The contested satellite is, perhaps, extremely minute, while some parts of its body may be less capable of reflecting light than others; and when the splendour of its primary, and our inconvenient station for watching it, are

* Sir David Brewster says that "Mr. Wargentin had in his possession a good achromatic telescope, which always showed Venus with such a satellite, and the deception was discovered by turning the telescope about its axis." This, however, must be a mere pleasantry, for it is impossible that the accurate observers cited could have been deceived through so gross a neglect. Cassini employed a 34-foot refractor, at epochs with fourteen years between them, and Short used two reflectors, to the second of which he applied three different eye-pieces, magnifying 60, 140, and 240 times.

considered, it must be conceded that, however slight the hope may be, the search ought not to be relinquished.

But the great service rendered by Venus to science, is the determination of the sun's parallax, that important element on which, our exact knowledge of the whole solar system depends. By Venus, as well as Mercury, sometimes passing across the sun, proof is afforded of her being an opaque body, and also, that her orbit is included within that of the earth. We have seen that Halley did not consider Mercury as an eligible object for the operation of finding the solar distance; but he thus provided a proper one:

> There remains, then, Venus's transit over the sun's disc, whose parallax—almost four times greater than the sun's—will produce the most sensible differences between those spaces of time in which Venus will be seen to go round the sun, in different regions of the earth. And from these differences, properly observed, I say that the sun's parallax may be determined even within a small fraction of a second. Nor do we require other instruments than telescopes and common, but good, clocks; nor in the observers more than fidelity and diligence, with a moderate acquaintance with astronomy. For it is not necessary that the latitude of the place be scrupulously sought out, nor that the hours themselves in respect to the meridian be accurately determined: it is enough when the clocks are properly corrected to the revolution of the heavens, if the time is counted from the total ingress of Venus within the sun's disc to the beginning of its egress from the same; that is to say, when first the opaque globe of Venus begins to touch the bright limb of the sun; which moments I know, by my own experience, may be noted within a second of time.

But as this transit can only occur when Venus is in her nodes, and the earth in the same longitude,—the phenomenon, besides its extreme rarity, can only happen in the months of June or December for many centuries to come. Supposing that Averroes must have seen a solar spot with the naked eye, and not Venus on the sun's face (1161?), the first transit of that planet ever known to have been seen by human eye, was observed by our countrymen, Horrox and Crabtree, in December, 1639. Halley awakened attention to the next, which happened in June, 1761; but though it was well observed, the discordance of the results shook dependence upon them. That of June, 1769, was more fortunate, and must for ever remain memorable in scientific annals, since the parallax of Venus, and the still more important desideratum, that of the sun, were satisfactorily obtained. The different sovereigns of Europe honourably attended to the call of science, and as the data were to be gained by making observations at those places on the earth's surface, where the duration of the transit would be the most lengthened and the most shortened, respectively, by the effects of parallax, appropriate sites were selected, and expeditions equipped, to fulfil the requisite duties. Besides preparation being made in the principal observatories in England and on the continent, Lapland and Kamschatka in the north, St. Helena and the Cape of Good Hope in the south, and the equatorial region of India in the east, were duly selected. But the most interesting of all was, the mission so munificently equipped by the British government, and dispatched under the intelligent Captain Cook, to observe the phenomenon at Otaheite.

It is unfortunate for science that so useful a phenomenon should occur so rarely. The last, as we have just seen, was in 1769, and there will not be another until 1874; even this will not be visible here. But it will be followed by one on the 6th of December, 1882, which will be seen in England, as I hope some of my readers will find; it will, however, be under unfavourable circumstances, nor will there be one sufficient to gladden the heart of a zealous observer, till the year 2004. Thus these phenomena succeed each other with alternate intervals of more than a century, and of eight years, and so they continue, for reasons which admit of very simple demonstration. Excepting these eclipses, Venus exhibits the same appearances to us, as to conjunctions, elongations and other elements, every eight years; and with such a regularity as to occur nearly on the same days as before. On comparison, it will be seen, that her dimensions approach more nearly to those of the earth than those of any other planet; but if M. Schroeter's conclusions are at all to be received, her surface must present a marvellous difference; for though the smaller of the two orbs, it is very confidently stated that she has protuberances of vastly superior elevation, one being nearly six times the height of Chimborazo. Were the centrifugal force of this planet suspended, and its circular motion stopped, it would fall to the sun in thirty-nine days and seventeen hours.

§ 4. The Earth ⊕.

Having thus passed the inferior planets, we arrive at the earth, the orb on which we dwell, and the third in order of distance from the sun. 'Tis true that, however boastfully we stickle for its importance, it is a most insignificant object to the inhabitants (if any such there be) of the exterior planets; but its consequence is enhanced by referring it to ourselves. In the earliest ages of the world, before the earth had taken its due rank as a celestial body, many fanciful and absurd notions respecting its figure prevailed, according to the respective opinions in philosophy or religion, as well as those arising from the illusions of the senses. Among these, the most incorrect general opinion was, that the earth was a boundless plane, and that all the celestial bodies were created solely for its use and ornament. According to the belief of Hesiod, it was located exactly half way between Heaven and Tartarus; and the distance between the realms of light and the dismal abyss, appears to have been pretty exactly considered:

> From the high heav'n a brazen anvil cast,
> Nine days and nights in rapid whirls would last,
> And reach the earth the tenth; whence strongly hurl'd,
> The same the passage to th' infernal world.

Now Hesiod would have been astonished to learn that our ponderous globe itself would, if released from its centrifugal trammels, require sixty-four days and thirteen hours to fall upon the sun, though continually accelerating its velocity in its descent: the years required for it to pass from the stars, would of course have been incomprehensible to his notions of their distance.

The spherical form of the earth has long been a received truth; and, indeed, is so perfectly consonant with the evidence both of our reason and of our senses, as to render almost unnecessary the arguments which substantiate it. Such are, watching a ship while she dips first her hull, and then her sails, as she recedes from the shore; the shadow of the earth on the moon during an eclipse; the different appearances of the constellations, and the alteration of the circle of the horizon, as we travel north or south; the varying elevations of the pole, and altitude of the stars; the culminations of the heavenly bodies; the length of shadows, and the duration of day and night. The globular figure is also shown, in the operation of ascertaining the height of distant mountains, where the spherical correction is an important co-ordinate; in levelling, also, it is found necessary to make an allowance between the true and apparent level, on the principle of terrestrial sphericity. Seamen have constant proofs of this rotundity on making the land, when they only see the lower parts gradually long after catching sight of the higher; when ships meet on the open ocean, and telegraph to each other, while only the upper part of their masts appear above the surface of the water; and in the now every-day exploit of circumnavigating the globe. Still the ascertaining of the true figure and dimensions of this globular mass, has demanded the closest attention of philosophers; and that it is an oblate spheroid has been proved by extensive and admirable measures of degrees of the meridian, and numerous pendulum-experiments, in various parts of the world. The whole progress of this delicate investigation, together with the conclusions derived from it, have been very ably set forth by Mr. Airy, in an essay entitled "Figure of the Earth," inserted in the *Encyclopædia Metropolitana*.

Combined researches, investigations, and experiments, have assigned as standard elements, for the commencement of the present century, the quantities in the following table. But it may be necessary here to remind the reader, that the *anomalistic year*, is the time intervening between two successive passages of the earth through an aphelion or perihelion; the *sidereal year*, the time occupied by the earth in its revolution from any point in its orbit, till its return to the same; the *tropical year*, is the time taken by the earth to move in its orbit from the vernal equinoctial point till it returns to the same again. The *solar days* introduced, are *mean* ones; and they signify the time which would elapse between the consecutive returns to the same meridian of an imaginary sun, supposed to move in the plane of the equator with a constant motion, being the *mean* of the real sun's true motion in right ascension; in other words, while the *apparent* solar day signifies the time elapsing between the return of the sun's centre to the same meridian, which, owing to known inequalities, is a variable quantity, the *mean* solar day is the medium of all the real days and fractions of a day which make up the tropical year. The *sidereal day*, is the time which elapses between the consecutive returns of any one fixed star to the same meridian; from the regularity of the earth's axical rotation, and the apparent fixity consequent on the infinite distance of the stars, this measure is at once unvarying and immutable.

Mean distance (95,000,000 miles) times its own semidiameter	23,984
Distance at the perihelion. Mean distance as unity	0·9832
Distance at the aphelion. Mean distance as unity	1·0168
Mean sidereal revolution, $365^d\ 6^h\ 9^m\ 9^s{\cdot}6$, or solar days	365·2563612
Mean tropical ditto, $365^d\ 5^h\ 48^m\ 49^s{\cdot}7$, or solar days	365·2422414
Mean anomalistic year, $365^d\ 6^h\ 13^m\ 49^s{\cdot}3$, or solar days	365·2595981
Entire revolution of the sun's perigee in solar days	7,645,793
Mean longitude, 20″ for aberration	100° 39′ 10″·2
Motion in perihelion in a mean solar day	1° 1′ 09″·9
Mean motion in a solar day, 0° 59′ 08″·33, or	0°·98564722
Mean motion in a sidereal day, 0° 58′ 58″·64, or	0°·98295603
Motion in aphelion in a mean solar day	57′ 11″·5
Mean longitude of perihelion	99° 30′ 05″·0
Annual motion of line of apsides, eastward	11″·8
Ditto, referred to the ecliptic	1′ 01″·9
Complete tropical revolution of the apsides, in years	20·984
Obliquity of the ecliptic	23° 27′ 56″·5
Annual diminution of ditto	0″·457
Semi-major axis of nutation	9″·4
Annual luni-solar precession	50″·4
General precession in longitude	50″·1
Complete revolution of the equinoxes, in years	25,868
Lunar nutation in longitude	17″·579
Solar nutation in longitude	1″·137
Ex-centricity of orbit, half major axis as unity	0·016783568
Secular decrease of ditto	0·00004163
Diurnal acceleration of sidereal or mean solar time	3′ 55″·91
From the vernal equinox to the summer solstice	$92^d\ 21^h\ 50^m$
From the summer solstice to the autumnal equinox	$93^d\ 13^h\ 44^m$
From the autumnal equinox to the winter solstice	$89^d\ 16^h\ 44^m$
From the winter solstice to the vernal equinox	$89^d\ 1^h\ 33^m$
Mass, sun as unity	0·0000028173
Volume	1·0
Density, sun as unity	3·9326
Ditto, water as unity	5·6747
Mean diameter, (equatorial 7924 and polar 7898,) in miles	7916
Centrifugal force at the equator	0·00346
Passage of light from the sun	$8^m\ 13^s{\cdot}3$
Orbital movement in the foregoing interval	20″·25

A study of these elements ought to fill the mind with admiration and gratitude, for the labours of talent and time are by them so placed before the tyro, that he may win the science almost *per saltum*. Considering the earth as a planet with its satellite, and the sun as its focal body, we are presented with an example of a system of celestial masses, revolving around their common centre of gravity, in the simplest possible form. The proximity of these bodies renders all the effects of their mutual attraction the most sensible to us, as well as the individual inferences, which still remain almost imperceptible in the more remote celestial orbs, whose angles are obtainable. We shall presently have occasion to recur to this, so that it may here suffice to say, that the intricate calculation of the multitudinous series, which was requisite in order to solve the problem of the three bodies, surpasses all other efforts of human inquiry and achievement.

There are three principal motions of the earth: its uniform diurnal rotation on its own axis from west to east, which causes an apparent motion in the heavens from east to west; its orbital movement round the sun, or more properly that of the common centre of gravity of the earth and moon round it; and the motion of its axis round the poles of the ecliptic, which produces the precession of the equinoxes. Its perihelion coincided with the vernal equinox about the year 4089 B.C.; it coincided with the summer solstice about 1250 A.D., and will coincide with the autumnal equinox about 6483 A.D. Now mathematicians demonstrate that these motions are all derived from one single impulsion; which impulsion must have been given by Divine energy at the creation; and it is certainly no more difficult, under such power, for reason to conceive the globe passing through its six hundred million miles of orbit, than that it should remain quiescent, resting upon nothing.

The atmosphere, that rare and elastic fluid which surrounds our globe, and is at once the region of the winds, lightning, and meteoric corruscations, has a more important relation to the animal and vegetable kingdoms than is at first sight obvious; and also to the exactness of astronomical observations. The refractions of the heavenly bodies in altitude will be elsewhere adverted to, but so wonderful and beneficial an envelope—one on which respiring beings depend for the continuance of their vitality—could not be passed without a word. The density of this fluid diminishes in proportion to the increase of distance from the earth, and is also affected by several other circumstances, of which the principal with respect to astronomy is, its variability of temperature. Were the earth at rest, the atmosphere would be exactly spherical; but affected by the centrifugal force connected with the law of gravity, its figure must become an ellipsoid, because the parts that correspond to the equator are further removed from the centre than the parts which correspond to the poles; and, moreover, it is further expanded by the sun's striking more directly on it in the space comprehended between the two tropics. The ancients imagined that this fluid reached as far as the moon, but the discovery of its weight and consequent pressure, has brought it within limits comparatively narrow; the extreme elevation, however, of this thin integument, is still matter of conjecture. If the air were not possessed of elastic power, and were of the same density in all parts, the whole height might be ascertained without any difficulty: for a column of air, one inch high, being to an equal column of mercury as 1 to 10,477·9,—at the level of the sea, in latitude 45°, the temperature at the freezing point, and the mean barometer 29·92 inches,—it follows that 10,477·9 such columns of air would equal in weight one inch of mercury; and consequently, the thirty inches of mercury sustained in the barometer require a column of air, supposing a uniform aërial density, of 26,151 feet, or 4·95 miles. But as the density decreases upwards in geometrical progression, it must be greatly higher than this; and atmospherical phenomena have been noted, which could not have been less than forty miles in height. In the celebrated aëronautic expedition of MM. Biot and Gay-Lussac, their balloon gained the enormous height of 25,000 feet, or nearly five miles; being the greatest elevation to which man has yet ascended. On the most careful analysis, in all seasons, climates, and heights, the heterogeneous particles of the atmosphere are found to consist of 79 parts of azotic gas, and the remaining 21 are oxygen gas; with the exception of three or four parts of carbonic acid gas in every 1000. The pressure of the atmosphere is about fifteen pounds on every square inch, so that every able-bodied man, when the barometer stands at 30 inches, counterbalances a weight of nearly fifteen tons.

Many half-fledged savans, more intimate with obvious celestial phenomena than with the grand results of astronomy, have indulged in woeful misgivings as to the stability of the earth; and fancied, on finding certain tropical productions buried in high latitudes, that the polar regions were once within the tropics, and that there is no mystery in the twaddle of the Egyptian priests to Herodotus. It is hardly worth while to show how Butler treats this; but Spenser's versification of the fact, in that astronomical opening of the fifth book of the *Faerie Queene*, may be quoted as in point:

> And if to those Ægyptian wizards old,
> (Which in star-read were wont to have best insight,)
> Faith may be given, it is by them told,
> That since the time they first tooke the sunne's hight,
> Four times his place he shifted hath in sight,
> And twice hath risen where he now doth west,
> And wested twice where he ought rise aright.

The question as to fossil remains, is certainly one of the deepest interest to geologists, and other inquirers; but it may be at once stated, that exact astronomy will render them but little aid. To account for the marvellous profusion of tropical animals, fruits, trees and seeds, which are often picked up in hyperborean realms, some theorists have conjured up a diminution of the terrestrial temperature; but Laplace drew a conclusion which is confirmed by the lunar theory, that the length of a day has not been lessened by the 200th part of a centesimal second, since the time of Hipparchus, in consequence of any diminution of the mean temperature of the earth; though, from the influence of its oblateness on the ecliptic, the tropical year is $4^{s}\cdot21$ shorter than when that philosopher flourished. He also showed, that the position of the earth's instantaneous axis of rotation, is subject to no secular inequality which can ever become sensible. Finding themselves thus baffled aloft, the cosmogonists turned their attention below, and the latent heat from the centre was considered as sufficient to account for these puzzling appearances. The internal structure of the globe, however, is matter of speculation as yet: the astronomer merely troubles himself about its dimensions and its density, and upon those points he is satisfied of being pretty near the mark. The magnitude of the earth was ascertained at a comparatively early period in the history of physical discovery; but the singularly difficult problem of weighing it, was reserved for our own day, when Cavendish solved the question, and Mr. Baily has lately confirmed his results.

There was, however, another phenómenon to marvel at. Though the ancients may not have been aware that a diminution of the obliquity of the ecliptic is going on, yet the aforesaid Egyptian wizards told Herodotus, that the ecliptic was once perpendicular to the equator. Now the plane of the earth's mean orbit being, in the language of the senses, the circle in which the sun rises, moves, and sets, it is comparatively under everybody's observation, and a handful of degrees would quickly be noticed; but we decisively know, that the assertion could not be true, and that, as far as most things are concerned, the slope of the ecliptic may be considered as invariable. The amount of the obliquity, is an element admitting of determination from the simplest observations of practical astronomy, by carefully ascertaining the sun's meridional zenith-distance on the days of the winter and summer solstice. It has, therefore, long been very diligently noted, and a few of the results will remove the alarm which has been excited:

	Date.	Obliquity.
Eratosthenes	230 B.C.	23° 51′ 20″
Ptolemy	140 A.D.	23° 48′ 45″
Albategnius	880	23° 35′ 00″
Arzachel	1104	23° 33′ 30″
Ulugh Beigh	1463	23° 30′ 17″
Kepler	1627	23° 30′ 30″
Cassini	1655	23° 29′ 15″
Flamsteed	1690	23° 29′ 00″
Römer	1706	23° 28′ 41″
Bradley	1750	23° 28′ 18″
Maskelyne	1800	23° 27′ 56″·5
Airy	1840	23° 27′ 36″·5

From this statement it will be seen that, in the space of 2070 years, during which practical astronomy has been able to grapple with the subject, the obliquity of the ecliptic has decreased its angle by 23′ 43″·5; and that it is still diminishing in the ratio of only 0″·457 per annum. This excites the bodily fear of various speculative enthusiasts, who apprehend that when the ecliptic shall coincide with the equator, then farewell to the animal and vegetable kingdoms: another set, however, anticipate such a coincidence with rapture, as the only means of equalizing the days and nights of all nations, and giving the polar regions their quota of solar benefit. But both parties must prove false prophets, since the cause of this diminution is governed by the theory of gravitation; and it is well known that, however worried by Venus and other planets, it cannot be permanent under existing causes, but the movement must go upon the other tack before its effect shall have amounted to a serious change.

§ 5. The Moon ☽.

The earth is attended by that wondrous satellite the Moon, which, next to the sun, is the most remarkable of the heavenly bodies to our vision; and so constant is this attendance, that, to the solar astronomers, she would never seem to depart from us by an angle greater than 10′. This apparently fine orb has ever been esteemed among mankind with love and respect: the Hebrews regarded it as the regulator of their fasts and festivals, and Selenolatria, or moon worship, obtained largely among the pagans. Poets, and poetasters innumerable, have essayed their aspirations for Cynthia, Luna, or Diana, while the smaller rhymesters

> Have bayed and bruited the silver moon,
> Till they made her dull as a pewter spoon.

At length, a master-mind was allured to the subject, and in rendering into English the description of the Greek bivouac from the *Iliad*, produced one of the finest bursts of poetry in our language. A straight-laced mathematician may object that it "proves nothing," and some morbid sages will assure us, that it is not Homer's; but Homer assuredly might have plumed himself upon the master-piece thus thrust upon him: let the reader judge for himself:

> As when the moon, refulgent lamp of night!
> O'er heaven's clear azure spreads her sacred light,
> When not a breath disturbs the deep serene,
> And not a cloud o'ercasts the solemn scene;
> Around her throne the vivid planets roll,
> And stars unnumber'd gild the glowing pole;

O'er the dark trees a yellower verdure shed,
And tip with silver every mountain's head;
Then shine the vales, the rocks in prospect rise,
A flood of glory bursts from all the skies:
The conscious swains, rejoicing in the sight,
Eye the blue vault, and bless the useful light.

We must, however, quit this beautiful picture for one of a more matter-of-fact character. The earth and moon may be considered as a two-fold planet, with all the intimate and opposed circumstances amenable to the law of gravitation: still, notwithstanding the simplicity exhibited by the leading features of this law, its strict application to the lunar movements in orbit, is laborious, difficult, and complicated. From the moon's proximity to the earth, and the great ex-centricity of her orbit, the perplexing nature of her motions long baffled the inquiries of astronomers, and formed a repulsive barrier: still they managed empirically to determine the broader elements of her orbit. But now the lunar theory, based on the Newtonian doctrine, and transcendentally treated by the ablest analysts, carries observation and prediction to so refined a concordance as to evince its close approach to perfection, and to stamp it the master-piece of human sagacity. It is proved that the moon moving in an ellipsis, of which the earth occupies one of the foci, is at the same time carried along by the earth in its revolution round the sun; and while the latter occupies a year in its journey, the moon has already traversed her own orbit thirteen times and a half: in stricter words, it is their common centre of gravity which makes its annual revolution about the grand centre. The moon turns upon her axis precisely in the same time as she takes to revolve round the earth; and this is the reason why she always presents to us, very nearly, the same face. If the rotatory motion were absolutely uniform, while the motion of translation is subject to secular variations, she would, in the course of ages, successively present to the earth all the points of her surface. But it is proved by theory, that the terrestrial attraction on the lunar spheroid communicates to the moon's axical rotation the secular inequalities of her orbital motion, so that one of the lunar hemispheres must be for ever concealed from the inhabitants of the earth. The question is intricate, since the lunar system displays a very singular coincidence of effects totally independent of each other. The nodes of the moon's equator tally with those of her orbit: the one is in motion from the action of the earth upon the moon, and the other arises from the action of the sun upon the moon: and the former is assisted by the constitution of the moon's body.

The extent of the moon's visible hemisphere is not always quite the same. Were her rotation round her axis and her mean revolution in her orbit equable, she would always present the same face to a spectator placed at the centre of the earth, if the plane of her equator passed through the centre of the earth. None of these conditions being exactly fulfilled, and the variations being small and periodic, the consequence is, that an additional small portion of the moon's surface on each of the edges alternately becomes visible, and obscure. This phenomenon is effected by an oscillating motion particularly designated the libration: the moon's motion in orbit being alternately accelerated and retarded, while that on her axis is uniform, small segments on the east and west sides alternately appear and disappear. This occasions what is called the moon's libration in longitude. A little more of her disc is also seen sometimes towards one pole, and sometimes towards the other, which occasions another vibrating kind of motion, called the libration in latitude; and it shows, that the axis of the moon is not exactly, though nearly, perpendicular to the plane of her orbit.

The lunar elements, at the commencement of the present century, under the same condition as stated on page 83, are:

Mean distance (above 237,000 miles) times diam. terr. equator	29·982175
Mean sidereal revolution $27^{d}\ 7^{h}\ 43^{m}\ 11^{s}{\cdot}5$, or solar days -	27·321661423
Mean tropical revolution $27^{d}\ 7^{h}\ 43^{m}\ 04^{s}{\cdot}7$, or solar days	27·321582418
Mean synodical revolution* $29^{d}\ 12^{m}\ 44^{h}\ 02^{s}{\cdot}87$, or solar days	29·5305887215
Mean longitude - - - -	118° 17′ 08″·3
Mean motion in a mean solar day - - -	13° 10′ 35″·0
Mean longitude of perigee - - -	266° 10′ 07″·5
Mean motion of apsides in a solar day - - -	6′ 41″·0
Sidereal revolution of the apsides, in solar days -	3232·5753
Tropical revolution of ditto - - - -	3231·4751
Mean anomaly - - - - -	212° 6′ 59″·9
Motion of ditto in a mean solar day - - -	13°·064992
Mean anomalistic revolution $27^{d}\ 13^{h}\ 18^{m}\ 37^{s}{\cdot}4$, or solar days	27·5545995

* This is called, a *mean lunation.*

Inclination of orbit - - - - -	5° 8′ 47″·9
Ascending node - - - - -	13° 53′ 17″·7
Motion of ditto in a mean solar day - - -	3′ 10″·6
Sidereal revolution of nodes, (18·6 Julian years,) solar days	6793·39108
Synodical revolution of ditto $346^d\ 14^h\ 52^m\ 35^s{\cdot}1$, or solar days	346·619851
Revolution from node to node $27^d\ 5^h\ 5^m\ 36^s$, or solar days	27·2122222
Ex-centricity of orbit, half major axis as unity - -	0·0548442
Greatest equation of the centre - - -	6° 17′ 12″·7
Inclination of axis - - - - -	1° 30′ 10″·8
Maximum evection - - - -	1° 20′ 29″·9
Maximum variation - - - - -	35′ 42″·0
Maximum annual equation - - -	11′ 12″·0
Minimum horizontal parallax - - - -	53′ 48″·0
Mean ditto - - - - - -	57′ 00″·9
Maximum ditto - - - - -	1° 01′ 24″·0
Apparent diameter when nearest to us - -	33′ 31″·1
Ditto, at mean distance - - -	31′ 07″·0
Ditto, when furthest off - - - -	29′ 21″·9
Mean diameter (about 2160 miles) or to earth as 1 to -	3·665
Volume, earth as unity - - -	$\frac{1}{49}$
Mass, ditto - - - - -	0·01252
Density, ditto - - - - -	0·615

And finally, the period of 223 mean lunations for the restitution of eclipses, is $6585^d\ 7^h\ 42^m\ 35^s{\cdot}65$. Here, then, is a roll of elements which form the key to the moon's doings; and, with the secular variations, to which they are sensibly subject, it exhibits a beautiful advance of human knowledge. A body weighing six pounds at the earth would weigh one pound at the moon, at the surface of which it would fall at the rate of about three feet in the first second; and were both the centrifugal and orbital courses stopped, she would descend to the earth in four days and twenty hours. Her secular motion is decidedly greater than it was 2500 years ago, yet this acceleration will never amount to a quantity sufficient to excite the apprehensions of the nervous. The lunar light is considered as being 300,000 times weaker than that of the sun, and its rays, collected by the aid of powerful glasses, do not produce any sensible effect on the thermometer. According to Dr. Smith, the disproportion in the quantities of light cast upon the horizon by the sun and moon, at equal altitudes, is no less than 90,000 to 1, he might have said 130,000, when the moon is full; so that the whole heavens covered with moons would only make daylight. The younger De la Hire, with a burning-glass three feet in diameter, and the best thermometer which Paris could provide, experimented upon the lunar light on a serene evening, when the moon was full, and on the meridian; but though the lunar rays were concentrated to less than the three-hundredth part of the space they naturally occupy, and consequently had as much power there as three hundred full moons would have in the ordinary way, not the least increase of heat was detected.

The intensity of the sun's light diminishes from the centre to the periphery of the solar orb; but in the moon the gradation is reversed. Their comparative strength has been experimented upon by Bouguer, Mitchell, Pemberton, Wollaston, and others, with widely different results. The most received disparity is that mentioned on p. 85; but by comparing the flame of a wax-taper, the illuminating power of which was determined by a photometer, Professor Leslie concluded the light of the sun to be only 150,000 times greater than that of the moon.

Although the phases of the moon are among the most observed phenomena, yet are they also among the most wonderful. Having an opaque spherical body, which appears luminous only in consequence of its reflecting the solar light, she can but have that side illuminated which is at any time turned towards the sun, the other side remaining in darkness; and as that part of her can only be seen which is turned towards the earth, it is evident that we must perceive different portions of her illuminated disc, according to her various positions with respect to the earth and sun. At the time of conjunction, having then her enlightened side towards the sun, and her dark side towards us, she is invisible on earth. In a short time after conjunction, she appears like a fine crescent in the afternoon; this crescent begins to fill up, and the illuminated part to increase, as she advances in her orbit. When opposite to the sun, she becomes full, with a round illuminated disc; whence she decreases gradually through the other half of her orbit, and disappears again at the conjunction. These lunations are divided into four quarters; while increasing her horns are towards the east, but towards the west during the decrease.

The late excellent Mr. W. Frend used to relate a remarkable circumstance: early one morning, a lady of his acquaintance noticed the wire-like crescent of the moon, then approaching nearly to her conjunction; and the day after, in the evening, she observed the opposite crescent in the west, soon after sunset; thus having seen in the morning of one day, and the evening of the next, the waning and waxing moon.

The Harvest Moon is a phenomenon in our latitudes, and those of a corresponding height in the southern hemisphere, observed by the husbandman long before it attracted the particular attention of astronomers. It occurs at the time of the full moon nearest to the autumnal equinox, and is beneficial to the farmer in affording light for several nights, at that important season of the year, immediately after sunset: it is therefore believed, by many in the rural districts, where the advantage is most felt, to be a special ordination of Providence that people may get in their grain. Instead of rising fifty minutes later every day, she makes her appearance during several nights nearly at the same time, by reason of the increase of declination consequent upon her position, which compensates the retardation that would otherwise arise from her orbital motion. In other words, the moon is always opposite to the sun when she is full, and of course, in the opposite sign and degree of the zodiac. Now, in the months of August and September, the sun is in the signs Virgo and Libra, which places the moon, when full in those months, in the signs Pisces and Aries, which make a much less angle with the horizon of places that have considerable latitude, than the opposite part of the ecliptic, and therefore a greater portion of it rises in a given time than an equal portion of any other part of it. Now as the lunar orbital motion is about 13° per diem, there will be less difference between the times of the moon's rising when in this part of her orbit than in any other. Although this must be the case every time that the moon is so situated, yet it is only attended to when she happens to be full, and this can only be in the harvest months. The latter part of this phenomenon, or the moon in Aries when the sun is in Libra, which occurs in October, is called the Hunter's Moon. Such is the farmer's beneficial period, but his medal has also a reverse: in the rural districts, the red moon of the spring is accused of nipping the buds and blossoms with frost; but M. Arago has stepped forth to rescue her from this *triste célébrité.*

The variations in the apparent size of the moon are mere optical illusions. A full moon in the horizon appears of an oval form, which is owing to the diminishing density of the atmosphere, in consequence of which the lower limb is more refracted than the upper, and therefore the vertical diameter appears to be shortened. To the naked eye, the lunar disc appears larger in the horizon than when in the zenith, even on the same evening, although she may actually be further from us in the first instance by a semi-diameter of the earth, or about four thousand miles; but this is entirely a visual deception, as can at all times be proved by an application of the micrometer; still the phenomenon is so remarkable, as to have exercised the ingenuity of Ptolemy, Alhazen, Roger Bacon, Kepler, Des Cartes, Wallis, Gregory, Desaguliers, and many others, whose hypotheses, however various, nearly arrive at the same point respecting the cause of the fallacy. Huyghens says, that we think "the sun, or anything else in the heavens, is remoter from us when it is near the horizon, than when it approaches towards the zenith, because we imagine everything in the air that appears near the vertex to be no further from us than the clouds that fly over our heads; whereas, on the other hand, we are used to observe a large extent of land lying between us and the objects near the horizon, at the further end of which the convexity of the sky begins to appear; which, therefore, with the objects that appear in it, is usually imagined to be much more distant from us." This opinion, however, has been disputed, because the horizontal moon seems equally large across the sea, where there are no objects to produce the effects here assigned to them. The inquiring reader will find all that is known upon this subject in Dr. Smith's *Optics*.

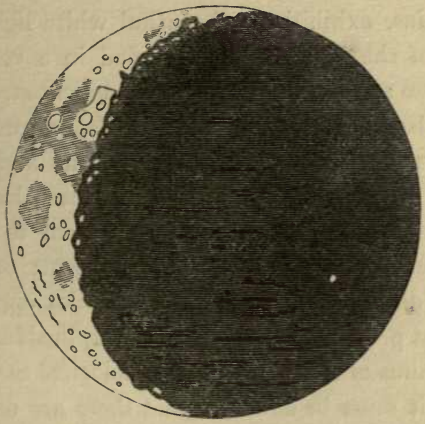
For some days after the new moon has appeared, the dark portion of her disc, not exposed to the solar rays, is distinctly visible; and is familiarly known, as the new moon with the old one in her arms. This effect is best seen a little after sunset, and when the moon is about three or four days old. The ancients ascribed it to the native light of the moon, and on account of its pale ashy hue, called it *lumen incinerosum;* but fuller knowledge ascribed it to the reflected light arising from scattered beams of the sun bent into the earth's shadow by the refraction of its atmosphere;

and though the whole of the effect is not thereby accounted for, the principal details harmonize so well with such an hypothesis, that it is received by astronomers. The earth being larger than the moon, and apparently of a similar quality, reflects more light; and since the light of the earth on the moon increases or decreases inversely to the light of the moon on the earth, it follows that at about the time of the new moon, the earth is nearly full to her, and reflects so much light upon her, that the whole of that side which is towards the earth becomes visible, exclusive of the illuminated part then enlightened by the sun. Schroeter even conjectures the terrestrial reflected light, to be visibly more or less vivid according as the solar rays hit upon the land or the sea. As the earth wanes to the Lunarians, this phenomenon vanishes; but an inference remains, that the moon's light is not altogether reflected,—and there seems to be a fair proof of spontaneous phosphorescent light. The subject is replete with interest, and naturally brings me to a particular mention of the occasional luminous appearances which have so repeatedly attracted the attention of astronomers, and led to the conclusion of there being active volcanoes in the moon. This may be told by an extract from a letter which I addressed to Mr. Francis Baily, on the 30th of December 1835, as inserted in the third volume of the Royal Astronomical Society's *Monthly Notices*, p. 141:

It is very desirable, in order to arrive at stronger conclusions, to draw more attention to the very remarkable luminous appearance so frequently seen on the dark part of a young moon, and which we readily enough ascribe solely to its being enlightened by the earth in an early stage of her age. Yet it is difficult to account for the different degrees of intensity under which this luminosity is seen at different epochs, I myself having observed it of every size, from the sixth to the tenth magnitude. As it is always at or near the centre of Aristarchus, there can be no doubt of its being the identical spot mentioned by Cassini, Sir W. Herschel, and Captain Kater; and also that described by Dr. Maskelyne, in the 84th volume of the *Philosophical Transactions,* which was seen with the naked eye, by two persons, in March, 1794.

As, from the absence of the sun, this is the favourable season for looking out for the phenomenon, I will here give you the registered note of the observation, of which I sent you so hurried a notice: indeed, I wrote off instantly, hoping the weather might continue fine.

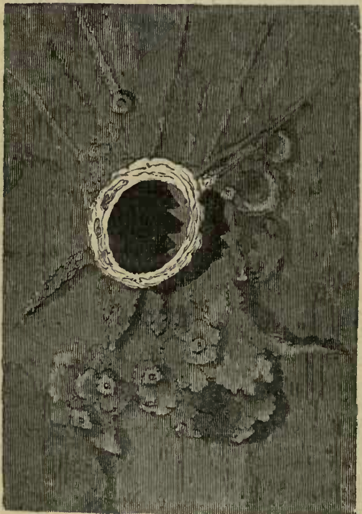
December 22nd, at 6^h 30^m P.M., the moon about an hour or more over the meridian, and 14° or 15° high; the weather fine, clear, and frosty, with a very light air from N.N.E.; the barometer was 30·46, the thermometer 33·2, and hygrometer ·717. Directed the telescope to the moon, and pointing it in the dark part for the vicinity of Aristarchus, soon saw the outline of that mountain very distinctly, formed like an irregular nebula. Nearly in the centre was a light, resembling that of a star of the ninth or tenth magnitude; it appeared by glimpses, but at times was brilliant, and visible for several seconds together.

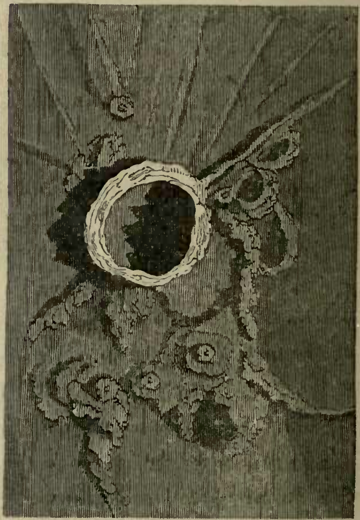


I saw the same phenomenon to great advantage on the Christmas day of 1832, when it resembled a star of considerable size; but though I saved the post that evening, still, in consequence of cross-roads, so much time was lost, that neither Professor Airy, nor Sir J. Herschel, received my letters till the moon's light had increased so much as to prevent observation. The ill success of my announcement shows, that those who are interested should themselves be on the watch during the new moons of the winter season.

I should add, that, though I have advanced no notions of my own on this subject, I am not at all surprised at its having been so repeatedly taken for a volcano.

In reasoning upon inaccessible objects, we can only proceed by analogy, and argue onwards from what we know; and since, on the earth, fire cannot be maintained without air, we are justified in making the same assumptions respecting the moon. If De la Hire, Rochon, Bode, Olbers, and other Phlegræans, be right in their conjectures, as to the actual existence of volcanic fires in our satellite, then is the contested point of the existence of a lunar atmosphere settled; but should time accept of the explanation afforded by supposing polished surfaces at the summits of certain mountains, on a well-cooled moon, then are we where we were. Aristarchus itself calls for explanation, since the singularity of the annexed appearance, as it is seen on the dark part of a young moon, is unquestionable. The hypothesis of a perfect reflecting surface in some degree affords an explanation; but the lustre appearing by glimpses only is rather against it, unless this can be referred to inconstant refractions in our atmosphere. As the enlightened limb enlarges, it advances into notice, till at length it becomes the brightest of the annular mountain chains, exhibiting a beautiful white light, above the gray surface of the Procellarian *Sea*, and in a very variegated district. Those streaky radiations, or divergent streams of light, such as are also magnificently seen at Copernicus and Tycho, emanate from the outer margin of Aristarchus, and extend from its base to a distance of many miles. These have been pronounced to be flowings of lava, but they seem to run over hill and vale without being at all modified by them; others consider them as vast disruptions, but many difficulties oppose this supposition, and at present they are totally inexplicable. Yet, in displacing the claims of these singular selenological *asteriæ* to being lava-streams, it must be admitted that there are certain igneous indications around; and the following diagrams of the principal





summit, with the inclined solar light casting the shadow on either side in waxing and waning, will show its analogy to a terrestrial crater, albeit its dimensions differ, being only 2500 feet high outside, to a depth of more than 7000 feet within.

The exact nature of the lunar light and its distribution are, however, matters of much uncertainty. The more general features are well understood, and may be considered as substantial axioms in the discussion. As the moon's axis is nearly perpendicular to the plane of the ecliptic, she can scarcely have any change of seasons. But what is still more remarkable, one half of the moon has no darkness at all, while the other half has two weeks of light and two of darkness alternately: the inhabitants, if any, of the first half bask constantly in earth-shine without seeing the sun, whilst those of the latter never see the earth at all. For, as just stated, the earth reflects the light of the sun to the moon, in the same manner as the moon does to the earth; therefore, at the time of conjunction, or new moon, her further side must be enlightened by the sun, and the nearer half by the earth: and at the time of opposition, or full moon, one half of her will be enlightened by the sun, but the other half will be in total darkness. To the lunarians the earth seems the largest orb in the universe, for it appears to them more than three times the size of the sun, and thirteen times greater than the moon does to us, exhibiting similar phases to herself, but in a reverse order; for when the moon is full, the earth is invisible to them; and when the moon is new, they will see the earth full. The face of the moon appears to us permanent, but to them the earth presents very different appearances; the Pacific and Atlantic Oceans, in the course of each twenty-four hours, will successively rivet their attention, and the velocity of motion must excite both surprise and conjecture. Though, as aforesaid, certain of those gentlemen only behold the earth for half a month at a time, those near the border see it only occasionally, and those on the side opposite the earth never see it at all.

The moon being but the fiftieth part of the bulk of our globe, and within 238,000 miles of us, may be brought by a proper telescope, which magnifies 1000 times, to appear as she would to the naked eye were she only 250 miles off*. Many

* Various recent announcements, of marvellous discoveries in the moon, raised the hopes of many ardent geo-selenographists to a most extravagant pitch. Mark how they are put down by a plain declaration from M. Mädler,

points of the utmost importance, as to the constitution of the moon, will no doubt follow the application of Lord Rosse's magnificent telescope; meanwhile we can only proceed by analogy. MM. Arago, Nicollet, and Bouvard, at Laplace's request, made a series of observations on the beautiful annular mountain, Manilius, near the centre of the lunar disc, which established the co-ordinates of latitude 14° 27′, longitude 8° 47′, and height 7224 feet, with 5·53 miles for the diameter of the crater. M. Nicollet, in 1822, published his 124 observations of the spot for libration; on comparing which with theory, he concluded that the moon is not homogeneous, and has not the form it would have, had it been originally fluid. Many suppose, that being a small mass, she has long ago refrigerated down to the temperature of the surrounding space, which is considered by Fourrier and others as being much below zero.

That the moon has been immemorially regarded as cognate with our globe, may be proved from many of the ancient writings; and the author of the *Orphic Hymns* not only ascribed mountains to her surface, but even cities also, thereby forestalling the recent visions of M. Grinthuisen on the furrows of the *Lacus Somniorum*, and the lunar dikes cut by sentient beings. But though neither towns nor fortifications appear, the assisted eye finds the lunar disc singularly diversified with hills and valleys, brilliant bands of light, volcanic craters and yawning cavities, with a profusion which seems to increase under every increase of optical power; and the longer we gaze, even upon known objects, the more we detect. The rocks and mountains throw perfectly visible shadows in a direction from the sun, which are

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the most exact selenographer of the day. "Assuming," says this gentleman, "that a German mile is the utmost limit of distance at which the keenest unassisted eye can distinguish human beings, to bring the moon to that distance, a magnifying power of 51,000 would be necessary; but, up to the present time, 300 is the highest power which has been applied to that object with advantage. Those, therefore, who wait for an improvement in the existing means of observation, with all the necessary adjuncts, in the proportion of 300 to 51,000, and who also encourage the hope, that in the mean while the earth's atmosphere will become 170 times more diaphanous, and anticipate that the apparent motion of the moon across the field of the telescope can be retarded 170 times by some peculiar means, may persist in the expectation that beings will be perceived in our satellite."

long and distinct when they are near the boundary of light and darkness, or when the sun is in the horizon; and they disappear when that luminary is 90° from the same boundary, or over head. The proper time, therefore, to study the interesting scene presented, is when the moon is either horned or gibbous; the edge about the confines of the illuminated part is then jagged and uneven, and the tops of the hills catching the solar beams before the intermediate plains become distinct, form beautiful islands of vivid light along the enlightened phase,—that side of her which appears soon after the change and to the full, being more uneven than the side we see on her wane. By the help of these shadows, as well as by other means, the altitudes of most of the lunar mountains have been measured; but excepting a very few, they are of moderate elevation,—the Apennine range, which is the highest, being from sixteen to eighteen thousand feet high. The abysses, however, are more remarkable, some of them being twenty or thirty miles in diameter, and three or four miles deep, with a very rugged and frightful aspect.

There are extensive districts which exhibit different colours, upon very strict comparisons; as for instance the grey tint of the Mare Procellosum, the dark tracts of Plato, and the light green fields of the Mare Serenitatis, Mare Crisium, and Mare Humorum,—all of which are discernible to the practised eye on the full moon, and two or three nights before and after it, with favouring atmospheric circumstances. The mountains almost universally exhibit the annular forms with flat floors, from which rises a conical central hill; the whole, of so volcanic an appearance as strongly to remind me of the craters of Astroni, and its brethren in the Phlegræan fields near Naples, which I formerly surveyed. Besides these, some abrupt solitary rocks will be found, which present a very singular aspect, and are seen at times casting fine shadows: Pico, a little to the north of Plato, is an excellent specimen, being distinct, insulated, steep, and nearly seven thousand feet in height. There are also many small furrows, which have been taken by some for water courses, and by others for artificial roads; but these roads would be nearly one thousand yards broad. As to the greyish portions heretofore called seas, they appear to be merely cavities in a proportionably

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level surface below the surrounding neighbourhood, and are too replete with bright glimmering inequalities to be extensive oceans; so that Kepler's *Do maculas esse maria*, *do lucidas esse terras*, is no longer received as a canon. Nothing indicative of the presence of water is discoverable on the moon's surface; but the usual objection to the existence of seas, the reflected image of the sun never having been observed upon them, is hardly sufficient, since the quantity of sunshine reflected, even from a smooth surface, would hardly be visible 238,000 miles off; and if the waters are rough, its dissipation would be great: of the light which falls upon water, only part is reflected, and of the rays which pass below the surface, many are absorbed,—therefore the bed of the sea will receive and reflect fewer rays than the land, and will consequently have a darker appearance. But there are other indications that prevent these extensive spots from being classed as seas, which the spectator perceives when scrutinizing them with a good telescope; albeit the general law of optics would tinge the waters green. Hence without water, clouds, or vapour, and consequently without sound, proper diffusion of light, and the essentials to the functions of smell and taste, the moon's inhospitable, dry, desolate wastes, so entirely unfit for the production and support of organized beings similarly constructed to those which inhabit the earth, must present a very different scene from that which Astolfo found. With reference to the sun, the moon has a day and a night of a whole sidereal month in duration, each part being 14¾ days in sunlight, and 14¾ days without it. The intense heat and cold which must thus alternate, however mitigated by possible evaporation and condensation, would destroy human life by the effects of fierce sunshine and keen frost,—the glare of direct irradiation and unmitigated proximity to total darkness. Still, however untenable the notion of *human* inhabitants may seem to be, the confident idea which has been circulated of the moon's being covered with everlasting ice and snow, or altogether composed of stupendous crags and dismal rocks, must be distrusted. The recent improvement in telescopes may, for some time yet, rather furnish new enigmas than solve problems; meantime it is our duty to observe facts most diligently, in the hope of by-and-bye tracing their relations.

Much of this view of the case has, however, arisen from assuming, either that the moon is a body in a state of decay, or one advancing to maturity; and that therefore there are no waters. How this became a *sequitur* it is hard to divine; but the run of the argument is this: There is a practical class who contend, from various examinations, that the stars undergo occultation without any change of colour or brilliance, and without any alteration of place by refraction, therefore there cannot possibly be any lunar atmosphere; or at least if there be one, it must be of such extreme tenuity, as to be utterly incompatible with the existence of water on her surface, because under so faint a pressure it would be rapidly converted into vapour. But here the conditions are unsound,—for moisture seems a necessary ingredient, if not one indispensably requisite, to the adhesion of matter; nor can it be absolutely affirmed that water, or a similar fluid, is entirely absent from the moon. Moreover, I have myself occasionally, though rarely, observed both a diminution of the star's brightness, and an apparent projection of the star upon the moon's disc at the instant of contact; and this was especially the case with the occultation of Aldebaran on the 23rd of October, 1831, recorded in the fifth volume of the *Memoirs of the Royal Astronomical Society*, p. 367*. The red flames, or protuberances of light, observed during total solar eclipses, and so correctly noted by the Astronomer Royal and Mr. Baily during that of July, 1842, seemed to be attributable to an atmospheric effect, albeit there may be no distinguishable atmosphere. So long ago as 1706, Captain Stanyan, at Berne, observed of the sun, "that his getting out of the eclipse was preceded by blood-red streaks of light from the left limb, which

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* For another projection of Aldebaran on the moon's disc, see Vol. II. of this work, α Tauri. But one of the most remarkable which I ever observed was that recorded in the fifth volume of the *Astronomical Society's Memoirs*, p. 368, of 119 Tauri, on the 18th of December, 1831. On that occasion the night was beautiful, the moon nearly full, and the telescope adjusted to the star, which passed over the lunar disc, and did not disappear till it arrived between two protuberances on the moon's bright edge. This was also noted by Mr. Snow, p. 375 of the same volume; but Sir James South saw nothing remarkable, although in a few minutes afterwards, he observed the star 120 Tauri perform a similar feat. Such anomalies are truly singular.

continued not longer than six or seven seconds of time." On this Flamsteed remarks, in a letter to the Royal Society: "The captain is the first man I ever heard of, that took notice of a red streak of light preceding the emersion of the sun's body from a total eclipse; and I take notice of it to you, because it infers that *the moon has an atmosphere;* and its short continuance of only six or seven seconds of time, tells us that its height is not more than the five or six hundredth part of her diameter." This phenomenon was again noted, during the total eclipse of the sun in April, 1715, by Charles Hayes, the author of a *Treatise on Fluxions;* who states, in his philosophical dialogue *Of the Moon*, that there was a streak of "dusky but strong red light" preceding the sun's re-appearance. There is much uncertainty, however, in all these observations, from their being liable to so many conditions of place, weather, instrument, and mind. From more than one observation, I had worked myself up to a belief that the globes of Saturn and Jupiter were more affected under occultation than could be assigned to the inflection of their light in passing by the lunar surface; and I also thought that I had seen the satellites of Jupiter change their figure at the instant of immersion. Thus prejudiced, so to say, I prepared to establish the point by the occultation of the 1st of June, 1831, and certainly observed it under a train of favouring circumstances; but my result, as stated in the second volume of the *Astronomical Society's Monthly Notices*, p. 37, is this:

Although the emersions of the satellites were perfectly distinct, they were certainly not so instantaneous as those of the small stars, which I think was more owing to light than disc. Jupiter entered into contact rather sluggishly; but though the lunar limb was tremulous from haze, there was not the slightest loss of light. Faint scintillating rays preceded the emersion, which was so gradual, that, as the planet re-appeared, the edge of the moon covered it with a perfectly *even* and black segment, which cut the belts distinctly, and formed clear sharp cusps, slowly altering until the whole body was clear. There was no appearance of raggedness from lunar mountains, and Jupiter's belts were superbly plain while emerging; but there was not the slightest distortion of figure, diminution of light, or change of colour.

Schröeter concluded that there existed a lunar atmosphere, but he estimated it to be only 5742 feet high; and Laplace considered it as being more attenuated than what is termed the vacuum in an air-pump. The slowness of the moon's motion, on its axis, may account for such results. The refraction of the rays of light at the surface of the earth must be at least a thousand times greater than at the surface of the moon, and her horizontal refraction cannot exceed $1''\cdot7$. The existence of this contested atmosphere cannot increase or diminish the moon's apparent diameter, because its effect on the rays of light when they enter it, will be exactly counteracted at the time of their emergence. MM. Mädler and Beer, whose selenographical researches have been carried to unprecedented extent, arrive at the conclusion that the moon is not without an atmosphere, but that the smallness of her mass incapacitates her from holding an extensive covering of gas: and they add, "it is possible that this weak envelope may sometimes, through local causes, in some measure dim or condense itself," the which would explain some of the conflicting details of occultation phenomena.

Though a work of this description has no actual connection with the tides, it is impossible for a seaman to proceed thus far without a word on that extraordinary and complex astronomical problem, so difficult on account of the disturbing action of winds, cliffs, channels, and rivers. A multitude of hypotheses has been suggested respecting these periodical fluctuations of the ocean; and though their relation to the moon had been remarked in the remotest antiquity, it may be repeated that Kepler first conjectured their dependence upon the attraction of that body, and Newton demonstrated their true cause. Deducing its legitimate consequences from the laws of gravitation, he explained how the same tides occur at once on the two sides of the earth opposite to the moon; that the alternate rise and fall follow our satellite's motions, so that high water is always found to succeed the time when the moon comes on the meridian, whether on the visible or invisible side of it; and that the land itself must feel the attractive or *drawing* influence of the moon in a greater degree than the portion of water which is most remote from her, thus causing the consequent apparent elevation. The oceanic waters possess a mobility which makes them yield to the slightest impressions, and, owing to the joint action of the sun and moon, the latter being three times that of the former, flow about six hours from south to north, swelling by degrees; the sea then remains about a quarter of an hour stationary, and again retires from north to south during the other six hours, modified, however, by the local impediments before alluded to. By such wondrous hydro-dynamic *lungs*, the waters of the ocean are prevented from becoming stagnant; and the currents thus created temper the frigid waters of the arctic circle with the tepid floods of the torrid zone, and mingle the correcting coolness of the former with the over-heated billows of the latter, never appealing to St. Pierre's fusion of the polar ices to aid and assist. Here, then, is the grand cleanser of harbours, and transporter of laden carracks, the mighty means of health and wealth among the civilized, and the bearer of many benefits even to the savage. In New Holland, whose aboriginals are perhaps the lowest in the race of the *homo sapiens*, there are many whose food is almost confined to shell-fish; and at low water, even when it occurs in the night, whole tribes resort to the shore in quest of prey, compelled by the certainty that they would be deprived of their next meal if they neglected the opportunity of procuring it, even at the most unseasonable hours. The instinct of many animals in this respect, is very extraordinary. In his letters on the *Western Isles of Scotland*, Dr. Macculloch observes: "The accuracy with which cattle calculate the times of ebb and flood, and follow the diurnal variations, is such, that they are seldom mistaken, even when they have many miles to walk to the beach. In the same way, they always secure their retreat from these insulated spots in such a manner, that they are never surprised and drowned."

§ 6. Solar and Lunar Eclipses.

But there is another grand point connected with the three bodies, Sun, Moon, and Earth, which has excited more curiosity, interest, and terror, than any other of the celestial phenomena; and that is an eclipse, or obscuration of either of the two first from the third, by the interposition of an opaque body between it and the observer. Before science had enlightened the minds of men, appearances of this kind were generally regarded as alarming deviations from the established laws of nature, designed by the gods as indicative of their hostility to men; and few were able to account for these extraordinary appearances. In the first year of the Peloponnesian war, when the Athenian fleet was ready to sail, there was an eclipse of the sun, which would have marred the expedition, but that Pericles, the commander, was competent to explain the general nature of eclipses. Yet eighteen years afterwards, an Athenian army was totally lost through the ignorance of Nicias, who was so much terrified by a lunar eclipse, as to be deterred from embarking at the right moment. Columbus put his knowledge of eclipses to some use in his celebrated voyage; for being in want of provisions, which the Indians refused to supply him with, he threatened them with the anger of heaven, in token whereof the full moon, then riding in majesty across the celestial space, would soon be deprived of her light. As this came to pass at the predicted time, the necessary supplies poured in. For still later opinions upon solar and lunar eclipses, and the dragon which causes them, the reader may consult Blundevil's exercises on *The Spheare*, 1594.

Considered with respect to the general principles of the science, the phenomena of eclipses are not of the high consequence, which those unacquainted with the arcana of mathematics imagine; to whom nothing appears more extraordinary than the accuracy with which they can be predicted*. Although they have longest engaged the care and attention of mankind, they are, in truth, merely incidental occurrences, totally unconnected with any maze of theory, and add but little to our knowledge of the great mechanism of nature. But though they are of less interest than formerly, when superstition regarded them with awe, eclipses are of considerable practical utility; before the improvement of instruments, they served to correct and increase

* As these phenomena appear at the same instant of *absolute* time, which is computed from the same moment, at all places on the earth where those celestial orbs are then visible, but at different hours of *relative* time, which is computed from different moments, according to the distance between the meridians of the places observed from, it follows that this difference of time converted into space will be the difference of longitude between those places.

the perfection of our solar and lunar tables; and they have afforded a means of determining the relative situation of distant parts of the globe. Eclipses still continue to be of importance to geography and chronology, and in some measure for the verification of the tables; but their principal interest to future knowledge is the light they may afford as to the physical constitution of the bodies in action. No longer the objects of popular terror, they are predicted with as much accuracy as the returns of day and night; and the palpable evidence thus given, even to ignorance, that there is something in astronomical science, has preserved many a hard-earned salary. They happen when the moon is near her nodes, that is, when she is either in the plane of the ecliptic, or very near it. The interposition of the moon between the sun and the earth, which can occur only with the moon in conjunction, or new, causes an eclipse of the sun; while that of the moon happens at the full, or when the moon is in opposition to the sun, and the earth interposes between them. The sun, earth, and moon, must therefore always be nearly in the same straight line at the time of an eclipse; and conversely, when these three bodies are nearly in a straight line, an eclipse must take place. Every *planet*, both primary and secondary, derives its light from the sun, and must therefore cast a shadow towards the part of the heavens which is opposite to that luminary. As the sun is much larger than the largest of the planets, the shadows cast by any one of these bodies must converge to a point, the distance from which to the planet will be proportionate to the size of that planet and its distance from the sun. The magnitude of the solar orb is such, that the shadow cast by each of the primary planets always converges to a point before it reaches any other planet; so that not one of the primary planets can eclipse another. This rule, of course, does not apply to satellites.

A solar eclipse is called *partial*, when a portion only of the eclipsed orb is hidden from view; *total*, when the whole body is under obscuration; *annular*, when the whole of the eclipsed body is hid except a bright luminous ring around it; and *central*, when the centres of the three bodies are in a direct line with each other. An eclipse of this kind would take place at every conjunction or opposition of the moon, were her orbit coincident with the plane of the ecliptic; but as she ascends and descends to an angle of about 5° 10′, she is never in the ecliptic except when she is in her syzigies, and near one of her nodes, so that there may be a considerable number of conjunctions and oppositions of the sun and moon without the occurrence of any eclipse. The mean number of eclipses in a year, will be about four; there cannot be less than two, nor more than seven, of which five will be of the sun, and two of the moon; and when there are only two, they will both be solar. They generally return nearly in the same order and magnitude at the end of 223 lunations. For in 223 mean synodical revolutions there are 6585·32 days; and in 6585·78 days there are nineteen mean synodical revolutions of the moon's node. Therefore at the end of this period the sun and moon will be found nearly in the same position with respect to the place of the moon's node. This period consists of eighteen Julian years and eleven days, with a trifling allowance for the number of leap years. And it will be found that there are generally about seventy eclipses in this interval, or cycle, of which twenty-nine will be lunar, and forty-one solar.

Full solar eclipses occur too seldom for the interests of knowledge, for there are numerous physical facts and indications therewith connected, which yet remain to be cleared up. The moon is always at some distance from the ecliptic, except she is in one of her nodes; and this distance is called her latitude, which is north or south, according as the moon is on the north or south side of the ecliptic. Now if the moon has any latitude, there cannot be a central eclipse, for this, as was before said, can only happen when the moon is in one of her nodes at the moment of conjunction, which is very seldom the case; and, of course, very few central elipses of the sun have taken place*. I never had the good fortune to witness a total solar eclipse, and therefore can say nothing of the red flames, of the lucid spot seen

* There will not be another total eclipse till 1887; but such of my readers as wish to witness an annular one, may repair to Devonshire or Cornwall in October, 1847.

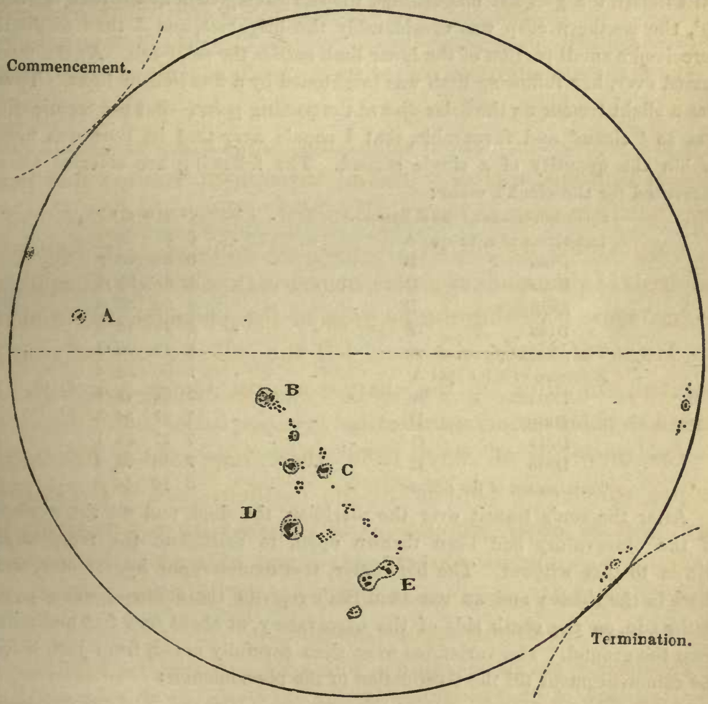
by Don Juan de Ulloa, and considered by some as a hole through which the sun shone, or of the wonderful approach of the shadow at a rate exceeding two thousand miles an hour: of these, and a world of optical illusions, I can therefore advance nothing from personal observation. But I accompanied Baron de Zach from Genoa to Bologna, to observe the remarkable annular eclipse of the sun which happened on the 7th September, 1820; and I must refer the reader to the Baron's report in the Appendix to this volume, as extracted from the fourth volume of his *Correspondance Astronomique*, p. 171. He will there see the vexatious incident which prevented my scrutinizing the formation and dissolution of the annulus; yet the duration of the phenomenon, and the Baron's instructive remarks, gave sufficient opportunity for one of the most satisfactory astronomical treats I ever enjoyed.

But the gratification of witnessing that eclipse, the most remarkable which had happened in this part of the world for fifty-six years, and which could not happen again during the lives of millions, was very general throughout Europe, and perhaps nowhere more so than in England, where, however, though of considerable magnitude, it was not annular. In London, hundreds of thousands of gazers, armed with coloured and smoked glasses, were watching the progress of the phenomenon; and in the House of Lords, the peers left the solicitor-general nearly deserted, summing up the charges against Queen Caroline, to attend to their astronomical call.

On the 15th of May, 1836, there happened a fine solar eclipse, which was annular in the northern part of Great Britain; but as other occupations interfered with my repairing to Scotland to view its phenomena, I was obliged to be content with its partial appearance at Bedford. Of this the reader may like to have the details as an example:

The weather was remarkably fine, with a light air from the N.W., and a very clear sky. A diagram of the solar disc was drawn just after the meridian transit was taken, and the vertical distances between the maculæ were measured with a double-wire micrometer; but the rapid approach of the celestial bodies did not afford time to take the transverses, nor is it of much object, since to those who wish to identify a spot, the vertical measurement, as cut by the moon's limb in its progress, will supply the deficiency.

The commencement of the eclipse was denoted by a slight undulatory impression on the solar limb, which instantly increased to a "shake." As the instrument used was the $8\frac{1}{2}$ feet refractor, with reduced aperture, and a micrometer with a power of 110, pretty exactly pointed to the computed point of first apparent contact, I cannot but think it was observed within the limits of three or four seconds. The appulse of the moon's limb to the edge of each macula was then carefully noted, and the disappearance of the "following" portion, the mean of the two being assumed as the occultation of the centre of the spot, or group of spots; those covered by the preceding limb being entered as immersions, and their re-appearance on the passing of the posterior limb as emersions. There was a great variety of maculæ, and some of them extended a long way from the solar equator; presenting, therefore, a different aspect from the annular eclipse of 1820, when the whole disc was clear,—or the partial one of the 16th of July, 1833, when there was but one small spot which disappeared in a lunar valley, as shown in my diagram in the eighth volume of the *Royal Astronomical Society's Memoirs.* This is a representation of their relative positions as seen in the telescope in 1836:



MICROMETRICAL MEASUREMENTS.

	Rev. Parts.			Rev. Parts.	
A from prec. limb	10 22·6	= 3′ 22″·93	B to C - -	5 49·4	= 1′ 49″·02
A to B - -	25 56·4	= 8′ 27″·31	D to E - -	13 46·7	= 4′ 27″·25
B to D - -	3 41·7	= 1′ 7″·81	E to second limb	43 37·7	= 14′ 20″·81

It may be remarked, that the usual practice of noting the commencement and the termination of a solar eclipse, is not the plan by which the greatest accuracy can be attained. An excellent method, by observing the differences of the N. P. D.'s or Æ's of the cusps, near the beginning and near the end of the eclipse, is described by Mr. Airy, in the *Memoirs of the Astronomical Society*, Vol. VIII., p. 115. Our object here, however, is with the rule-of-thumb course.

During the progress of the phenomenon, there were fewer peculiarities than usual on such occasions, the edge of the moon, though slightly serrated here and there, being much smoother, and sharper defined than I ever saw it before in solar eclipses*. At first the lunar limb was somewhat tremulous, but before passing over spot B, it had become steady, and glided very smoothly over the solar surface. The spots vanished without the slightest appearance of projection on the moon's disc, and the ever-varying cusps were beautifully defined; the planet in a compound orbicular path, describing an ellipsis between south, north, and west, intercepting the solar rays until the eclipse reached its extent, leaving an annular segment of the sun from south to east, which was equal in depth to about one fourth of the whole solar diameter. A little before the greatest obscuration, the sun having then an altitude of about 40°, the southern cusp was considerably the brightest, and I then distinctly perceived a small portion of the lunar limb *outside* the solar orb. As the moon passed over, her following limb was brightened by a fine line of light. There was a slight tremor on the solar disc at the parting point,—but the termination was so "clean" and favourable, that I should aver that its time was noted within the quantity of a single second. The following are sidereal times, corrected for the clock's error:

Commencement of the eclipse		5h	21m	47s·7
Immersion of solar spot	A	5	37	39·6
Ditto	B	6	00	48·9
Ditto	C	6	07	29·5
Ditto	D	6	09	30·9
Ditto	E	6	25	46·6
The greatest phase, about		6	53	48·5
Emersion of solar spot	A	7	00	08·4
Ditto	B	7	22	47·7
Ditto	D	7	27	34·3
Ditto	C	7	27	36·1
Ditto	E	7	38	28·5
Termination of the eclipse		8	10	10·8

After the sun's transit over the meridian, the door and all the windows of the observatory had been thrown open, to assimilate the temperature within to that without. The barometer, thermometer, and hygrometer, were there in the shade; and an excellent Six's register thermometer was exposed to the sun, on the south side of the observatory, at about four feet and a half from the ground. The variations were then carefully noted, from just before the commencement till the termination of the phenomenon:

* The first visible impression made on the solar disc by the moon's limb, is designated the *first external contact;* the limb getting inside is the *first internal contact;* the moon then moves on to her *second internal contact,* and when terminating the eclipse, makes her *second external contact.* The *cusps,* are right lines touching the moon's horns.

Time, P.M.	In the Sun.	In the Observatory.		
	Therm.	Barom.	Therm.	Hygrom.
		Inches.		*Parts.*
At $1^h\ 40^m$	91°·3	30·54	69°·6	·298
2 30	79°·0	30·53	69°·5	·282
2 50	74°·7	30·52	68°·0	·261
3 15	67°·6	30·51	66°·9	·259
3 44	74°·5	30·51	64°·8	·272
4 0	79°·8	30·50	65°·8	·275
4 38	81°·9	30·50	67°·1	·283

As the sun obfuscated, the air sensibly cooled, the atmospheric light became mellowed, deepening to a darkness which bore no resemblance either to morning or evening twilight; and, at the greatest obscuration, assumed the peculiar lurid gloom which commonly heralds in a summer thunder-storm. Mercury was now seen in the finder; and Venus with the naked eye, but the time of her earliest visibility was omitted to be noted. Still the darkness was considerably less than was expected by those who forgot how much of the sun would remain uneclipsed, and which had prompted the very singular general order to defer the afternoon's service in our churches. The effect on the temperature was more remarkable than that on the light, a difference which may be ascribed to the effect of radiation. The vegetation in a line with the sun assumed a silvery purplish hue, and in the shade an orange tinge; while the crocus, gentian, and anemone, partially closed their flowers, and re-opened them as the phenomenon passed off: and a delicate South African mimosa, which we had reared from a seed, entirely folded its pinnate leaves until the sun was uncovered. More than one person took notice, that while the temperature was at its lowest scale, the earth-worms crept from their holes; and among other remarks made by friends during the eclipse, I may mention a very striking though well known optical property: one was looking at the eclipse from near a tree, the shadow of which was cast on a white dead wall. Turning his back to the sun, he perceived the shade from the leaves, where, under ordinary circumstances, each little interstice is a complete circle, assuming the crescent shape as the eclipse progressed, waxing, waning, and shifting the cusps, thus affording a perfectly reflected image of the whole phenomenon.

The end of this eclipse, as might be expected, was everywhere observed to a greater nicety than its beginning. That at Bedford, being at $4^h\ 36^m\ 27^s{\cdot}1$, mean time, affords, by comparison, the following geographical arcs:

	Mean time.	△ Longitude.
Altona - - -	$5^h\ 21^m\ 23^s{\cdot}2$	$41^m\ 32^s{\cdot}5$ E.
Armagh - -	4 38 55 ·5	24 47 ·7 W.
Cambridge - -	4 4 58 ·9	2 11 ·9 E.
Edinburgh - -	4 19 21 ·6	11 00 ·8 W.
Greenwich - -	4 39 12 ·3	1 48 ·9 E.
Paris - -	4 52 21 ·6	11 12 ·1 E.

Having thus got the sample of a solar, the tyro may desire to have one of a lunar eclipse. Visible phenomena of this description are of very frequent occurrence, but on account of the indefinite limits of the umbra and the indistinctness of the border of the penumbra, the correct observation of such eclipses is generally difficult and unsatisfactory. They are visible from all points which have the moon above their horizon, being of the same magnitude and duration to every spectator on the surface of the earth, because of the moon's great proximity to us, compared with the distance of the sun. The phenomenon is caused by the moon's passing through the shadow of the earth, which shadow is a projected cone 3½ times longer than the distance between the earth and moon, but not sufficiently long to reach Mars: it has been calculated that this cone is 800,000 miles in length, with a breadth where it is traversed by the moon, of nearly three times that satellite's diameter. This dark cone is the *umbra;* but on each side are shadows less dense called the *penumbra*, formed by the interruption of a part only of the sun's rays, the intensity of which diminishes in proportion as they recede from the conical shadow. At the point intercepted by the lunar orbit, the umbra is equal to the sum of the horizontal parallaxes of the sun and moon, less the sun's semi-diameter. The magnitude and duration of every lunar eclipse will consequently vary according to the magnitude of those quantities at the given time, and the relative positions of the luminaries. A lunar eclipse cannot last longer than 5½ hours, from the moon's first entering into the earth's penumbra to her quitting it: she cannot be eclipsed partially and totally more than 3¾ hours; and she cannot be totally eclipsed more than 1¾ hours. There was a total eclipse of the moon on the 13th of October, 1837, of which I made the following observations in my observatory at Bedford. The evening was remarkably fine, and the moon shining with a splendour which hid all but the primary stars; the following occurrences were then noted, in corrected sidereal time:

$22^h\ 55^m\ 00^s$. A light grey penumbra appearing.
$22^h\ 55^m\ 40^s$. The moon suffused with a copper tint.
$22^h\ 57^m\ 12^s$. The dark shadow impinged on the lunar limb, and gradually marched over Grimaldus (*a*).

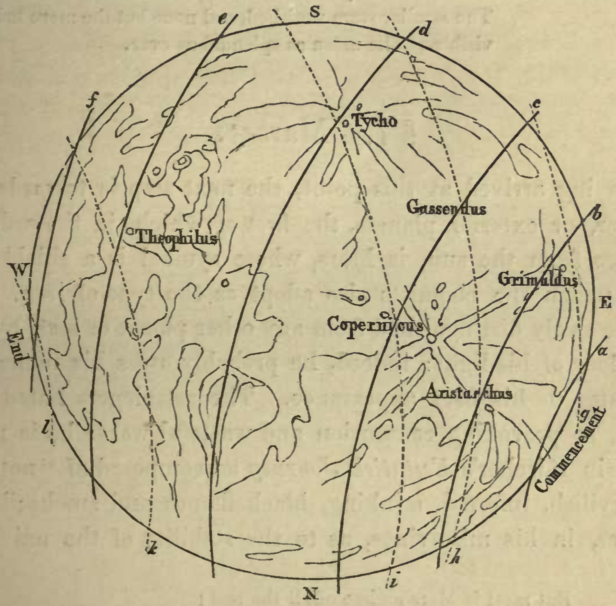
$23^h\ 01^m\ 17^s$. Touched the crater of Aristarchus, the shadow filling the valleys as it advanced, then ascending the hills, and extinguishing their bright summits (*b*).

$23^h\ 13^m\ 25^s$. Reached the fine regions of Copernicus, part of the cloud to the south crossing Gassendus. The stars gradually increasing in brightness (*c*).

$23^h\ 32^m\ 38^s$. Across the lunar disc, and through the streaky range of Tycho. Darkness increased so as to show the Milky Way (*d*).

$23^h\ 44^m\ 47^s$. The umbra passed the rugged mountains of Theophilus, soon after which sea-green tints were observable (*e*).

$23^h\ 54^m\ 10^s$. The shadow became more transparent, and the whole orb visible, so that the spots and other particulars of the selenography were revealed (*f*).



$0^h\ 08^m\ 08^s$. The sea-green tint spread all over the moon. A star nearly in a line with Aristarchus and Copernicus close to the moon's limb, was occulted 25^s afterwards.

$0^h\ 22^m\ 40^s$. The moon became lighter all over. Perhaps the retina of the eye had been fatigued by the lunar brightness at first, and was now awakening to delicate impressions.

$0^h\ 58^m\ 40^s$. The shadow seemed to be of a dark neutral tint, diluted in its intensity by refracted light; a streak of sea-green towards Aristarchus. Turned the telescope upon the nebula 76 Messier, as a gauge, and saw it beautifully; but it gradually faded as the moon emerged.

$1^h\ 28^m\ 21^s$. While the experiments were being made on nebulæ, during the total obscuration, the green tints were displaced by the copper ones, and a silvery light appeared over Grimaldus (*g*).

$1^h\ 40^m\ 29^s$. Aristarchus became uncovered, and its brightness rendered the obscured part more opaque (*h*).

$1^h\ 52^m\ 12^s$. Copernicus and Tycho uncovered. The smaller stars retiring, and all of them dimming (*i*).

$2^h\ 20^m\ 58^s$. Theophilus re-appeared almost in full splendour. The nebula 76 Messier only perceptible from a knowledge of its form and place (*k*).

$2^h\ 29^m\ 30^s$. The small obscured segment of a curious dark tint, lessening with a smooth motion (*l*).

$2^h\ 31^m\ 04^s$. The shadow entirely left the moon, and the eclipse terminated. The smaller stars vanished, and none but the more brilliant visible. The moon as splendid as ever.

§ 7. Mars ♂.

Having arrived at this point, the next step is towards the superior, or exterior planets, the first of which, in the order of distance from the sun, is Mars, whose symbol is a shield and spear, which the chemists also adopt as the type of iron. He may be easily distinguished from any other planet or star, by the red colour of his light: indeed, he probably owes his name and attributes to his fiery appearance. The astrologers hated this planet, as provoking contention and wasteful wars; he is mentioned in Kircher's *Ecstatick Journey* as composed of "nothing but devilish, infernal, stinking, black flames and smoke;" and Spenser, in his misgivings, as to the stability of the universe, says,

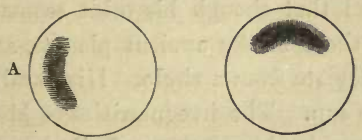
> But most is Mars amisse of all the rest;
> And next to him old Saturne, that was wont to be the best.

The analogy between Mars and the earth is greater than between the earth and any other planet of the solar system. Their diurnal motion is nearly the same; the inclinations of their equators to the planes of their orbits, on which the seasons depend, are not very different; nor is the length of his year very different from ours, when compared with the years of Jupiter, Saturn, and Uranus. The earth, however, appears to be the more favoured of the two, since water would not remain fluid even at the equator of Mars, and alcohol would freeze in his temperate zones. The force of gravity on his surface is about one tenth greater than at the surface of the earth; but his density is much less than that of the earth. A body which weighs one pound at our equator, would weigh only five ounces and six drachms at that of Mars; and were his course stopped, 121 days and 10 hours would elapse before he dropped upon the sun. Should sentient beings exist there, they see the sun's diameter less by one third than we do, and consequently the degree of light and heat they receive is less than that received by us, in the proportion of 4 to 9, or rather less than 1 to 2; liable, however, to variations from the great ex-centricity of his orbit. If their atmosphere be as dense as is supposed, they probably scarcely ever discern Mercury and Venus, which will appear to *borrow* on the solar rays; the earth and moon, however, will afford them a beautiful pair of planets alternately changing places with each other under horned or falcated phases, but never quite full, and not more than a quarter of a degree distant from each other. This appearance is not reciprocated, for though it is not at all impossible but that he may have a satellite revolving around him, it is probably very small, and close to his disc, so that it has hitherto escaped our best telescopes; yet being further from the sun than the earth is, Mars —if at all habitable—would seem to stand even more in need of a luminous auxiliary.

The ruddy colour of Mars is imputed to the density of his atmosphere, which is considered as being of great extent. Cassini has recorded, that in October, 1672, he saw ψ Aquarii, a star of the fifth magnitude, at the distance of six minutes from the planet's disc, become so faint that it could not be seen by the naked eye, nor even with a three-foot telescope; which observation, together with Römer's confirmatory remarks, established the conclusion of an *extensive* atmosphere. M. Flaugergues of Viviers, considered it as similar to our envelope, in reflecting the blue and violet rays, and allowing only the yellow and red to pass. Sir William Herschel, however, questioned the accuracy of some of the observations of the dimness caused by the approach of this planet to the fixed stars; yet he admits that it has a considerable atmosphere,—"for," says he, "besides the permanent spots on its surface, I have often noticed occasional changes of partial bright belts, and also once a darkish one in a pretty high latitude: and these alterations we can hardly ascribe to any other cause than the variable disposition of clouds and vapours floating in the atmosphere of the planet." I had myself entertained doubts as to the extent of the supposed atmospheric influence, since on watching the appulse of several small stars which I fished up, I could discern no effect but what might be imputed to the superior light of the planet. Cassini and Römer are assuredly great names; but may they not have been deceived by a cosmical cloud, or some other anomaly?

This point, however, may now be considered as conclusively settled by Sir James South, who, in the *Philosophical Transactions* for 1831, has given very detailed observations to justify our denying the existence of an *extensive* atmosphere to Mars.

There is not a planet within the reach of our telescopes, which presents an aspect so like that of the earth as Mars, whose surface, independently of the changeable atmospheric influences, shows an appearance of well-defined seas and continents; and this was very especially the case in August, 1830, when the *geographical* lines of demarcation were so beautifully distinct, that Sir John Herschel called my attention to them, saying that he was able to make a tolerable map of the surface. The predominant brightness of the polar regions leads to the supposition, that the poles of Mars, like those of the earth, are covered with perpetual snow; and Sir William Herschel concluded, that the observable changes in luminosity and magnitude, are connected with the summer and winter seasons in that planet. Sir John Herschel also remarks, that the brilliant polar spots are probably snow, as they disappear when they have been long exposed to the sun, and are greatest when just emerging from the long night of their polar winter. The latter astronomer, aided by the full power of the twenty-foot reflector, pronounced the seas to be of a greenish hue, resembling the colour of our own, and the land of a red tint, perhaps owing to a quality in the prevailing soil, like that which our red sandstone districts would exhibit to an observer beholding the earth from the surface of Mars. This diversity of appearance is not always visible, and when visible, is not always equally distinct, because of the varying transparency of the atmosphere; but when the colour and relative situation of the spots are distinct, they never alter their form. Singular anomalies, however, are liable to be found in the gaseous envelope of this planet. In July, 1828, I received a letter from Slough, in which Sir J. Herschel asks: "Do you perceive anything in the spots on Mars different from the great one always observed on its disc? Dr. Pearson writes me word of a singular change of situation of this spot. He says that on June 22nd it stood as in A, and that four nights after—the planet being in the same situation—it stood as in B. Pray look at this, and if you see any such change, note it, as your attention is directed to that planet."



These same *geographical* features were curiously figured as spots, when first telescopically examined. In March, 1666, Dr. Hook observed them with a thirty-six foot telescope, and finding they had a motion, he concluded that the planet turned round its centre*. In the same year, J. D. Cassini made similar observations at Bologna, and concluded the rotation to be performed in $24^h\ 40^m$, which was afterwards confirmed by his nephew, Maraldi, whence both the motion and the natural day of the planet were determined. From observations made by Sir W. Herschel in 1779, he concluded that the rotation of Mars cannot well be less than $24^h\ 39^m\ 05^s$, nor more than $24^h\ 39^m\ 22^s$. When examined by a sufficiently powerful telescope, it is found that all the traits which the planet exhibits at any moment, gradually disappear in $12^h\ 20^m$ nearly, at the expiration of which time he shows an entirely different face.

* It is said that Fontana, of Naples, suspected this rotation before the year 1643; but a claim is also made to Fontana's having invented the telescope in 1608, which just cuts out both Jansen and Lippersheim. He, moreover, assigned seven satellites to Jupiter.

But by continuing to observe him, the former features come successively into view, and all his original lineaments are restored after the lapse of the same time; he has, therefore, all but the same intervals of day and night as we have. A year in Mars, however, is almost twice as long as our year.

In the achronical rising of Mars, as the ancients termed the opposition to the sun, or 180° difference of longitude, he is found five times nearer to us than when in conjunction with the sun, which is one reason why he appears so much larger and brighter at one time than another. Hence his visible and telescopic appearances are very variable; but by observing his opposition in different parts of the heavens, or when he is in different parts of his orbit, his apparent diameter is still nearly the same: whence it was inferred, that the sun is nearly in the centre of the orbit of Mars, and that though his orbit seems to be the most ex-centric of all those of the ancient planets, save Mercury, it does not greatly deviate from a circle. His parallax, at times, is double that of the sun. The irregularities of Mars, in his orbit, being the most considerable of those of all the primary planets, Kepler fixed upon them as the first objects of his investigations respecting the nature of the planetary courses (see p. 43). But after extraordinary and patient labour, he at last discovered that the orbit of this planet was elliptical, that the sun is placed in one of the foci, and that there is no point round which the angular motion is uniform. This proved to be the key to his great laws.

The phases of Mars were first observed in 1638 by Fontana, the optician; but Kepler had already spoken of his being gibbous, from theory: deriving his light from the sun, and revolving around it, his phase increases and decreases according to his various positions with respect to that luminary and the earth. He may be observed almost bisected, when in his quadratures with the sun, or in his perigæon; but he is never seen horned, or falcated, as the inferior planets are, which both shows that his orbit includes the earth's within it, and that he shines not by his own light. His presenting sometimes the whole of his enlightened hemisphere to the earth, and sometimes only part, is another reason why he varies greatly in brightness. He is at once most bright, as far as this cause affects his brightness, and nearest to us, when he is in opposition and the earth between him and the sun; being then distant from us not more than half our distance from the sun, and appearing under an angle of about 18″.

Owing to these changes Mars varies, in particular instances, from an almost imperceptible speck to a dazzling orb with a large apparent diameter. Baron de Zach states, in his *Correspondance Astronomique*, Vol. II., p. 293, that in August, 1719, the planet then being both in perihelion and opposition, its brightness was so great under these favourable circumstances, as to cause considerable alarm among the ignorant. Its real form cannot be often observed, for when the planet is near enough to be viewed with advantage, it is gibbous; and its oppositions, which occur only after the known intervals, are of so short a duration, that in the space of two years there are not above three or four weeks for such a scrutiny. It is, therefore, not at all surprising, that the spheroidal shape of this planet should have remained undetected until the time of Sir W. Herschel, who discovered that the polar diameter of Mars is one sixteenth less than his equatorial one.

When Mars first emerges from the sun's rays, a few days after his conjunction, he rises some minutes before the sun, and his motion is found to be progressive towards the east. But the rate of the earth's movement in the same direction is nearly double that of Mars, which has the effect of making that planet appear to recede from the sun towards the west, though his real motion, with respect to the fixed stars, is towards the east. This continues for nearly a year, when his angular distance from the sun amounts to about 137°; he then appears to be stationary for a few days. After that his motion becomes retrograde, or towards the west, and continues so till he is 180° distant from the sun, or in opposition, so as to be on the meridian at midnight. His retrograde motion is then the swiftest; it afterwards becomes slower, and ceases altogether when the planet again comes to be about 137° on the other side of the sun. His motion then becomes progressive again, and continues so till he replunges into the solar rays, when the phenomena are renewed, but with a considerable difference as to the extent and duration of the movements. The retrogradation commences or finishes when the planet is at a distance from the sun, which varies from 128° 44′ to 146° 37′, the arc described being from 10° 6′ to 19° 35′; the duration of the retrograde motion in the former case is 60 days 18 hours, and in the latter 80 days 15 hours. The period in which all those changes take place, or the interval between one conjunction or opposition and the next, is 780 days, which is the length of a synodical revolution of this planet. Mars and the earth come *nearly* to the same relative position every twenty-three years; but several centuries must elapse before they come *precisely* to the same again.

Such is Mars, our celestial cousin-german; and these are his elliptical elements for the epoch mentioned at p. 83:

Mean distance (142,000,000 miles), earth as unity	1·5236923
Mean sidereal revolution	$686^{d}\ 23^{h}\ 30^{m}\ 41^{s}\ 4$
Mean synodical ditto, in solar days	779·936
Longitude of perihelion	332° 23′ 56″·6
E. motion of apsides per annum	15″·8
Ditto, apparent for precession	1′ 05″·9
Inclination of orbit	1° 51′ 06″·2
Annual decrease of ditto	0″·014
Longitude of ascending node	48° 0′ 03″·5
W. motion of ditto, per annum	23″·3
E. ditto, referred to the ecliptic	26″·8
Ex-centricity of orbit, half major axis as unity	0·0933070
Secular increase of ditto	0·00090176
Greatest equation of centre	10° 40′ 50″
Annual decrease of ditto	0″·37
Rotation on his axis	$24^{h}\ 39^{m}\ 21^{s}·3$
Inclination of axis	30° 18′ 10″·8
Mean apparent diameter	6″·29
Diameter at conjunction	3″·60
Ditto at opposition	18″·28
True diameter (4100 miles), earth as unity	0·517
Volume, earth as unity	0·1386
Mass, sun as unity	0·0000003927

§ 8. The Asteroids.

Ceres ⚳. Pallas ⚴. Juno ⚵. Vesta ⚶.

Quitting Mars, we now arrive at a singular family of small bodies recently discovered, the history of which forms a planetary episode of no common interest; whether considered as a general astronomical gain, or a glory to the speculative fancy and untiring diligence of the scientific Germans, to whom the world is chiefly indebted for them. They are so utterly unlike the other primary planets in size and motion, so much resembling small stars even with good telescopes, and require so exclusive a mode of treatment in calculation, that Sir William Herschel proposed the name of *Asteroids*, as a distinctive appellation for the group; and although their paths round the sun, contained within the orbits of the greater planets, and their borrowed light, stamp them as planets, their various singularities seem to demand a peculiar appellation. Sir William's own definition of asteroids is, that they are celestial bodies, moving in orbits the plane of which may be inclined to the ecliptic in any angle; their motion may be direct or retrograde; and they may or may not have considerable atmospheres, very small comas, discs, or nuclei. Some, however, have carped at this designation, as improperly lowering the standard of bodies which they think, when compared with Mercury, are not smaller than Mercury is compared with Jupiter, and ought therefore to be allowed the style and title of Extra-zodiacal Planets, or, at the very least, Planetoids. Others, without supplying a better, have objected that the name of Asteroid is not the most expressive and appropriate that could have been applied.

Although from a love and awe of the mystic number *seven*, Kepler, by the sage device of making a monochord give the seven tones to the gamut, had been induced to hold that there could not be more than seven planets; he afterwards returned to an opinion broached in the very first work which he published, that there was a planet between Mars and Jupiter, and another between Mercury and Venus. From a deep conviction of the harmony of the solar system, he became persuaded, that an undiscovered body must exist in the vast space between Mars and Jupiter; and although the idea slumbered, the German school were strongly inclined to resuscitate it. It was noted that between the orbits of Mercury and Venus there is an interval of thirty-one millions of miles; between those of Venus and the earth, twenty-seven millions; and between those of the earth and Mars, fifty millions. But between the orbits of Mars and Jupiter there intervenes the tremendous gap of three hundred and forty-nine millions of miles, to the apparent interruption of the general order, which, however, is again resumed beyond Jupiter. At length Herschel's discovery of Uranus in

1781, although on the outer verge of the system, aroused the most lively interest among astronomers; and Kepler's notion was in some degree realized by a process equally novel and successful, in an empirical scheme of Professor Bode's, which will presently be given, and which received such attention, that in 1784, Baron de Zach even employed himself in analogical computations of an orbit of the latent body. Delambre, speaking of Bode's views, says, "Quand on s'est mis en devoir de chercher la planète inconnue, ce n'était pas d'après les idées de Kepler, c'était d'après une loi presque aussi chimérique, mais au moins bien plus spécieuse." In 1800, the Baron was one of six astronomers assembled at Lilienthal, who resolved to establish a society of twenty-four practical observers to examine all the telescopic stars of the whole zodiac in zones, for the express purpose of searching out this concealed planet. They elected M. Schroeter as the president of the association, and the Baron was unanimously chosen their perpetual secretary. Such a determined arrangement was irresistible, and their operations were rewarded by the detection of four planets within the interval of six years; and a striking instance was afforded of those anticipations by which sagacity sometimes outstrips its age and country. On the new-year's day of 1801, ere they had well got into harness, Piazzi, one of their number, made an observation of a small star in Taurus, which he took for one of Mayer's, close to his own No. 103, Hora III. On the 2nd of January, he found that the supposed star had retrograded no less than 4′ in Æ, and $3'\frac{1}{2}$ in north declination. This retrogradation continued till about the 12th, when the movement became direct, and he followed the body till it was lost in the solar rays. Illness, however, prevented his getting observations enough to establish its nature, and he considered it to be cometary. Meantime he had written to Bode and Oriani on the subject, but the delays of the post in that comparatively recent day, by keeping back the intelligence, precluded its being examined during that apparition. Curiosity and zeal were, however, on the alert; Bode immediately suspected the real nature of the stranger; and Olbers, Burckhardt, and Gauss, computed its orbit from the slender data thus afforded. The knowledge of its having been stationary on the 12th of January, with an elongation from the sun of $4^s\ 2^\circ\ 37'\ 48''$ aided the computation, and proved it to be a superior planet. In April, Bode communicated his views to Baron de Zach, who remarks:

On reading this letter, I immediately had recourse to my old calculations of 1784 and 1785, and showed to Professor Pasquich, who was present when it arrived, that my elements of the orbit of this planet, calculated from analogy, and inserted in the *Berlin Almanac* for 1789, gave as its distance from the sun 2·82, and as its period of revolution 4·74 years, or four years and nine months. Professor Bode, from Piazzi's observations, had found the distance 2·75, and the revolution the same as I had deduced from analogy, viz. four years and nine months. I immediately sent an answer to Professor Bode's letter, and informed him, that my two elements of the orbit of this so long concealed planet, calculated, provisionally, sixteen years before, amidst my analogical dreams, and which I had deposited in his hands in a sealed note in October, 1785, when I had the pleasure of forming a personal acquaintance with that worthy friend at Berlin, corresponded perfectly with his own, and consequently with those of Piazzi. I was therefore of opinion that the supposed comet might be the invisible planet so long sought for in vain.

As it was found that no parabolic orbit could agree with the observations, there was a keen look-out for the re-appearance of the body, but the re-discovery was difficult on account of its extreme smallness. At length, after many patient trials, Baron de Zach, though then busily engaged on a map of Thuringia, again picked it up on the last day of the year 1801. Nor was this the only debt which the asteroids owe to that active astronomer; he had just established his *Monatliche Correspondenz*, which admitted of greater scientific detail, and fuller expositions of theoretical and physical views, than such publications do in general, at least in that day of clogged communication. Hence the Baron Lindenau demands, "What would have been the fate of the small planets, if the *Monatliche Correspondenz* had not then existed?" The planet, however, was now discovered, its conquest insured, and the relation completed which before was wanting. Bode, reasoning upon analogy, had produced the scheme before alluded to; and concluded that the excesses of the distances of the planets above Mercury form a geometrical series, of which the common ratio is 2. Now, by assuming our distance from the sun as being 10, the new planet's orbital radius was found to be = 3·2; not far from 2·8, which should have been the mean distance of Kepler's supposed body; according to Lambert, Bode, and

Wurm; who found this curious but purely empirical law in the first difference of the radii vectores:

Mercury .	$4 = 4$	Saturn .		$100 = 4 + 3 \times 2^5$
Venus .	$7 = 4 + 3 \times 2^0$	Uranus .		$196 = 4 + 3 \times 2^6$
Earth .	$10 = 4 + 3 \times 2^1$	At and beyond the aphelia of comets		$388 = 4 + 3 \times 2^7$
Mars .	$16 = 4 + 3 \times 2^2$			$772 = 4 + 3 \times 2^8$
Ceres .	$28 = 4 + 3 \times 2^3$			$1540 = 4 + 3 \times 2^9$
Jupiter .	$52 = 4 + 3 \times 2^4$			$3076 = 4 + 3 \times 2^{10}$*

Thus was Ceres discovered at Palermo on the 1st of January, 1801. Its diameter, according to Sir W. Herschel, is only 163 miles, but Schroeter makes it 1624 miles; which great difference, according to the latter, arose from Herschel's observing with his projection-micrometer at too great a distance from his eye, and measuring only the middle clear part of the nucleus. Delambre thinks the one determination is too small, and the other in excess. The mean distance of the planet from the sun is about two hundred and sixty-three millions of miles; the ex-centricity of its orbit is not so great as that of Mercury, but its inclination to the ecliptic exceeds that of all the old planets very considerably. It was found to perform its sidereal revolution in 1681·3931 mean solar days; and its synodical circuit in 466·62 days. Ceres is not visible to the naked eye; but when observed by a telescope, appears something like a ruddy star of the eighth magnitude; raising the magnifying powers, under favourable circumstances, makes its disc—or sensible breadth of surface—clearly perceptible, and leaves the inference of an extensive atmosphere. Its density is considered, by mere inference, as about twice that of water; and it receives less than one seventh of the light that the earth does. Sir William Herschel made many observations to assure himself whether two very small specks of light which he perceived near Ceres, were satellites; but they

* Bode's *law* teaches, that the interval between the orbits of any two planets, is about twice as great as the inferior interval, and only half the superior one. Among other singular astronomical co-incidences, the following respecting the "three bodies" may be cited:

	Miles.	Ratio.	
⊕ Diameter	7,912 ×	110 =	870,320, the estimated diameter of the sun.
☉ Diameter	870,320 ×	110 =	95,735,200, average mean distance between ⊕ and ☉.
☽ Diameter	2,160 ×	110 =	237,600, average mean distance between ☽ and ⊕.

were so small, that with a twenty-foot telescope, they required a power of 300 to be seen; and the planet had to be occulted by a thick wire at the time of scrutiny. Ceres, however, reasoning by analogy, appears to be too small a mass to retain satellites in her orbit.

While Bode and the associated astronomers were rejoicing in the supposed order of the planetary distances from the sun, which seemed to be established by this discovery, it was deranged by an announcement from Dr. Olbers, of Bremen, that he had found another planet, on the 28th of March, 1802, with a mean distance from the sun nearly the same as that of Ceres, and similar sidereal and synodical revolutions. This little wanderer is less ruddy than Ceres, but seems to be nearly of the same magnitude, to be surrounded by a similar atmosphere, and to undergo similar changes; yet its light exhibits greater variations. Still with all my coaxing, I never raised a disc, as I could readily do with Ceres. It was designated Pallas; and the indefatigable Gauss quickly fitted it with an orbit, the elements of which, however, broke the barriers of the zodiac, which had been designed just to give latitude to the excursions of the inferior planets. On a careful comparison of the two orbits, their major axes were found so nearly equal, and however their ex-centricities and inclinations differed, the orbits approached so near at the intersection of their planes, that they consequently occupy but a narrow zone at the nodes. Olbers, duly weighing all this, conceived that they might be the fragments of a great planet, which formerly revolved about the sun in an orbit situated nearly in the same part of space, but which had been destroyed by some cosmical convulsion. As this reasonable hypothesis led to the inference that there were still other pieces to pick up, the hint proved sufficient to set the associates to work again; and the place where the astronomical congress had first met, was soon to be the site of another discovery.

On the 2nd of September, 1804, M. Harding of Lilienthal, while engaged in making a catalogue of all the stars which were near the orbits of Ceres and Pallas, for the purpose of forming an express zodiac for them, determined the position of what seemed an 8th-magnitude star near the tail of Cetus, and not far from one of the nodes of the asteroids. On the 4th it had moved to the south-west, and observations on successive nights confirmed its motion, and pointed out the direction it was taking. This newly-discovered body was announced to the world under the name of Juno. It is of a reddish colour, and free from that haziness which surrounds Pallas; its orbit is so elliptical that its greatest distance from the sun is nearly double its least; and the inclination of its orbit to the ecliptic, is about 13°. This great ex-centricity has a remarkable effect on the planet in its orbit; for it moves through that half of its orbit which is nearest the sun, in nearly half the time that it moves through the other part. Schroeter gives it a diameter of 1425 miles; but that astronomer seems to have over-rated the magnitude of all the asteroids, the measurements of which are attended with every difficulty. Other authorities state that it does not much exceed seventy-nine miles, so that an inhabitant of that planet, says Mrs. Somerville, "in one of our steam-carriages, might go round his world in a few hours." Schroeter is also inclined to give it a dense atmosphere, and a rotation on its axis of twenty-seven hours. It performs its sidereal revolution in 1592·6608 mean solar days, and its synodical circuit in 473·95 days. This was joyful news for the planet hunters, for there now seemed no end to their quarry; and it was pretty obvious, that if these little bodies were but fragments of a larger planet, with orbits cutting each other, the intersections of their orbital planes must fall nearly at the same part, in two opposite points of the heavens.

Meanwhile Olbers, not content with the laurels he had won, most perseveringly pursued the game thus sprung. He conjectured that one of the two opposite constellations, Virgo or Cetus, was the place where the planet had been shivered by an explosive force, and where, therefore, the orbits of all the fragments must pass, as they had all diverged from the same point, however differently inclined to the ecliptic. Prosecuting this idea, he every year scrutinized the small stars in the defiles near the nodes of Ceres and Pallas, until at length, on the 29th of March, 1807, his diligence was requited with the discovery of a little planet in the wing of Virgo, which Gauss named Vesta. Its diameter is only 250 miles, and it makes its synodical revolution in 503·41 days. Small as it is, however, it may be seen by a sharp naked eye on a clear evening when in a favourable position, as its light is more intense than that of its compeers, and it is not surrounded by any nebulosity. Its orbit cuts that of Pallas, but not in the place where it is intersected by the orbit of Ceres.

Thus, then, was completed one of the most remarkable triumphs of scientific zeal; and this singular coincidence of theory with observation, ingenious fancy with happy consequences, affords a strong presumption of the truth of the *Olbersian* hypothesis. Borrowing from Laplace's conjecture before alluded to, of a great contraction of the sun's atmosphere, a convulsive disorganization of some planet may be supposed to have taken place, by a force capable of overcoming the mutual attraction of its particles, and the mass of matter so broken would inevitably be dispersed in every direction, and in parts of various sizes. The impulses given by the explosion would gradually diminish, and the parts, in gravitating towards the sun, would become influenced by progression and rotation. To this view there does not appear to be any demonstrable objection. It was suggested, that under such a disruption the form of the orbits assumed by the fragments, and their inclination to the ecliptic, or to the orbit of the original planet, would depend upon the size of the fragments, or the weight of their respective masses: the larger mass would deviate least from the original path, while the smaller fragments being thrown off with greater velocity, will revolve in orbits more ex-centric and more inclined to the ecliptic. Now that is precisely what happens. Ceres and Vesta are found to be the largest of the asteroids, and their orbits have nearly the same inclination as some of the old planets; while the orbits of the smaller ones, Juno and Pallas, are inclined to the ecliptic 13° and 34°·5 respectively. Lagrange computed the force of explosion requisite to burst a planet, and convert a portion of it into a systematic wanderer. By the process described in the *Connaissance des Tems* for 1814, he arrived at the conclusion, that were a fragment to be impelled with a velocity equal to a hundred and twenty-one times that of a cannon-ball, it would become a *direct* comet, but a *retrograde* one if the velocity were a hundred and fifty-six times. With weaker impulse, however, the fragment would describe an ellipse, and thus, it is presumed, the asteroids probably were impelled with only twenty times that velocity. The exact circumstances of these extraordinary bodies are not yet sufficiently determined, and the correction of future observations is urgently necessary; but the following table, constructed from details in the *Nautical Almanac* for 1845, exhibits a very close approximation to their principal elements. The planets are arranged in their order of distance from the sun; and in the semi-axes of their orbits, the semi-axis of the earth's orbit is taken as unity.

Elements.	Vesta.	Juno.	Ceres.	Pallas.
Mean longitude . .	69° 32′ 15″·3	115° 43′ 15″·1	327° 41′ 07″·8	304° 56′ 26″·4
Longitude of perihelion	251° 02′ 37″·4	54° 08′ 33″·3	148° 14′ 06″·2	121° 22′ 43″·5
Long. of ascending node	103° 20′ 03″·4	170° 52′ 28″·9	80° 48′ 18″·7	172° 41′ 48″·1
Inclination to ecliptic	7° 08′ 23″·2	13° 03′ 05″·6	10° 37′ 08″·7	34° 37′ 40″·2
Angle of ex-centricity	5° 05′ 19″·9	14° 42′ 23″·7	4° 32′ 58″·9	13° 54′ 01″·2
Excen. in parts of semi-axis	0·0887007	0·2538691	0·0793237	0·2402336
Mean daily sidereal motion	977″·43636	813″·05349	771″·53786	769″·16607
Mean distance or semi-axis	2·36206	2·67057	2·76553	2·77121
Epoch for mean equinox	Dec. 3, 1845	Feb. 18, 1845	Aug. 17, 1845	Aug. 5, 1845

Such are the extraordinary conditions of the asteroids, whose intersecting orbits leading them almost within hail of each other, so to speak, at the rate of more than forty thousand miles an hour, may eventually lead to mutual disturbances, which the attraction of the larger planets cannot control. Although the strange coincidences attending this group may be *accidental*, in general phrase, yet their phenomena cannot but be considered as evidence tantamount to demonstration, of their having once composed a single planet, and having diverged by the explosive force of a tremendous cataclysm: and in addition to their orbital vagaries, the bodies themselves are not round, as is said to be indicated by the instantaneous diminution of their light on presenting their angular faces. After the discovery of Vesta, no other fragments were found, although the searching examination at the points of re-union was continued till 1816: then, and not till then, did the energetic Olbers utter "Jam satis!" Nor has there since been any prospect of another till September, 1835, when I received the letter from N. Cacciatore quoted under 32 P. XII., in Vol. II., p. 264, notifying an object which it may require a long course of years to recover.

§ 9. Aërolithes.

This hypothesis of the Asteroids naturally brings another phenomenon before us, to which the excited attention of the last several years has given an extraordinary interest, namely, the masses of solid matter occasionally falling from the higher regions of the atmosphere, under the various designation of aërolithes, fire balls, shooting stars, bolides, eolides, meteoric stones, uranolithes, falling stars, meteorolithes, meteorites, and the like, which have just begun, perhaps fancifully, to be included among the periodical phenomena of nature. They have attracted attention from the earliest times, and the popular credence that they fell from heaven, affords a striking instance wherein the probable hypothesis was embraced by ignorance and rejected by philosophy. Both Livy and Pliny record the falling of showers of stones; and they were the "nocturnasque faceis" of Lucretius. Mohammed, in the chapter Al Hejr of the *Koran*, alludes to the falling star as the visible flame which the angels, guarding the constellations, hurl at the devils who come too near*. Virgil makes it a telegraph between Jupiter and poor old Anchises:

De cœlo lapsa per umbras
Stella facem ducens multâ cum luce cucurrit.

It soon became certain, that aërolithes are not found naturally on any part of the surface of our globe; it was therefore presumed that they were formed by aggregation in the atmosphere,

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* Thus Moore, in *Lalla Rookh*, makes his Peri fly through space:

Rapidly as comets run,
To th' embraces of the sun:
Fleeter than the starry brands,
Flung at night from angel hands
At those dark and daring sprites,
Who would climb th' empyrial heights.

or the incandescence of its gases. But no analysis of air, (and it has been analyzed from the level of the sea to the highest elevation attainable by a balloon,) has detected the slightest particle of the constituent elements of those stones. Yet the undeniable fact of large pieces of compact rock falling from regions beyond the clouds, was a sad stumbling-block to the philosophers, especially when the notion of their having been generated in the atmosphere, or thrown from terrestrial volcanoes, was scouted. It was impossible for conjecture to remain idle, while the phenomenon was constantly awakening attention. Deprived of atmospheric and terrestrial sources, Laplace, Hutton, Poisson, Benzenburg, and many others, held that they possibly might be projected from the moon. By abstract demonstration, it had been established, that a body projected from the surface of the moon, with a momentum that would cause it to proceed with the initial velocity of about 8500 feet in a second of time, and the direction of which should be in a line passing, at that moment, through the centre of the earth and moon, would not fall again to the lunar surface, but would become a satellite to the earth, to which it might, even after many revolutions, be precipitated by the force of its primitive impulse*, or by the disturbing action of the sun. A mass so small, when compared with the three bodies attracting, would necessarily undergo enormous perturbations. Projection from a lunar crater will satisfactorily meet all the observed phenomena; still this theory cannot admit of demonstration, until it can be proved that active volcanoes are actually subsisting on the surface of the moon.

Those shooting stars which were seen to descend, were often called thunderbolts, though their descent being mostly in serene weather and clear sky, would show that their origin cannot be ascribed to causes which operate in producing tempests. The fragments are generally of from one pound to fifty, some of seventy, and others still weightier. A well-authenticated meteorolithe is in the museum of my friend Dr. Lee, at Hartwell

* A body projected horizontally from the surface of the earth to the distance of about 4·35 miles, if there were no resistance in the atmosphere, would not fall again to the earth, but would revolve round it as a satellite, the centrifugal force being then equal to its gravity.

House, in Buckinghamshire: it fell at Launton, near Bicester, on the 15th of February, 1830, at about half-past seven in the evening, and it weighs 2·279 pounds. It must have been only part of a larger mass, since it was precipitated after a violent explosion; and, in many of the details, we are reminded of Montanari's description of a meteor which passed over Italy in 1676, thus quoted by Halley in the twenty-ninth volume of the *Philosophical Transactions:* "that in all places near its course, it was heard to make a hissing noise as it passed, 'ronzare, far strepito comme un fuoco artificiale, fisciare per aria comme un raggio di polva,' giving a blow 'tuona di maggior rumore di grossa cannonata.'" But independently of the interest connected with Dr. Lee's meteorolithe, from the authenticity of its fall and ascertained picking up, it is something to handle an indubitable bit of a star; for that these masses are *débris* of the wrecks of such bodies, seems about as plausible a supposition, under the actual dearth of our knowledge, as any other. Some are of great magnitude, as that of 1807. Mrs. Somerville mentions, that one which passed within twenty-five miles of us, was estimated to weigh about six hundred thousand tons, and to move with a velocity of about twenty miles in a second. Luckily a fragment of this terrific mass alone reached the earth, and she adds, "The obliquity of the descent of meteorites, the peculiar substances they are composed of, and the explosion accompanying their fall, show that they are foreign to our system."

Experiment shows that we ought to make two principal and essential divisions in their mineral character, by considering meteoric iron apart from meteorolithes. The first is commonly covered with a smooth coating of brown oxide; it is malleable, from 6½ to 7½ in specific gravity, and contains from 3½ to 10 per cent. of nickel, with occasionally a small admixture of chrome and olivine. But meteorolites are found to contain such a multitude of substances, that taking all the specimens together, one third of the known chemical elements may be stated to have been detected in them. The usual constituent parts are: chromate of iron, sulphuret of iron, oxide of tin, various silicates of magnesia, potassa, and alumina; magnetic iron and native iron, with traces of carbon, phosphorus, magnesium, manganese, nickel, cobalt, tin, and copper. Their general specific gravity varies from 3·4 to 3·7; but they are occasionally found of a scoriaceous structure, and then exhibit still more strongly the effects of fire. The more compact ones bear a strong resemblance to each other, in their dark and equal colour, smooth exterior, and principal components. It may be useful to remark the occurrence in them of small grains of iron with nickel, which being the only two magnetic metals, gave strength to the hypothesis that the auroras, aërolithes, and comets, result from cosmical atoms aggregated by magnetic attraction. And who that has witnessed the wonderful chemical agencies recently disclosed by experiments with the voltaic battery, will question the grander energies of nature in the composition or decomposition of compounds, and the treatment of their affinities?

The altitudes and velocities of aërolithes are equally various and uncertain; but the late inquiries into their parallax have placed them much higher than the sensible limits given to our atmosphere by received theories; while their apparent speed is sometimes nearly double that of the earth's course round the sun. The direction most commonly taken by them, seems diametrically opposed to that of the earth in its orbit. For some years past, they have been periodically seen on the 9th and 10th of August, and on the 12th and 13th of November; offering at times the grand display of many thousands of shooting stars. Thus, according to M. Arago, "an observer at Boston compared them, when at the maximum, to half the number of flakes seen in the air during an ordinary snow storm. When their number was greatly diminished, he counted 650 stars in fifteen minutes, although he confined his observations to a zone which did not include a tenth part of the visible horizon. This number, in his opinion, was not more than two thirds of the whole; thus there must have been 866 for his circumscribed zone, and 8660 for the visible range, which last number would give 34,640 stars per hour. Now, as the phenomenon lasted seven hours, the aërolites that appeared at Boston must have exceeded 240,000." Such a wonderful announcement attracted general attention. MM. Arago, Herschel, and Erman—adopting the views of Chladni—think that there may be myriads of bodies, composed probably of nebulous matter similar to the tails of comets, circulating round the sun; some of which, drawn from their course by the earth's attraction, fall towards it, and taking fire when they enter the atmosphere, in consequence of their prodigiously rapid motion, present the luminous phenomenon of falling stars. These groups are thought to sweep round the solar focus in two annular streams, or zones, intercepting the ecliptic about those places through which the earth passes in August and November.

This hypothesis, under slight modifications, has been very generally embraced; but in the present inadequate state of our knowledge, the various opinions of Brandes, Quetelet, Olbers, Biot, Wartman, Capocci, and other philosophers, can only be admitted as more or less probable conjectures. In a paper written expressly upon this matter, by my friend Mr. Galloway, Secretary to the Royal Astronomical Society, inserted in the fifth volume of its *Monthly Notices*, there is a succinct detail of the several conflicting hypotheses, with the evidence on which they are founded, and the objections which are still to be urged against each. To this essay the reader's attention is directed; it being merely here necessary to quote the difficulties which Mr. Galloway opposes to the Chladnian theory just mentioned:

First, that bodies moving in groups in the circumstances supposed must necessarily move in the same direction, and consequently, when they become visible from the earth, would all appear to emanate from one point, and move towards the opposite. Now although the observations seem to shew that the predominating direction is from north-east to south-west, yet shooting stars are observed on the same nights to emanate from all points of the heavens, and to move in all possible directions. Secondly, their average velocity (especially as determined by Wartmann) greatly exceeds that which any body circulating about the sun, can have at the distance of the earth. Thirdly, from their appearance, and the luminous train which they generally leave behind them, and which often remains visible for several seconds, sometimes for whole minutes, and also from their being situated within the earth's shadow, and at heights far exceeding those at which the atmosphere can be supposed capable of supporting combustion, it is manifest that their light is not reflected from the sun; they must therefore be self-luminous, which is contrary to every analogy of the solar system. Fourthly, if masses of solid matter approached so near the earth as many of the shooting stars do, some of them would inevitably be attracted to it; but of the thousands of shooting stars which have been observed, there is no authenticated instance of any one having actually reached the earth. Fifthly, instead of the meteors being attracted to the earth, some of them are observed actually to rise upwards, and to describe orbits which are convex to the earth; a circumstance of which, on the present hypothesis, it seems impossible to give any rational explanation.

The merit of first suggesting observations of aërolithes, as a means for the determination of geographical longitudes, is claimed by Olbers and the German school, for M. Benzenburg, who published his views thereupon in 1802; but in this respect Halley, whose duties as a naval captain and maritime surveyor probably drew his attention to the subject, must be acknowledged the *præses*. In 1714, this all-observant philosopher wrote an account of the extraordinary "Meteors or Lights seen in the Sky," which is inserted in the twenty-ninth volume of the *Philosophical Transactions*, and four years afterwards, in describing the remarkable meteor of the 19th of March, 1718, after establishing its mean height at sixty-eight miles, he comes to this conclusion: "This suggests a very great use that might be made of these momentaneous phenomena, to determine the geographical longitude of places. For if in any two places two observers, by the help of pendulum clocks duly corrected by celestial observation, do exactly note at what hour, minute, and second, such a meteor as this blows up and is extinguished, the difference of those two times will be the difference of longitude of the two places, as is well known. Nor does it require so much as the use of a telescope, as in the methods hitherto put in practise for that purpose; so that if these appearances could be predicted, and notice given of their coming, that we might know when to expect them, I should make no difficulty to prefer this way of settling the geography of a country before all others." Halley's method was reproduced by Mr. George Lynn, of Southwark, and again by Dr. Maskelyne in 1783; and I was so impressed by their representations, as to call the attention of naval officers to the point, in a letter to the editor of the *United Service Journal*, 20th of January, 1829, an extract from which may close the argument:

Sept. 29th, 1828.—A fine clear evening, the stars shining brightly, and many small meteors seen; but the wind was blowing freshly from S.W. It was about half-past eight o'clock, when going outside the observatory, I suddenly perceived a formidable belt of light, whose first glance gave a sensation which might be termed awful. It arose from a dense black cloud in the

W.S.W., crossed the Via Lactea at an elevation of about sixty degrees, and deflected towards the E.N.E. Its apparent breadth varied from two to three and a quarter degrees, and was not equally lucid throughout; the faintest parts resembled the Milky Way, but the largest portion was infinitely more luminous. In about an hour it was gradually dispersed, to the great comfort of some of my neighbours, who *had sent to me for an explanation.*

The stars were distinctly visible through this extraordinary zone; it arose between α and β Ophiuchi, covered ϵ and ζ Aquilæ, and passing to the north of Aquila and Delphinus, crossed Pegasus below λ. It then trained south of Andromeda, and terminated just below the Pleiades. The thermometer was at 59°·3, and the barometer stood at 29·29 inches. A slight Aurora Borealis was afterwards seen, about seven or eight degrees in height, towards the north and north-west quarters.

There cannot be a doubt but that the phenomenon was caused by some electrical action, whose laws are as yet unknown; it would therefore be of some importance that its height above the surface of the earth should be accurately determined. The star, ϵ Pegasi, was seen shining through its centre; now, if any person, at a place considerably distant in latitude, had observed the same, if not very high, it would have a sensible parallax. Difference of longitude would not avail, on account of the azimuths being nearly east and west.

Previous to closing this letter, permit me to call upon such of your readers, as are interested in science, to attend to any remarkable meteor which they may notice; and carefully enter upon record its time, direction of motion, and the stars amongst which it passes, to the best of their ability. They are to be seen on every clear night, but are of more available occurrence during the absence of the moon; and it is then that caudated meteors assume so brilliant an appearance as to become grand and interesting objects. Such phenomena are now beginning to be rigidly investigated, and notwithstanding the difficulties arising from uncertain commencement, erratic course, and transient duration, they may yet afford an admirable mean, if exactly observed, of determining the difference of longitude between the several places of observation.

§ 10. Jupiter ♃.

We now come to the largest planet of the solar system, and next to Venus, whom, however, he sometimes even surpasses, the brightest. This is Jupiter, who performs his revolution round the sun in an orbit which includes all the planets yet described, at a mean distance of about 485 millions of miles from the central orb: and these are his elliptical elements, for the epoch named in page 83.

Mean sidereal revolution (nearly 12 years), solar days -	$4332^d\ 14^h\ 02^m\ 08^s{\cdot}5$
Mean synodical revolution, solar days - -	398·867
Mean longitude - - - -	112° 15′ 23″·0

Mean orbital motion in a solar day	4′ 59″·26
Ditto, per annum (somewhat more than a sign)	30° 20′ 32″·0
Longitude of perihelion	11° 08′ 34″·6
Annual motion of apsides, eastward	6″·96
Ditto, referred to the ecliptic	57″·06
Inclination of orbit to plane of ecliptic	1° 18′ 51″·3
Annual decrease of ditto	0″·226
Longitude of ascending node	98° 26′ 18″·9
Motion of ditto, W. per annum	15″·8
Ditto, E., referred to the ecliptic	34″·3
Ex-centricity of orbit, half major axis as unity	0·0481621
Secular increase of ditto	0·000159350
Greatest equation of centre	5° 31′ 13″·8
Annual increase of ditto	0″·6344
Axical rotation	9h 55m 49s·7
Inclination of axis to that of ecliptic	3° 05′ 30″·0
Mean apparent diameter (equatorial)	36″·74
Ditto, at conjunction	30″·00
Ditto, at opposition	45″·88
True diameter (nearly 90,000 miles), earth's diameter as unity	10·860
Volume, earth as unity	1280·9
Mass, sun as unity	0·0009341431
Density, sun as unity	0·99239
Mean distance (485,000,000 miles), that of earth being unity	5·202776

Thus Jupiter is about one fourth of the density of the earth, or but little heavier than water; so that the quantity of matter actually contained in his enormous bulk, is not greater than that in the earth, after the same proportion as that in which his volume is greater: it is only about 331 times that of the earth. Were his orbital motion suddenly stopped, his fall to the sun would occupy 765 days 15 hours. From the time of Newton to the present day, the mass of Jupiter was regarded as being to that of the sun in the proportion of 2 to 2141; but our present Astronomer-Royal, Mr. Airy, has rigidly investigated the problem, and concludes that the mass of Jupiter is to that of the sun in the proportion of 1 to 1046·77, or 2 to 2094 nearly. The force of gravity on the planet's surface is about eight times as great as that on the earth's surface; so that an inhabitant of the earth transported thither, would have labour enough to bear up against a load eight times greater than that which he here sustains, on a soil far lighter. Yet the specific gravity is so much less, that while two globes of granite of equal dimensions with the earth would be required to balance our planet, Jupiter would only require a globe of wood—perhaps ebony, or lignum vitæ—of his own dimensions. A weight of one pound at our equator, if removed to that of this planet, would weigh 2·716 pounds; but this must be diminished about a ninth part, on account of the centrifugal force. A heavy body at his surface would fall through forty-two feet per second. From Jupiter the sun appears only one twenty-seventh part of the size he does from the earth; and the proportion of light and heat the planet receives, on a given portion of his surface, is one twenty-seventh of that which is received on an equal portion of the earth's surface*. But he is in some measure compensated in the quick return of the sun, occasioned by his own prodigiously rapid rotation; while, in order to supply him with light, he is accommodated with four satellites, together equal in bulk to thirteen of our moons, which revolve round him according to a law in virtue of which they can never be all dark, or new, at one and the same time. The motion on his axis being performed in ten hours, it will readily be inferred that his form, like that of the earth from a similar cause, is spheroidal. Its compression is sufficiently great to be sensibly perceived in the telescope, the equatorial diameter being to the polar as 177 to 167: Laplace, from theory, deduced this proportion to be 10,000,000 to 9,286,922. A reduction of various measures taken by myself, both with rock-crystal prisms and the wire micrometer, show that Jupiter is flattened very nearly in the usually assigned proportion of 14 to 13; whence his greater diameter exceeds the smaller by above six thousand miles.

The axis of Jupiter is so nearly perpendicular to his orbit, that he has, fortunately for his polar inhabitants, if he has any, no very sensible change of seasons; but for an enormous globe, nearly ninety thousand miles in diameter, or thirteen hundred times as large as the earth, to whirl round his axis so as to cut his days and nights into five hours each, must occasion such rapid mutations of sky, as to make the sun, planets, and stars seem to fly across the celestial arch rather more than twice as fast as they pass over ours, and present the most diversified and sublime scene imaginable. While this forms the *distance* of the picture, it has also a noble foreground; and although the largeness of the globe will not make the mutations of the sky more rapid, so vast a

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* The proportion of light and heat received by Jupiter from the sun is 0·0369; that received by the earth being considered as unity.

feature cannot but be alluded to*. His first satellite presents, in the space of 42½ hours, all the appearances of a new moon, crescent, half, gibbous, and full moon, with a motion sixteen times more rapid than that of our own satellite: the other three attendants exhibit similar phenomena, but in different periods of time. At intervals, two or three of these moons, and occasionally all four, will be seen shining in the Jovian firmament at the same time, and under various phases. From the earth Jupiter's course sometimes appears retrograde. The arc of retrogradation which he then describes, varies from 9° 51′ to 9° 59′: its duration in the former case is 116^{d} 18^{h}; and in the latter case 122^{d} 12^{h}. This retrogradation commences, or finishes, when the planet, as seen from the earth, is at a distance from the sun which varies between 113° 35′ and 116° 42′. And it may be observed as a general rule with the superior planets, that the further they are from the sun, the less is their arc of retrogradation, but the longer is the time taken up in describing it.

Thus, then, we perceive that Jupiter has no change of seasons of importance; and that, as the rays of the sun fall perpendicularly on the body of the planet, and always continue to do so, the heat must be, as nearly as possible, equal at all times of his year,—a perennial summer. This is a striking display of beneficent arrangement. The Jovian year contains nearly twelve mundane years; and if there were a proportionate length of winter, that cold season would be three of the earthly years in length, and tend to the destruction of vegetable life. And on the other hand, the intensity of heat produced by the solar rays acting in direct line without any variation, is moderated by the rapid rotation of the planet on its axis. The length of the day and night is equal all the year round to all parts of the planet's body; and the noon-day heat is extremely transient, the entire day being but five hours. But though there are no seasons in Jupiter similar to ours, we are not to imagine that there is therefore no diversity of aspect. The day and night, it is true, are nearly equal in every part of the surface; but to the places

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* The vast size of this glorious orb may be conceived, on recollecting that a line carried out from the earth to the moon, would not extend round Jupiter.

near the equator, the sun will appear to rise to a high elevation above the horizon, and to move through the heavens with great rapidity, while, near the polar regions, his motion will be comparatively slow, and he will seem to describe only a small semicircle above the horizon.

The surface of Jupiter is remarkable, in being always covered with a number of streaky zones or stripes, of various degrees of shade, the intensity of which differs at different times. These are called Belts, and are, for the most part, not only parallel to each other, but likewise to the planet's equator. They were first observed at Naples by the Jesuit Zuppi, and by Fontana and Bartoli; shortly afterwards, about 1643, they were observed by Grimaldi and Riccioli. While, however, Giuseppe Campani was viewing them in 1658, with one of his own refractors, he perceived the shadow of a satellite on the belt, and followed it across the disc. Bright and dark spots were now made out: the first spot was observed by Dr. Hook in May, 1644, with his twelve-foot telescope, "on the biggest of the three obscure belts;" in the following year Cassini determined the period of the planet's rotation, by closely watching the spot's movement, —and the prediction of its re-appearance was verified by a deputation from the Royal Academy. These maculæ were found to offer much matter for speculation, nor has the interval of a couple of centuries greatly enlarged our acquaintance with them. They are generally perceived in the belts, and when a belt disappears, these spots vanish with it; on some occasions they have been observed to change their forms gradually, and sometimes with very unequal velocities. Some astronomers impute these appearances to the effect of changes in the Jovian atmosphere, owing to the immense velocity of his rotatory motion (near 30,000 miles per hour); while others regard them as indications of great physical revolutions on the surface of the planet. Under the difficulty of acquiring fuller knowledge of so very distant an object, the easy decision of *utrum horum*, &c., might be applied to these opinions; but a preference may be due to the first hypothesis, because, though it may not account for the permanence of some of the spots, it appears to explain the variations in the form and magnitude of the belts, while the diurnal rapidity of the planet's motion assigns a cause for their parallelism. A large spot, considered as that observed by Hook and Cassini, has both vanished and re-appeared often enough to connect it with the surface of the planet. During the winter of 1834, that ancient spot, as it is called, and a smaller one, were again very distinctly visible: the last may have been the changeable object noticed by Cassini in 1699.

The great interest excited by this noble orb, may plead as an apology for dwelling a moment longer upon the subject, even at the risk of repetition. A long personal acquaintance with the mutable disposition of the streaks and patches of light and shade over the visible face of Jupiter, certainly induce me to rank the belts as unequivocal evidences of an atmosphere; while the equatorial distribution of its clouds, strongly impresses a relationship between them and the trade-winds of our own tropical *belt.* Now admitting, as most contemplative and steady gazers must do, the actual presence of clouds, it follows that water, rain, evaporation, electricity, sound, alternations of wind, and the full powers of vegetation, must exist there, and that Jupiter may be the happy abode of sentient beings. The apparently inexplicable rapid rotation common to those greater planets, Jupiter and Saturn, and no doubt Uranus also, may be a means whereby processes conducive to the generation of light and heat by the solar rays are called forth. At all events, such wondrous and obvious testimony of a symmetrical combination, awakens a sense of the impressive manifestation of design, and the agency of a DEITY, however incomprehensible his nature must ever remain to us. But though impressed with these ideas, I am by no means disposed to adopt the dreamy details indulged in by the plurality-of-worlds' men in general. Some have imagined creatures of bat-wing locomotion, and others have considered the Jovials as inveterate dancers; while Sir Humphrey Davy suggests that the body of those beings may be composed of numerous convolutions of tubes, more analogous to the trunk of the elephant than anything else. Wolfius, however, is the most exact: he asserts not only that there are inhabitants in Jupiter, but also shows that they must necessarily be much larger than those of the earth,—in fact, that they are of the giant kind, and nearly fourteen feet high, by *eye*-measurement. And thus he *proves* it. It is shown in optics that the pupil of the eye dilates and contracts according to the degree of light it encounters. Wherefore, since in Jupiter the sun's meridian light is much weaker than on the earth, the pupil will need to be much more dilateable in the Jovial creature, than in the terrestrial one. But the pupil is observed to have a constant proportion to the ball of the eye, and the ball of the eye to the rest of the body; so that, in animals, the larger the pupil the larger the eye, and, consequently, the larger the body. Assuming that these conditions are unquestionable, he shows that Jupiter's distance from the sun, compared with the earth's, is as 26 to 5; the intensity of the sun's light in Jupiter is, to its intensity on the earth, in a duplicate ratio of 5 to 26; and it therefore follows, that even Goliath himself would have cut but a sorry figure among the natives of Jupiter. That is, supposing the Philistine's altitude to be somewhere between eight feet and eleven, according as we lean to Bishop Cumberland's calculation, or to the Vatican copy of the *Septuagint*. Now Wolfius proves the size of the inhabitants of Jupiter to be the same as that of Og, king of Bashan, whose iron camp-bed was nine cubits in length and four in breadth,—or rather he shows, in the way stated, the ordinary altitude of the *Jovicolæ*, to be $13\frac{819}{1440}$ Paris feet, and the height of Og to have been $13\frac{1296}{1440}$ feet. See his *Works*, Vol. III. p. 438.

From the impression that this planet governed the wind and weather, causing lightning and tempests when displeased, and making corn and fruits grow abundantly when appeased, great attention was paid to it by astrologers. Pliny tells us, that lightning was believed to come from Jupiter, because he is located between the excessive cold of Saturn and the immoderate heat of Mars; but he considers that the Phrygian measure, in the harmonic scale of the spheres, assigned to him by Pythagoras, as a refinement more pleasant than needful—"jucunda magis, quam necessaria subtilitate." The oft-quoted MS. Almanack for 1386, shows that "Jubit es hote and moyste, and doos weel til al thynges and noyes nothing:" unlike Mars, who, according to the same grave authority, delights in "manslaughter and byrnygs of houses, and in werres." But we must now hasten to bodies, of the existence of which neither Pliny nor the almanack-maker had the slightest conception.

The satellites of Jupiter were discovered by Galileo on the 8th of January, 1610; and they may be considered as one of the first fruits of the telescope. He at first took them for telescopic fixed stars, but continued observation soon convinced him that they really move with the planet. In honour of his patron, Galileo denominated his prizes the *Astra Medicœa;* but the discovery startled the scrupulous, some of whom could not imagine why Providence should give companions to such a planet merely to immortalize the Medici family; and others declined even looking at them when entreated by the philosopher so to do, lest they should authorize impiety. Sizzi, an astronomer of Florence, was especially ingenious on the occasion, maintaining that as there were only seven apertures in the head,—viz. two eyes, two ears, two nostrils, and one mouth,—and as there were only seven metals, and seven days in the week, so could there be only seven planets. But notwithstanding the conclusiveness of this argument, the actual presence of the strangers was generally admitted; Cosmo de Medici struck a commemorative medal, on the reverse of which is a ship sailing under a planet and its satellites, inscribed *Certa fulgent sidera;* and a story goes, that Galileo was invited, by the senators of Venice, to show these new phenomena. This, however, cannot be quite correct. The telescope which the Tuscan thus exhibited was his *first*, which magnified only about three times, and could scarcely show the satellites; besides, it was in the summer previous to their discovery, that he thus played the showman, and got his salary doubled. He certainly made a present of a second telescope to the senate; but those sages of the Lion's Mouth were not bent on astronomy,—they only anticipated how to obtain, by means of the new instrument, advantage over their enemies, by spying out the ships of war. Yet in spite of such authentic and minute details, there are some who assert that the satellites had been previously seen, both by Jansen and Lippersheim. Baron de Zach attributed the discovery to Thomas Harriot; but this has been confuted by my late friend, Professor Rigaud; and the memorable claim to priority in this respect, which was made by Simon Mayer in his *Mundus Jovialis*, bore internal evidence against itself, and was finally beat into the dirt by Delambre.

Certain *esprits fort* express surprise that Galileo should have been so gratified by this discovery, since they hold that the satellites of Jupiter are often seen by the naked eye; and they cite the Apennines, and Etna, and the West Indies, and various other fine-climate places, as the spots where such a feat is frequently done. Nay, more than one person has gravely assured me that he had actually seen them; but these were each of them instances in which I could rather question their knowing what they looked at, than suspect any wilful breach of veracity. Hodierna seems quite astonished that, as they appear like stars of the sixth magnitude in the telescope, they should not have been seen earlier; and is satisfied that their not having been perceived, is entirely owing to the brightness of the planet. I had myself been a gazer in the clearest skies in the world, and had given great attention to the matter on the summit of Mount Etna, with an eye which, on comparison, I never found reason to complain of; and the conclusion I arrived at was, that these little moons, from their fainter light, are not perceptible to unassisted vision, or they must otherwise have been detected by attentive observers among the ancients. This conclusion seems to be directly at variance with several respectable statements; and it is impossible to deny that visual organs of extraordinary power may exist. Baron de Zach relates, that the late Père Hell told him, that he had known an officer of the Hungarian Guard at Vienna, who could see Jupiter's satellites with the naked eye; as was proved by simultaneous observation with the telescope. The Baron also states that Dr. Muschenbrok knew some persons whose unarmed eye possessed such power; another instance the more, he adds, of men who see to no purpose: "*Il y a beaucoup de gens qui* regardent, *mais qui ne* voyent *pas*." M. Mädler mentions that the post-master, Nernst, saw *one* satellite of Jupiter with the naked eye, and drew a diagram of its position; but when the telescope was applied, it was found that three of the satellites had nearly closed, and their united brightness thus drew the piercing eye of M. Nernst. On lately discussing this very curious instance with a friend, he assured me that Sir

J. Herschel had *frequently* seen these objects while at the Cape of Good Hope. I was somewhat startled by the assertion, having also been at the Cape, but thought the shortest way of getting at the facts, was by direct application to Sir John himself: his answer certainly did not corroborate my friend's statement, which must have been given by mistake; as is shown by the following extract from his letter, dated May 1st, 1844:

> I never saw Jupiter's satellites with my naked eye at all, and I regard all accounts of their having been so seen as in some degree apocryphal. Dr. Wollaston, who had a keen eye, told me he had never succeeded, though he cut off the light of the planet by hiding the body behind a distant object.

The satellites are designated according to their respective distances from the primary, that being called the first whose distance from Jupiter is the least when at the greatest elongation, and so on with the others. Though they are of different magnitudes, their apparent diameters are so nearly insensible, that their real size cannot be accurately measured. An attempt to ascertain this point has been made, by observing the time they take to enter the shadow of Jupiter; but there is a great discordance in the observations, and the results are, of course, uncertain. The *third*, however, is the largest; the *fourth* is the second in magnitude; the *first* is the third in magnitude; and the *second* is the least, being very nearly the size of our moon. They all move round their primary as the centre, under the same laws as those by which that primary moves round the sun; their relative situations, therefore, with regard to Jupiter, as well as to each other, are continually changing. Sometimes they may be all seen on one side of Jupiter, and sometimes on the other; but most frequently some on one side and some on the other. The mean angular velocities, or mean motions, as they are termed, of the first three satellites, are related to each other by an extremely singular analogy. For, if the mean sidereal or synodical revolution of the first be added to twice that of the third, the sum will equal three times that of the second. And the mean sidereal or synodical longitude of the first, *minus* three times that of the second, *plus* twice that of the third, produces a constant equal to 180°, or two right angles. It follows, therefore, that for a vast number of years, at least, the first three satellites cannot be all eclipsed at once; for, in the simultaneous eclipses of the second and third, the first will always be in conjunction with Jupiter, and *vice versâ*. One instance, however, is recorded, of a total disappearance of all the satellites; this was seen by Molyneux on the 2nd of November (*styl. vet.*), 1681,—a conjunction which will require more than three thousand billions of years to occur again. The following table exhibits their several elements at one view:

Elements.	Satellites.			
	First.	Second.	Third.	Fourth.
Sider. revol., mean solar days -	$1^d\ 18^h\ 28^m$	$3^d\ 13^h\ 14^m$	$7^d\ 3^h\ 43^m$	$16^d\ 16^h\ 32^m$
Ditto, for computation - - -	$1^d{\cdot}7691378$	$3^d{\cdot}5518101$	$7^d{\cdot}1545528$	$16^d{\cdot}6887697$
Mean apparent diameter - -	1‴·015	0‴·911	1‴·488	1‴·273
Ditto, in miles - - - - -	2508	2068	3377	2890
Mass, Jupiter as unity - - -	0·0000173	0·0000232	0·0000885	0·0000427
Mean dist., Jup. eq. s. d. as unity	6·04853	9·62347	15·35024	26·99835
Ditto, in parts of the circle - -	1′ 57‴·92	3′ 07‴·64	4′ 59‴·32	8′ 46‴·48
Ditto, in miles - - - - - -	260,000	420,000	670,000	1,180,000
Orbital incl. to that of Jupiter -	3° 05′ 30″	*Variable.*	*Variable.*	2° 58′ 48″

The ex-centricities of the first and second satellites are insensible; those of the third and fourth are small, but variable in consequence of their mutual perturbations. The inclination of all their orbits is very nearly in the plane of Jupiter's equator. The nodes of the second and third satellites have a retrograde revolution, respectively of about thirty and a hundred and forty-two years; but the nodes made by the orbit of the fourth have a direct motion of 4¼ minutes per annum. From having observed certain periodical changes in the intensity of the light of the satellites, Sir William Herschel inferred that they revolve on their axes, and that the period of their rotation is equal to the time of their orbital revolution, thus confirming their striking analogy with our moon. The whole shows that the theory of Jupiter and his satellites is beautifully accordant with the laws of gravitation, though the variable quantities and perturbations which affect their elliptical motions, render the problem complicated. The system offers, however, a fine instance of an exquisite miniature system, entirely analogous to the larger one of which Jupiter is a member.

In consequence of the smallness of the angle by which Jupiter's equator is inclined to the ecliptic, and of the small inclination of the orbits of the satellites to the plane of the equator, all the satellites, except the fourth, undergo an eclipse in every revolution. Thus the Jovian astronomers witness four thousand five hundred eclipses of their moons, in the course of their year, and about the same number of eclipses of the sun: it is also possible that they eclipse each other. When the satellites interpose between the sun and the primary, they produce real solar eclipses, precisely similar to those which the moon produces on the earth; and when they disappear in the shadow which Jupiter projects behind him, the disappearance is perfectly similar to eclipses of the moon. When the satellite goes behind the body of the planet, with respect to a spectator on the earth, it is said to be occulted, being hidden from our sight by his body, whether in his shadow or not; and when the satellite in a line with Jupiter and the earth, appears on his disc as a round black spot, it is termed a transit of the satellite. Immersions into the shadow at the quadratures take place at some distance from the disc of the planet, which distance diminishes as Jupiter approaches. This affords a fine proof of their being enlightened by the sun; for the third and fourth satellites sometimes disappear and re-appear on the same side of the disc, and the duration of all these eclipses answers to the time which should elapse while they traverse the cone formed by the planet's shadow. Hence it becomes evident that the satellites move from west to east, in returning orbits round the planet. The eclipses thus afford the most exact means of investigating the Jovian theory of the motions of the satellites; a theory which the labours of Laplace and others have brought to a high degree of perfection. Their mean sidereal and synodical revolutions, as regarded from the centre of Jupiter, are very accurately determined by comparing eclipses at long intervals from each other, and observed near the opposition of the planet. It was thus discovered, that the orbits of the satellites are nearly circular and uniform, especially those of the first, second, and third; and the velocity of their motions is nearly uniform. It is because of their small inclination, as above stated, that the three nearest fall into the shadow, and are eclipsed in each revolution; but the orbit of the fourth is so much inclined, that it escapes by regular intervals. The act of passing into the shadow, or disappearing behind the planet itself, is called an immersion; and that of coming out of it, or re-appearing from behind the disc, an emersion; and the eclipse being independent of the earth's position, the observation can certainly be made, unless Jupiter be too near the sun, or that they be within 18° or 20° of each other. Before he is in opposition, or so long as he passes the meridian in the morning, the shadow lies west of the planet, and the immersions happen on that side; but after the opposition, the immersions happen to the east. It never occurs that both the immersion and emersion can be observed, in the case of the first satellite, and rarely in that of the second; though it is otherwise with the third and fourth, obviously in consequence of their relative distances on the shadow's projection. The eclipses of the four satellites last respectively about 2¼, 2¾, 3½, and 4½ hours, one time with another. In transits, the spot or shadow of the satellite will precede it in its progress over the disc before, and follow it after opposition.

From their connection with numerous practical, theoretical, and physical points of importance, the satellites of Jupiter have been earnestly attended to; and James Gregory, the illustrious inventor of the reflecting telescope which bears his name, might truly be called a martyr to them; for in October, 1675, being intent upon them with his instrument, he was suddenly struck with total blindness, and died a few days afterwards at the early age of thirty-seven. This was the very year in which Römer, also studying those interesting objects, detected those important facts, the progressive motion and appreciable velocity of light, which had hitherto been considered as instantaneous in its effects. To this grand discovery my late friend N. Cacciatore, of Palermo, wished to make an addition that would complete our scientific debt to those little attendants of Jupiter; and he put a proposition into my hand, for deducing a constant for the aberration of light from their eclipses. His argument certainly read very well; but on referring the question to Sir John Herschel, he returned me the following useful answer in a letter from Slough, dated 27th May, 1830:

I am obliged to you for the extract from Cacciatore's letter, but I disagree with him in thinking that observations of Jupiter's satellites ought to have any weight in determining the constant of aberration, at least unless under very cautious superintendence:

1. Only those of the first satellite should be taken.

2. Those only with the same identical telescope and observer.

3. That immersions be compared only with immersions, and emersions with emersions.

4. Those only which include the times at or adjacent to the greater or least distances from the earth at which the observations *can* be made. Now it will be remarked, I know not if the remark has been made, but it is most material, that the observations in the opposition of Jupiter, and near his conjunction with the sun, take place under such very different circumstances of atmospheric illumination as to render them difficultly comparable. A satellite will disappear sooner in a strong twilight than at deep midnight, be the telescope what it may. In the twilight I can see with difficulty stars of the twelfth magnitude, at midnight I can go on to the sixteenth. And then, too, the apparent distance from the body of Jupiter has a material effect on the limit of visibility.

Galileo was not long in finding, that the frequency of the eclipses of Jupiter's satellites would furnish the long-sought desideratum of deciding the longitude of places on the earth; but he forbore making the discovery public, until he could arrive at a tolerably correct knowledge of the time occupied by each of the four moons in its circumvolutions. He repeatedly offered to dispose of his secret to Spain, then a great maritime power; but his proposition not being properly received there, he tendered it to Holland, from whence two persons were immediately dispatched to obtain it from him. But although he had been observing the eclipses for twenty-four years, ten of which were very assiduously devoted thereto, he still wished to obtain a longer series to complete his theory; but becoming blind under "fatica veramente Atlantica," he was compelled to resign its prosecution into the hands of his pupil and friend, Vicenzo Reineri, a Genoese monk. The combined fruits of this inquiry, which especially included Galileo's ten years' ephemerides of observations of the satellites, were pilfered from the monk's cell, while he was on his death-bed; and although there was not the least reason or proof for the allegation, the agents of the Inquisition bore the obloquy of the theft for two hundred years. Supposed to have been smothered in the oblivious dens of the Holy Office, the lost papers were duly deplored by Viviani, Perelli, Fabroni, Cassini, Montucla, De Zach, and a battalion of others; but, to the surprise of the scientific world, they were found in their proper place, the Library of the Palazzo Pitti, in April, 1843. This discovery was made by Signor Albéri; and the truants are to appear in the fifth volume of the complete edition of Galileo's Works, now in the press at Florence, under the Grand Duke's auspices.

Meantime M. Peyresc, of Aix, who had observed the satellites in November, 1610, caught at the idea of graphically examining these phenomena, and even sent observers to Aleppo and other places, to mark the differences in the positions of the satellites by configurations, and thus to approximate the difference of longitudes between those places; but hearing that Galileo and Kepler were occupied in the same inquiry, he desisted*. A manuscript exists in the Library at Carpentras, near Avignon, recounting that J. Lombard observed an eclipse of a satellite at Malta, so early as 1612; and as it also contains some latitudes determined by him in Cyprus, Tripoli, and other places, it is probable that Lombard was one of the *savans* so munificently despatched by Peyresc, especially as he was also of Aix. Kepler was the first to notice the method of determining geographical longitudes by means of the occultation of a known

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* Hodierna published tables of the Jovian theory, at Palermo, in 1656, and they were the first given to the public. In my *Memoir of Sicily*, (1824,) I mentioned his being buried at Palma, on the south coast of that island, with a notice which may be thus cited: "Here he observed and published, for the first time, an account of the immersion of the first satellite of Jupiter, the eclipse having taken place at twelve hours, six minutes, on the 27th of June, 1652. La Lande, in commenting on Hodierna, has assigned the position of this town as being in latitude 37° 20′ N., and longitude 13° 39′ 40″ E., but by angles from Alicata, carried on to Girgenti (by myself), the position of the building called Calvary, (the probable site of the observatory,) is in latitude 37° 09′ 10″, and longitude 13° 45′ 20″ E. of Greenwich. My worthy friend, the Baron de Zach, says, 'Les Siciliens prétendent que Hodierna devança Newton sur la décomposition de la lumière; mais le P. Piazzi a écrit à feu M. de la Lande, qu'il n'a pas vu une chose aussi exagérée; Hodierna observait cependant avec le prisme. On lui attribue à plus juste titre, une autre découverte, c'est qu'il fut le premier qui avança que la reine-abeille faisait seule tous les œufs.'"

star by the moon, when in the nonagesimal, which will be found in the description of a nautical chart, in the *Rudolphine Tables*, 1627, fol. 41 and 42. In that edition Kepler says he *hoped* to publish this chart, but I have never seen it; and it seems that very few copies of the Tables are furnished with it.

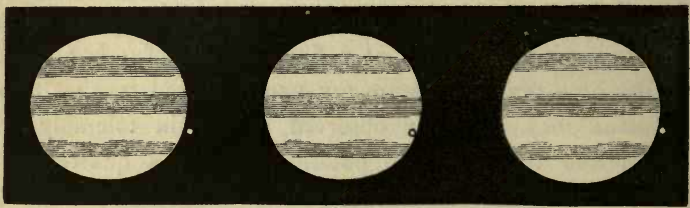
Yet it was not till fifty years after the inquiries of Galileo and Reineri, that Jupiter's satellites were regularly observed, a neglect which was, perhaps, more owing to the imperfection of watches and methods, than to any want of zeal. Nor have they since been scrutinized with the diligence which so very interesting objects would seem to claim. Flamsteed, to be sure, invented the *Jovilabe*, and made every endeavour to promote the practice of observing the satellites, but his manner was rather *crisp:* "I must confess," he remarks, "it is some part of my design, to make our more knowing seamen ashamed of that refuge of ignorance, their idle and impudent assertion *that the longitude is not to be found*, by offering them an expedient that will assuredly afford it, if their ignorance, sloth, covetousness, or ill-nature forbid them not to make use of what is proposed." Probably the recommendation of telescopes of fifteen or twenty feet for this object, by Dr. Maskelyne, repeated annually in the *Nautical Almanac* from 1767 to 1825, might have deterred some who would overlook his adding that those of 3½ feet, of Dollond's construction, are still more convenient. It is singular that these lengthy *weapons* should have been insisted on so recently, when Dr. Hook said, in 1690, "I will undertake to accommodate navigators with telescopes of two feet in length, with which they shall be enabled, not only easily to find the object, but to discover also the times of the eclipses of the satellites of Jupiter, as exactly as shall be needful." But though Maskelyne's long telescopes have been laughed at, seamen must never forget that they are indebted to him for the *Nautical Almanac*, the management of chronometers, and the establishment of lunar observations: and he made most strenuous efforts to conquer the difficulties of observing eclipses of the satellites at sea, by a full trial of Irwin's marine chair proposed for the purpose, on his well-known voyage to Barbadoes, for the trial of Harrison's time-keeper.

On the whole, though it cannot be called the most accurate of the celestial methods of obtaining the longitude, I strongly recommend the *amateur* to observe the satellites of Jupiter whenever he can; and as these phenomena frequently occur, and the predictions are always published in the *Nautical Almanac* three or four years in advance, he will be provided with the basis in any part of the world. When several of these occurrences have been observed with a good telescope, at any particular place, the mean of the differences between the computed Greenwich times and the corresponding times of observation will give the longitude, east or west of Greenwich, accordingly as the observed times are greater or less than the times in the almanac. Greater accuracy will, of course, follow a comparison of the observation with one taken at a fixed observatory; but I can, from my own practice, assure my nautical readers, that these phenomena may be fairly observed at sea, in tolerably fine weather, and the longitude obtained within a quarter of a degree. The amount of accuracy will be more or less, according to the practice of the observer, the goodness of the instrument, and the correctness of the computed prediction. The usual sea-telescope with a magnifying eye-piece of about fifty times, is a competent tool in the hands of one who is versed in taking an angular distance with the sextant. It may also be borne in mind, that when Jupiter, or any of the superior planets, is in opposition to the sun, he is then at the least distance from the earth, and at his greatest when in conjunction with the sun: the contrary is the case with the inferior planets.

Before we take leave of this truly magnificent orb, I must relate a singular occurrence which fell under my notice at Bedford; because it is desirable that all anomalies, whether they arise from the illusions of vision, the interposition of cosmical clouds, or incidental changes in the deflection of light, should be faithfully recorded, in order to add a link to some future chain of evidence. I communicated the fact to the Royal Astronomical Society, and it was thus announced in the second volume of their *Monthly Notices*, p. 38:

On Thursday, the 26th of June, 1828, the moon being nearly full, and the evening extremely fine, I was watching the second satellite of Jupiter as it gradually approached to transit its disc. My instrument was an excellent refractor, of 3¾ inches aperture, and five feet focal length, with a power of 100. It appeared in contact at about half-past ten, by inference, and for some minutes remained on the edge of the limb, presenting an appearance not unlike that of the lunar mountains coming into view during the first quarter of the moon, until it finally disappeared on the body of the planet. At least twelve or thirteen minutes must have elapsed, when, accidentally turning to Jupiter again, to my astonishment I perceived the same satellite *outside the disc!* It was in the same position as to being above a line with the apparent lower belt, when it remained distinctly visible for at least four minutes, and then suddenly vanished.

In illustration of this letter, the following diagram may be introduced; for though drawn without measurement, it shows the anomaly nearly:



As I had observed the phenomena of Jupiter and his satellites for many years, without any remarkable irregularities, I could not but imagine that some optical or other error prevailed, especially as the satellite was on this side of the planet. But a few days afterwards I received a letter from Mr. Maclear, of Biggleswade, informing me that he had also observed the same, but that he had considered it a "Kitchener's wonder:" and about the same time, Dr. Pearson having favoured me with a visit, asked me whether I had noticed anything remarkable on the 26th, for that he had, in accidentally looking at Jupiter, *seen the second satellite re-appear!* Here, then, were three observers, at distant stations, with telescopes of different apertures, all positive as to the extraordinary deviation from rule. It may be borne in view that Biggleswade is twelve miles from Bedford, and South Kilworth, Dr. Pearson's residence, is thirty-five; while the telescopes used were:

Mr. Maclear's - -	3·3 inches aperture	3½ feet focal length.
Dr. Pearson's - -	6·8 "	12 "
Captain Smyth's - -	3·7 "	5 "

§ 11. Saturn ♄.

Saturn moves in an orbit still more extensive than that of Jupiter, and in consequence of his greater distance from the sun, has but a feeble light: yet he is one of the most extraordinary and engaging objects which astronomy presents to our view. The ancients, who were utterly ignorant of his strong claims to notice, merely regarded him as a dreary, malignant star, with a leaden hue and a snail's pace; and from that slow motion, his symbol was adopted as the hieroglyphic of lead. Lucan says

> Frigida Saturno glacies, et zona nivalis,
> Cessit.

But the well known astro-meteorologist, John Goad, assures us that Saturn is not such a "plumbeous blew-nosed" planet as antiquity believed him to be. Still there are some awkward points which prevent any advocate from placing the Elysian fields in his orb. It is clear, that since his distance from the focal centre is nearly ten times greater than that of the earth, he can only bask in about one-ninetieth part of the heat and light which the earth enjoys*: the sun, however, returns more than twice as soon to the meridian of any place on his surface, owing to the planet's quick rotation on its axis. His days are not of equal length, the axis being inclined about 29° to the orbit; hence, as the length of his year, or course round the sun, is 10,759 mean solar days, or 29½ mundane years, it follows that for above seven years at a time the poles of the planet are immersed in perpetual winter, not receiving any rays directly from the sun. But to compensate both for the general scantiness of his light, and the lengthy intervals of darkness, a plentiful supply of reflected light is afforded by the aid of no fewer than seven satellites; and he is moreover distinguished from all other known planets by a broad luminous ring of attenuated matter, which surrounds his body; so that after all he probably gladdens in luminiferous medium to an intensity which would rival that of a

* The proportion of light and heat which Saturn receives from the sun is about 0·011; that received by the earth being considered as unity.

thousand of our full moons. From his surface, the sun only appears to be rather more than 3′ in diameter, and the greatest digressions of the planets are, ☿ 2° 19′, ♀ 4° 21′, ⊕ 6° 01′, ♂ 9° 11′, ♃ 33° 03′; so that, as Delambre says, a Saturnian can only know Mars and Jupiter, nor can he do more than guess at Mars, from his diminutiveness.

The shape of Saturn resembles that of an oblate spheroid, as with Jupiter, but still more elliptical, the equatorial diameter being to the polar, as 12 to 11. This very considerable flattening is an obvious consequence of the rapid rotation around its axis of so vast a body, whose density is not quite half that of water, or little more than that of cork. The form has another peculiarity, inasmuch as its diameter is not, as in other planets, largest at the equator, but at the parallel of about 45°. This, as well as the conjecture that the planet is not exactly in the centre of his ring, is inappreciable by the means which I have been able to employ; but it was thus noticed by Sir William Herschel, on the 5th of May, 1805:

In order to have the testimony of all my instruments, on the subject of the structure of the planet Saturn, I had prepared the 40-feet reflector for observing it in the meridian. I used a magnifying power of 360, and saw its form exactly as I had seen it in the 10 and 20-feet instruments. The planet is flattened at the poles, but the spheroid that would arise from this flattening is modified by some other cause, which I suppose to be the attraction of the ring. It resembles a parallelogram, one side whereof is the equatorial, the other the polar diameter, with the four corners rounded off so as to leave both the equatorial and the polar regions flatter than they would be in a regular spheroidal figure.

In the summer of 1807, the same indefatigable investigator found that the two polar regions presented a very different shape, the northern regions being flattened, but the southern more curved, or bulged outwards. This singularity was verified by the younger Herschel on the 16th of June of that year; and it is, I believe, his first recorded astronomical effort. Besides these anomalies of shape, Saturn long perplexed astronomers with phases so extraordinary, that it was difficult to unravel their meaning. Hevelius observed him sometimes to be *monospherical*, sometimes *trispherical*, *spherico-ansated*, *elliptico-ansated*, and *spherico-cuspidated*. But Huyghens, conceiving that such strange aspects must be owing to the badness of the tools used, closely attacked the planet with a superior telescope, and reduced the phases to three principal ones, viz., *round*, *brachiated*, and *ansated*. He likewise found that the surface of Saturn, like that of Jupiter, is diversified by regular stripes, or belts, nearly all parallel with the planet's equator; and of these he observed five very distinctly. In November, 1793, Sir W. Herschel perceived a bright, uniform, and broad belt, close to which was a dark one divided by two narrow white streaks; so that he saw the same number of stripes as Huyghens, three of which were dark and two bright. The belts cover a larger zone of Saturn's disc, than those of Jupiter occupy on his surface.

The Saturnian elements, at the commencement of 1801, under the condition detailed on page 83, are:

Mean distance (about 890,000,000 miles), earth as unity	9·538786
Mean sidereal revolution (29,456 Julian years), mean solar days	10759·2198
Mean synodical revolution, in mean solar days -	378·090
Mean longitude - - - -	135° 20′ 06″·5
Mean orbital motion in a solar day - -	2′ 00″·6
Ditto, in a solar year - - - -	12° 13′ 36″·1
Longitude of perihelion - - -	89° 09′ 29″·8
Annual motion of apsides, eastward - -	19″·4
Ditto, referred to the ecliptic - - -	1′ 09″·5
Inclination of orbit to plane of ecliptic - -	2° 29′ 35″·7
Annual decrease of ditto - - -	0″·155
Longitude of ascending node - - -	111° 56′ 37″·4
West motion of ditto, per annum - -	19″·4
East ditto, referred to the ecliptic - - -	30″·7
Ex-centricity of orbit, half major axis as unity -	0·0561505
Secular decrease of ditto - - - -	0·000312402
Greatest equation of the centre - - -	6° 26′ 12″
Annual decrease of ditto - - -	1″·279
Rotation on axis - - - -	$10^h\ 29^m\ 16^s·8$
Inclination of axis to that of ecliptic - -	31° 19′
Apparent diameter at mean distance from the earth -	16″·20
True diameter (about 76,068 miles), earth as unity -	9·982
Volume, earth as unity - - -	995·00
Mass, sun as unity - - - -	0·0002847380
Density, sun as unity - - -	0·550

The course of Saturn sometimes appears retrograde. The arc which he describes in such cases varies from 6° 41′ to 6° 55′; its duration in the former case is $138^d\ 18^h$, and in the latter case $135^d\ 9^h$. This retrogradation commences or finishes when the planet is at a distance from the sun, which varies from 107° 25′ to 110° 46′. If by any possibility the centrifugal force of this vast planet, a planet nearly a thousand times the bulk of the earth, were suspended, and its orbital motion stopped, it would fall to the sun in 1901 days, or 5 years 76 days. A heavy body would drop at his surface, at the rate of sixteen feet in the first second of time.

Saturn is surrounded by a thin flat ring, encompassing his body without touching it, like a separated prolongation of its equator, in the midst of which the planet, as seen in a telescope, appears to repose. This ring is a peculiarity that has no parallel in our whole solar system; and, from the creation, the planet had made 190 revolutions before the beautiful appendage became revealed to the eye of man*. At length Galileo, "through optic glass," which confounded both planet and ring, discovered that the figure of Saturn was not round, but oblong, like an olive. Closer observation, with his very indifferent instrument, made it appear like a central globe between two smaller ones; and this he announced in 1610, under the veil of a logograph which sorely puzzled Kepler. This was not to be wondered at, for it ran

SMAISMRMILMEPOETALEVMIBVNENVGTTAVIRAS.

The which, when the turns are taken out, stands

ALTISSIMVM PLANETAM TERGEMINVM OBSERVAVI.

Thus opened a new discovery, which was, in a manner, completed by Huyghens; for though unconscious of its being multiple, he was the first who drew the conclusion that the globe of Saturn was encompassed by a permanent ring, and accordingly produced his *Systema Saturnium* in 1659. This annulus he considered as an opaque substance, reflecting the light of the sun; he also concluded that its plane was inclined to the orbit of Saturn. With respect to its disappearance, a phenomenon which had astonished Galileo, the Dutch astronomer assigned two causes; one that the plane of the ring, regularly changing its position, occasionally passes through the earth and occasionally through the sun. In the first case, the edge only is

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* Maurice, in his *Indian Antiquities*, gives an engraving of *Sani*, the Saturn of the Hindùs, from an image in a very ancient pagoda. A circle is formed around him by the intertwining of two serpents; whence the writer suggests that, by some means or other, the phenomenon of Saturn's ring may have been known in remote ages.

presented to us; and in the other, the edge only is enlightened by the sun; consequently, in both cases, as the thickness of the ring subtends an angle which is insensible, the ring is necessarily invisible to a mundane spectator. Flamsteed viewed it when the *ansulæ* had disappeared, in 1671, with a 14-foot telescope, "the aperture being 1½ inch, and its eye-glass drawing two inches." The correspondence in those times, among astronomers, is curious and interesting, as showing the great trouble which was taken to ascertain Saturn's particulars: much of it is preserved among the manuscript letters in the archives of the Royal Society. Every incident was caught with avidity; and Whiston informs us, that Dr. Clarke's father actually saw a fixed star between the ring and the body of the planet. This must have occurred when the ring affected the elliptic form, at which time the extremities of its major-axis are called *ansæ*.

In 1665, Messrs. Ball, of Minehead, saw the dark elliptical line which divides the ring, as it were, into two concentric portions, as related at p. 51. Ten years afterwards it was more regularly observed by Dominic Cassini, who noted the unequal brilliancy of the rings, the inner one being the brightest: he also perceived a dark line or belt upon the planet, parallel to the greater axis of the ring. Hadley perceived that the outer part of the ring seemed narrower than the inner part, and that the dark line was fainter towards its upper edge; he also saw two more belts, and noticed the shadow of the ring upon Saturn. Maraldi proved the views of Huyghens, by establishing that the ring remains invisible from the time that its plane passes through the earth, till it reaches so far above or below the plane of the earth's orbit that the sun's light upon the former plane becomes great enough to render it visible, and that it remains invisible while the plane of the ring lies between the earth and the sun, because then the dark side is turned towards us. In October, 1714, when the plane of the ring very nearly passed through the earth, and was approaching it, the same diligent observer perceived, that while the ansæ were decreasing, the eastern one appeared a little larger than the other for three or four nights, and yet it vanished first. This inequality of the ring induced him to suspect that it was not bounded by exactly parallel lines, and that it turned about its axis. James Cassini, remarking that the disappearance and re-appearance of the two sides of the ring do not take place respectively after equal intervals of time, concluded that the whole annular surface is not exactly in one plane; and Messier, in 1773, from certain inequalities of the light, as well as from the appearance of distinct luminous points when the breadth of the ring was very much diminished, was satisfied that its surface must be considerably diversified with hills and valleys. This admirable want of uniformity, so far from a blemish, is a condition absolutely necessary for preserving its equilibrium; hence Laplace, (*Mécanique Céleste*,) says, "J'ajoute que ces inégalités sont nécessaires pour maintenir l'anneau en équilibre autour de Saturne; car s'il étoit parfaitement semblable dans toutes ses parties, son équilibre seroit troublé par la force la plus légère, telle que l'attraction d'une comète ou d'un satellite, et l'anneau finiroit par se précipiter sur la surface de Saturne." He also considered it as a necessary condition to maintain the ring in equilibrium, that the particles on its surface should not have a tendency to separate from it, a condition to be fulfilled only by a rapid rotatory motion of the ring in its plane and round its centre*.

The shadow cast by the body of Saturn had been noticed, as above mentioned, by Hadley; but Sir W. Herschel was the first who discerned the shadow cast by the ring on the planet itself, at a time when the edge of the former, being turned towards the earth, was invisible. This resulted from the use of his powerful telescope; for to the means employed by other astronomers, the disappearance seemed entire, and recorded times of the ring's

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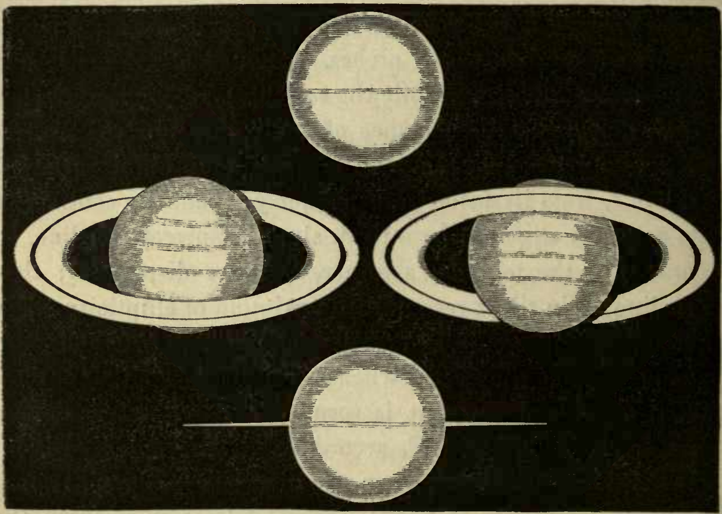
* "Supposing the rings mathematically perfect in their circular form," says Sir J. Herschel, "and exactly concentric with the planet, it is demonstrable that they would form (in spite of their centrifugal force) a system in a state of *unstable equilibrium*, which the slightest external power would subvert, not by causing a rupture in the substance of the rings, but by precipitating them, *unbroken*, on the surface of the planet." And, after further investigation, he adds, "the observed oscillations of the centres of the rings about that of the planet is in itself the evidence of a perpetual contest between conservative and destructive powers, both extremely feeble, but so antagonizing one another as to prevent the latter from ever acquiring an uncontrollable ascendancy, and rushing to a catastrophe."

vanishing, owing to atmospheric and instrumental differences, disagree by several days. Sir William thinks the edge of the ring is not flat, but spherical, or spheroidical; and its breadth is to the space between it and Saturn, as about 5 to 4. The semi-axis minor of the ring being greater than the semi-diameter of the planet, the former projects on each side; but its inclination cannot be directly obtained by observation, because the earth never acquires a greater elevation, relatively to Saturn, than 27°. It is therefore requisite to wait till the ring projects sensibly, and measure the *ansæ* repeatedly, a process only feasible during one third of Saturn's revolution.

Seen from Saturn, the rings must appear as vast and inconceivably splendid luminous arches, stretched across the heaven from horizon to horizon, while the satellites, adding their variety of phase, increase the radiance of the scene. In the planet's course round the sun, the zone assumes a beautiful variety of oval forms, from its being seen obliquely; gradually contracting from a certain elliptical form to an almost imperceptible line, or, according to the telescope's power, to entire disparition; then expanding again till it resumes its maximum of ellipticity. The intersection of the ring and of the ecliptic is in 170° and 350°; consequently the ring wanes when Saturn is near either of those points; on the contrary, it is seen to the greatest advantage when he is in 80° or 260°, according to the earth's position: thus the ring is most open when the planet is in the nineteenth degree of Gemini, or of Sagittarius; and least so when in the nineteenth degree of Pisces, or of Virgo. In other words, twice in each of Saturn's revolutions, that is, every fifteen years, the earth being in the plane of his ring, we only see its thin edge; therefore it becomes invisible, except in the mightiest telescopes. When the sun illumines the side of the ring opposite to that on which the earth is, it will also be invisible to us, except that with good optical aid, its existence may be detected by a narrow shadow cast across the body of the planet. The progress of this disparition is an interesting phenomenon for an amateur to watch, since it will conclusively test the power of his telescope. In 1819, I was much amused in showing the denuded orb to some islanders in the Adriatic, with the same instrument which had, the year before, shown them what they called "a star with a hoop round it." In April, 1833, I took advantage of the ring's absence, to scrutinize the satellites, and examine the diameter of the planet. Sir W. Herschel once saw the little moons as beads along a line of light, "like pearls strung on a silver thread;" but though my instrument did not furnish this sight, I was enabled, by a general mean of measures, to conclude that the equatorial diameter exceeded the polar one, nearly as 13 to 12*. To such readers as have never gazed at these wonderful changes, the following appearances may be explanatory.



We now arrive at the *questio vexata*, as to the number of concentric layers into which the wondrous ring of Saturn may be divided; and it is a subject upon which discussion is still alive. Laplace has shown, in the *Mémoires de l'Académie Royale des Sciences*, for 1787, in an essay "Sur la Théorie de l'Anneau de Saturne," from the inferred destructibility of the ring, had it been similar in all its parts, as already quoted, that the grand annulus which encircles Saturn, may be concluded to be composed of several different rings lying one within the other,

* On the 26th of April, I lost the ring; but Sir J. Herschel did not consider the disappearance as complete, with his 20-foot reflector, till the 29th.

exactly in the same plane; and that plane, coinciding with that of the planet's equator, remains always parallel to itself. In thus establishing the theory of the division of the Saturnian ring into an assemblage of concentric components, he pronounced that these rings are irregular solids, of unequal breadth in different parts of their circumference, so that their centres of gravity do not coincide with their centres of figure; and that these centres of gravity may be considered as so many satellites circulating round Saturn, at distances depending on the inequality of the parts of each ring, and with periods of rotation equal to those of their respective rings, "such as would be the aggregate of the orbits of the satellites of Jupiter, if each left a permanent light in its path." From this it follows, that the ring will turn round its centre of gravity in the same time that it revolves round the planet. It was pronounced to be essential to this system, that the centre of the rings, instead of being fixed in that of the planet, should describe a small orbit; that is, that the rings should have a slight oscillating motion to and from the planet, combined with an oscillating motion of their planes. Such was the *à priori* theory of a master-mind, yet it was one which experienced rather a cool reception. Short, indeed, thought he had seen the ring quadruple, though others could make out but two; Sir W. Herschel remarked that no observation will justify the supposition of multiple rings; and Plana proceeded to prove analytically, that the assumption is unnecessary. I have gazed at Saturn with Sir James South's large refractor of 11·7 inches aperture, and other most powerful telescopes, without a perceptible symptom of more than one division; and I have often, with my own instrument, *fished* equatoreally for a star so in the planet's path that its appearance and disappearance among the rings might be noted; but my efforts have always been unsuccessful. Professor Robison mentions a star's having been seen in the interval between the two known rings.

Such was the state of the question, when, in the winter of 1829, being on a visit to the late Captain Kater, and looking over some of his manuscripts, I met with a detailed statement of his having perceived concentric black lines on Saturn's exterior ring. This account was so fully corroborated by the intelligent Mrs. Kater, the "person" alluded to in his narrative, that I persuaded the Captain, as a bounden duty, to write out a copy of the details, and allow me to present the manuscript to the Royal Astronomical Society. This he accordingly did, and the paper was published in the fourth volume of that Society's *Memoirs*, pp. 383 to 390. It will be there seen that Captain Kater, and two other persons, saw the ring divided, on the 17th of December, 1825, and other nights, with two reflecting telescopes, one of 6¼ and the other 6¾ inches aperture; and it is also shown, that M. Quetelet, director of the Brussels observatory, saw the outer ring divided into two, in December, 1823, with an achromatic telescope of ten inches aperture, which was then exhibiting at the grand *exposition* in Paris. Now if, as was said, these appearances were attributable to tremors, or instrumental defects, such would not be confined to the outer ring: and that other observers with large instruments did not perceive such lines or subdivisions, is but a negative testimony, especially where the object itself is pronounced to have a very dense atmosphere. Counter presumptions were, however, so strong, that many remained incredulous of the existence of any subdivisions; though the memorable discussions about that time, as to whether Aldebaran were projected on the lunar disc previous to occultation, or not, might have served as a beacon. Early in November, 1843, happening to meet the Rev. W. R. Dawes, on his return to London, he told me of his having visited Mr. Lassell, at Liverpool, and that he had there seen Saturn's outer ring divided, albeit the planet was inconveniently low: I was so struck with this conclusive settlement of the question, that I begged of him to place it on record, by immediately sending an account of it to the Royal Astronomical Society. Mr. Dawes complied with my wish, and the inquiring reader will be gratified by an extract from the letter which he forthwith sent:

September 7, 1843. At Mr. Lassell's observatory, Starfield, near Liverpool. The day had been cloudless and remarkably warm, the maximum of the thermometer being 76°, where all precautions had been taken to keep it as cool as possible. In the evening the sky was hazy and the stars dull. At about 9 P.M. Mr. Lassell turned his equatoreally-mounted 9-foot Newtonian reflector, of 9 inches aperture, upon *Saturn*, with a power of 200, and was electrified at the beautifully sharp and distinct view of the planet presented to him.

Having applied as an eye-piece an achromatic lens (being the object-glass of a microscope) which produced a power of 450 times, Mr. Lassell examined the planet for a few minutes. I then took my place at the telescope, and Mr. Lassell requested me to examine carefully the extremities of the ring, and say if I observed anything remarkable. Having obtained a fine adjustment of the focus, I presently perceived the outer ring to be divided into two. This perfectly coincided with the impression Mr. Lassell had previously received. For some minutes I scrutinized this interesting object, and occasionally, for several seconds together, had by far the finest view of *Saturn* that I was ever favoured with. The outline of the planet was very hard and sharply defined with power 450; and the primary division of the ring very black and steadily seen all round the southern side. *When this was most satisfactorily observed,* a dark line was pretty obvious on the outer ring. I was not only perfectly satisfied of its existence, but had time during the best views carefully to estimate its *breadth,* in comparison with that of the division ordinarily seen. The proportion appeared to me to be as one to three; but Mr. Lassell estimated it at *scarcely* one-third. It is certainly rather *outside* the *middle* of the outer ring, and is broadest at the major axis, being in this respect precisely similar to the primary division. *It was equally visible at both ends of the ring.*

For further satisfaction, other eye-pieces were tried. A positive double eye-tube, magnifying 400 times, came nearest to the achromatic lens in efficiency; yet the latter gave the impression of equal sharpness and light, with an increase of 50 in the power. With 400 the secondary division was perceptible during occasional best views of the planet; but no lower power displayed it at all, though with them the usual features of Saturn were splendidly distinct. A positive double eye-piece producing a power of 520 was also applied; but by this time the state of the air had deteriorated; and though some confirmatory glimpses were obtained, the view was not so good as with the achromatic lens.

After such unquestionable evidence, there can be no reasonable doubt of the outer ring's being multiple.

This, however, does not close the wonders of Saturn's ring: MM. Schwabe and Harding found that it was not mathematically concentric with the ball, but that the planet lay towards the west in the ring,—a condition which, by oscillations of much complexity, is found to add to the stability of the system. This announcement, in 1828, induced Professor Struve to give a rigid investigation of the matter, with the great Dorpat refractor; and his delicate micrometrical operations produced a result of 11″·073 for the left vacancy, and 11″·288 for the right one. He found that the inclination of the ring to the ecliptic was 28° 5′ 54″: and the other measurements, reduced to the mean distance of the planet, are,

			Miles.
Outer diameter of exterior ring	- -	40″·095	176,418
Inner diameter of ditto	- - -	35″·289	155,272
Outer diameter of interior ring	- -	34″·475	151,690
Inner diameter of ditto	- - -	26″·668	117,339
Equatorial diameter of the body	- -	17″·991	79,160
Breadth of division between the rings	-	0″·408	1,791
Distance of the ring from the ball	-	4″·339	19,090

To the eye, the breadth of the ring is analogous to its distance from the surface of the orb of Saturn; that is, about one third of the diameter of the planet; and its thickness does not exceed 100 miles.

Such are Saturn and his ring, the phenomena of which afford a beautiful display of the joint effects of gravity and centrifugal force. Respecting the design of the Omnipotent Demiurgus in forming this extraordinary arch, conjectural astronomy can only bow and be silent. Some insist that it is a conductor of solar light and heat, because by dividing the square of Saturn's distance from the sun by the square of that of the earth, the quotient 92, proves that when the thermometer is at 92° on the earth, it stands at 1° above zero in Saturn: and as it never reaches 184° with us it is never 2° above zero in that planet. It is therefore manifest, they say, that as there could be no clouds floating about in such a temperature, and yet there are various facts to prove that there is an atmosphere, this vast and beautiful ring is beneficently placed to moderate and diversify the seasons. Yet it periodically deprives vast regions on which it throws its shadow, of the sun's light, sometimes for several years; and for many years together, in certain situations, the only day will be the emergence of a part of the sun from the ring for a short time. Kepler and Halley supposed our earth may possibly be composed of several crusts, or shells, one within the other, and like the well-known Chinese toy, concentric to each other. This supposition induced Mairan's idea, that the ring of Saturn may be the fragment or remaining ruin of his former exterior shell, the rest of which is broken or fallen down upon the body of the planet. Maupertius maintained, that this luminous girdle was the tail of a comet, which the attraction of Saturn had compelled to circulate round him; and Buffon imagined it to be part of the planet's equator, detached by the excess of centrifugal force. There are, however, a few stumbling blocks in the way of each hypothesis, of which a principal one is, that the ring must have had some external power supporting it while formed; and it must have been formed in its present position about the planet, or it never could, by the law of gravity, have acquired its present permanent situation, with progressive velocity nicely adjusted to the orbital velocity of Saturn. Its formation was probably, therefore, contemporary with that of the planet.

There are seven satellites revolving about Saturn, of which the brightest, called the Huyghenian satellite, and Saturn's guard, was discovered by Christian Huyghens, in March, 1655. The first, second, third, and fifth, were detected, some years afterwards, by the elder Cassini, who dubbed his prizes *Sidera Lodoicea*, in compliment to Louis XIV., in whose reign, and under whose auspices, they were discovered; but though his nation dubbed him *le Grand*, astronomers have refused to ratify the Uranian honour. The finding of these new bodies, is thus related by Christian Huyghens, in the letter to his brother on the *Planetary Worlds:*

Jupiter you see has his four, and *Saturn* his five moons about him, all plac'd in their orbits. The *Jovial* we owe to *Galilæo*, 'tis well known: and any one may imagine he was in no small rapture at the discovery. The outermost but one, and brightest of *Saturn's*, it chanc'd to be my lot, with a telescope not above 12 foot long, to have the first sight of in the year 1655. The rest we may thank the industrious *Cassini* for, who used the glasses of *Jos Campanus's* work, first of 36, and afterwards of as many above 100 foot long. He has often, and particularly in the year 1672, shown me the third and fifth. The first and second he gave me notice of by letters in the year 1684, but they are scarce ever to be seen, and I can't positively say I had ever that happiness; but am as satisfied that they are there as if I had, not in the least suspecting the credit of that worthy man. Nay, I am afraid there are one or two more still behind, and not without reason. For between the fourth and fifth there's a distance not at all proportionable to that between all the others. Here, for aught I know, may lurk a sixth gentleman; or perhaps there may be another without the fifth that may yet have escaped us: for we can never see the fifth but in that part of his orbit which is towards the West; for which we shall give you a very good reason.

Perhaps when *Saturn* comes into the northern signs, and is at a good height from the horizon (for at the writing of this he is at his lowest), you may happen to make some new discoveries, good Brother, if you would but make use of your telescopes of 170 and 210 foot long; the longest and the best, I believe, now in the world. For tho' we have not yet had an opportunity of observing the heavens with them (as well by reason of their unwieldiness, as for the interruption of our studies by your absence) yet I am satisfied of their goodness by our trial of them one night, in reading a letter at a vast distance by the help of a light. I cannot but think of those times with pleasure, and of our diverting labour in polishing and preparing such glasses, in inventing new methods and engines, and always pushing forward to still greater and greater things.

This letter was written in the ripened experience of Huyghens: for when he was fortunate enough to discover the bright satellite more than thirty years before, he imprudently concluded that there remained no more satellites to be detected, because their number then equalled that of the primary planets (see p. 51). Prediction, however, in questionable cases, is always dangerous. Thus, on the same topic, Mr. J. Harris, a Fellow of the Royal Society, and a man of merit in his way, in an astronomical work which he published in 1729, says, "'Tis highly probable that there may be more satellites than the five moving round this remote planet; but their distance is so great, and their light may be so obscure, as that they have hitherto escaped our eyes, and perhaps may continue to do so for ever; for I don't think that our telescopes will be much further improved." The names and achievements of Short, Dollond, Herschel, Fraunhofer, Tulley, and the Earl of Rosse, form the best reply to so unlucky an opinion. The very first moment that Sir William Herschel directed his 40-foot telescope to the heavens, the sixth satellite of Saturn was caught; and this was followed, within less than a month, by the discovery of that most difficult test-object, the seventh satellite. When we recollect what an excellent instrument it requires to distinguish even five of these little moons, such results were proud triumphs of the huge reflector.

By comparing the places of the satellites with the ring in different points of their orbits, and the greatest minor axes of the ellipses which they appear to describe, compared with the major axes, the places of the orbits of the first four are found to be very nearly circular, and in the plane of the ring: they therefore are inclined to the orbit of Saturn about 30°. But the course of the fifth is considerably more inclined to the ecliptic; and when this satellite reaches its greatest western elongation, it exceeds all the others in splendour; but when it arrives at its greatest eastern elongation, it disappears altogether, and continues invisible for half the time it requires to perform its revolution round its orbit. This defalcation is not occasional, for it always recurs when the satellite is in the same position: hence it is inferred that, like our moon, it revolves on its axis in a period exactly equal to the time of its revolution round Saturn. Its disappearance was first noticed by Cassini, but the inference derived from it was drawn by Newton (*Principia*, l. iii., prop. 17); and this remarkable instance of analogy among the secondary planets, was confirmed by the elder Herschel, who regularly traced the periodical changes of light which this satellite passed through, during more than ten entire revolutions.

Although so much has been achieved, the attainment of a full knowledge of the system of Saturn is beset with numerous difficulties, of which that of exactly ascertaining the inclination of the ring, and consequently of the satellitian orbits, is not the least. It results from Laplace's theory, that the *flattening* of the planet must keep the rings and the orbits of the interior satellites in the plane of the equator; but the amount of that flattening being unknown, we can only see that if we refer the orbits of the satellites to a fixed plane, as is done with Jupiter's, the inclination of that plane to the equator will be insensible to us, and that the last satellite preserves always the same mean inclination, with an uniform retrograde movement. M. Bessel made a strenuous attempt to clear up the doubts of his theory, in a memoir noticed in the *Monatliche Correspondenz* for September, 1811. In this he corrected the principal elements, and established the mass of the ring as being to that of the planet $\frac{1}{213}$; which, Delambre says, is the utmost that can be assigned to it. On the establishment of the Astronomical Society of London, one of the first measures of its council was, proposing the Society's gold medal, and twenty guineas, for the best paper on the theory of the motions and perturbations of the satellites of Saturn: "the investigation to be so conducted as to take expressly into consideration the influence of the rings, and the figure of the planet as modified by the attraction of the rings, on the motions of the satellites: to furnish formulæ (adapted to the determination of the elements of their orbits, and the constant co-efficients of their periodical and secular equations) from observation: likewise to point out the observations best adapted to lead to a knowledge of such determination." The prize was not awarded; but the following table of Saturn's attendants contains elements which are pretty passable, though of course far less perfect than those for the satellites of Jupiter:

Satellite.		Sidereal Revolution.	Mean Distance.			Inc.	Discoverer and Date.
Ord. fr. Pla.	Old Ord.	Mean Solar Days.	♄'s *s. d.* as 1.	Sub-tended.	Miles.		
I.	7	0^d 22^h 38^m or 0^d·94271	3·351	29″·15	120,000	30°	W. Herschel, 1789
II.	6	1 08 53 or 1·37024	4·300	31″·19	150,000	30°	W. Herschel, 1789
III.	1	1 21 18 or 1·88780	5·284	45″·13	190,000	30°	D. Cassini, 1684
IV.	2	2 17 45 or 2·73948	6·819	1′ 00″·93	243,000	30°	D. Cassini, 1684
V.	3	4 12 25 or 4·51749	9·524	1′ 24″·86	340,000	50°	D. Cassini, 1684
VI.	4	15 22 41 or 15·94530	22·081	3′ 26″·50	788,000	30°	C. Huyghens, 1655
VII.	5	79 07 55 or 79·32960	64·359	9′ 28″·00	2,297,000	24¾°	D. Cassini, 1671

These numbers are necessarily rather *round*, for on account of the difficulties alluded to, we can only become acquainted with the full disturbing effects of the ring, by an accumulation of accurate observations. Unlike the horizontal path pursued by Jupiter's moons, those of Saturn may be called vertical with respect to our view of them, and therefore cannot be eclipsed, except, perhaps, when the ring looks edgeways to the earth by means of its parallelism. Occultations of the planet, however, by the moon, are phenomena of great interest, and may be so easily observed, that the one on the 8th of May, 1832, which is recorded in the fifth volume of the *Astronomical Society's Memoirs*, was taken when the whole welkin was covered with clouds: at such times it is curious to observe, that in a few seconds from the first contact, that immense body, 177,000 miles in diameter, is completely hidden by the interception of our little satellite! Among other singularities worthy of note, it will be seen by the above elements that, notwithstanding the vast disparity of distance and consequent orbits, the hourly motion of the second and third, and also of the fifth and sixth, are very closely similar. The place of all their nodes is 5^s 17° 5′, except that of the seventh, which is 4^s 25° 5′. The inner satellite performs 11,000 revolutions about its primary during the time its primary makes one about the sun; our moon only thirteen. The *peri-kronion*, or line of the apsides of the Huyghenian satellite completes a revolution in 718 years, and the nodes in 36,000 years; in the case of our moon, these periods are 8·8 and 18·6 years. The celestial scenery there must be variegated and resplendent beyond description: the glorious arch majestically rolling around its primary orb, and the seven satellites alternately presenting their ever-varying phases. Three of these attendants are far within the distance of our moon from the earth, and those beyond that distance, are still of a magnitude sufficient to render them very conspicuous. The inner one, just alluded to as rapidly flying through its manifold revolutions, may be taken as a principal feature. This will not be above one third of the distance from the surface of Saturn, that our moon is from us, yet it will present a disc nearly ten times as large; and in the course of 22½ hours, will exhibit all those phases which our moon consumes a month in performing.

Some confusion has arisen from the nomenclature of the satellites in configurating their appearances*. The numbers heretofore used denote the order in which they were discovered, except respecting the fourth, and not their distances from the primary, as in the case of Jupiter. Since the discoveries of the elder Herschel, it has been customary to rank them in the order of their distances from the planet; and if this order be inverted, they will then be placed according to their comparative brightness, with the exception of the fifth, which, though the largest, perhaps nearly of the size of Mars, never equals the fourth in splendour. These two are very readily seen under optical aid, but it requires an instrument of power to discern the next three; and none but the most powerful telescopes

* Lalande describes a *Saturnilabe,* or instrument for finding the position of Saturn's satellites for any particular time.

hitherto constructed, can show the two interior satellites. I *thought* all the seven were visible in the great refractor at Camden Hill, in February, 1830, but certainly cannot make affidavit to the fact: I never saw the planet in greater beauty.

§ 12. Uranus ♅.

This body, so recently added to our system, is the planet, of all yet known, the most remote from the sun, and its orbit embraces those of all the others. Its discoverer, Sir William Herschel, gratefully designated it the Georgium Sidus, in honour of George III., a real patron of astronomy; but others abbreviated the name to Georgian. The continental savans, however, were not satisfied with either; and Laplace contended that it ought to bear the name of him who brought it to light. Many adopted this suggestion, and there are still numbers who call it Herschel; but the general feeling was in favour of a mythological term, and as the situation of the new planet was in regular gradation beyond Jupiter and Saturn, father and son, it was dubbed Uranus, the sire of Saturn, and the name is now generally adopted. The vote of nautical savans, however, would have been either for the appellation Herschel, or the mythological Neptune; which latter, with the trident as a symbol, would have stamped the maritime state in which the discovery was made.

Uranus was discovered by Sir William on the 13th of March, 1781: he happened on the evening of that day to be engaged in examining some small stars near the feet of Gemini, when he observed that one of them appeared to have a more sensible amount of diameter and less brightness than the others. High magnifying powers rendered this circumstance still more perceptible; he therefore measured its distance from the neighbouring stars, and obtained direct proof that the object of his attention actually moved at the rate of $2\frac{1}{4}''$ per hour. Still so little notion of another planet was dreamt of, that the stranger was announced to the Royal Society as a comet; but it speedily became an object of engrossing interest to the astronomical world.

It was quickly found and observed by Dr. Maskelyne, who almost immediately declared that he suspected it to be a planet. M. Lexell, who was then in England, applied himself to compute the orbit as a cometary parabola, though he soon concluded that it must be nearly circular, and that its distance from the sun was about twice as great as that of Saturn: the President Bochard de Saron, about the same time, also found that its orbit was circular, with a radius ten times our distance from the sun; and Jerome F. Lalande pronounced the period of its revolution to be about eighty-two years.

Thus the supposed comet was recognised as a superior planet, resembling the rest of the system in every possible point of comparison; and so prodigious an enlargement of the system excited the warmest speculation. Certain disturbances and deviations in the courses of Jupiter and Saturn seemed now to be accounted for. Saturn had long been *reasoned* upon as the evident boundary of the solar scheme*, because being so far off, it was requisite to equip him with seven satellites and a ring, it having been laid down that the number of satellites was necessarily increased according to the increased distance of the planets, as a necessary compensation for the gradual decrease of solar influence over such vast interplanetary spaces. All this methodical arrangement was upset by the introduction of Uranus. Within a year after its discovery, Laplace, by means of several excellent observations, ascertained the ellipticity of the orbit, its principal elements, and the perturbations to which it is subject by the attractions of Jupiter and Saturn: and it is a striking circumstance that, among these, he detected two, producing equations of its mean motion, of which one is accomplished in 90 years, and the other in 569 years. This, as Voiron points out in his *Histoire de l'Astronomie*, exhibits the astonishing power of analysis: by observation alone the variations in the movements of the planet could not be ascertained till after long periods of time, and in proportion as they became sensible to the observer; but

* The Burmans mention eight planets: the Sun, the Moon, Mercury, Venus, Mars, Jupiter, and Saturn, and another named *Ráhu*, which is invisible. "An admirer of Oriental literature," says Buchanan, "would here discover the Georgium Sidus, and strip the industrious Herschel of his recent honours."

the geometer penetrates into the depth of future ages, and besides foreseeing several other inequalities, is enabled to discover a correction of its mean motion amounting to the small quantity above mentioned, and compensated periodically in more than five hundred years.

The difficulties of the case were, however, only encountered, not conquered; and the labours of Nouet, Filxmillner, Oriani, Caluso, and other working astronomers, were arduously devoted to the inquiry. A reference to former catalogues showed that Uranus had been once observed as a star by Bradley, five times by Flamsteed, once by Mayer, and no less than twelve times by Lemonnier, the last of whom, according to Delambre, would have been the discoverer of the planet, had he only arranged his three observations of 1765 methodically. He would thus, continues the same writer, have anticipated Sir William Herschel by sixteen years; "à qui il seroit encore resté assez d'autres titres pour que son nom fut immortel dans les fastes de l'Astronomie." And again he reproaches Lemonnier's accident, "faute d'avoir fait un rapprochement bien simple, il manque une découverte importante." But there can be no question that the length and consequently apparent slowness of its orbital march, kept off suspicion of the planet's motion. The Academy of Sciences at Paris then proposed the new planet's theory as the subject for the prize of 1790, although from having been observed but eight years, only one tenth of its orbit was known. The guerdon was carried off by Delambre. The orbit, however, is of such extreme difficulty, that the ellipse is not yet absolutely determined. The elements, for the period and conditions mentioned at p. 83, are:

Mean sidereal revolution (84·02 years) solar days	30686d·821
Mean synodical revolution, solar days	369·656
Mean longitude	177° 48′ 23″·0
Mean orbital motion in a solar day	42″·37
Ditto, per annum	4° 17′ 45″·16
Longitude of perihelion	167° 31′ 16″·10
Annual motion of apsides, eastward	52″·50
Inclination of orbit to plane of ecliptic	46′ 28″·44
Longitude of ascending node	72° 59′ 35″·30
Annual motion of ditto, eastward	14″·16
Ex-centricity of orbit, half major axis as unity	0·04667938
Greatest equation of centre	5° 20′ 57″
Mean apparent diameter (35,000 miles), scarcely	4″·0
True diameter, earth as unity	4·344
Mass, sun as unity	0·0000558098

Volume, earth as unity - - -	82
Density, sun as unity - - -	1·100
Mean distance (1,800,000,000 miles), that of earth as unity	19·182390

Under these conditions, Uranus occupies eighty-four years in going his round; but slow as he apparently is, he journeys at the rate of sixteen thousand miles an hour: should this course be suddenly stopped, and the centripetal force acquire its full action, this vast planet would not fall to the sun under 5425 days, or nearly fifteen years. A body weighing one pound at the mundane surface, would weigh only 14 oz. 14 drachms if removed to that of Uranus. The proportion of light and heat which he receives from the sun, according to the square of the distance, is about 0·003, that received by the earth being considered as unity; so that his daylight is about equal to the light which would be afforded by three hundred of our full moons. His summer half-year is forty-two of our years in duration, and his winter half-year is equally long, at intervening periods of which, or intervals of fifteen years, his inhabitants may rejoice in a distinct view of Saturn, as a fine morning and evening star in the immediate vicinity of the sun; and they perchance get a glimpse of Jupiter when just clear of the solar rays: but all the planets within Jupiter are absolutely invisible to them. Though thus deprived of a full view of the solar system, the Uranian astronomer must be well stationed for watching comets; and he may also aim at stellar parallax, since he will have a base-line of 3,600,000,000 of miles, or nineteen times the length of that which we are confined to. A contemporary, however, is rather indignant to hear it even suggested that Uranus, a desert of darkness, where all fluid such as water must be constantly frozen, is by possibility inhabited. Now it may be true enough, that no animated beings, constituted as the inhabitants of the earth are, could exist on its surface; yet there are too many evidences of design and harmony in the admirable mechanism before us, to allow of our suppressing the idea that it may be the abode of reason and intelligence! Thus the axis on which Uranus may be presumed to rotate, since Sir W. Herschel was "pretty well convinced" that the disc is flattened at the polar regions, falls in the very plane of its orbit, in consequence of which the sun turns in a spiral form round the whole planet, so that even the two poles sometimes have that luminary in their zenith. The orbital inclination is less than that of any of the other planetary orbits: his arc of retrogradation is 3° 36′, and the duration of the retrograde motion 151 days. The density of Uranus is nearly equal to that of water; and a heavy body would fall at his surface, through about seventeen feet in the first second of time, the accelerating force of gravity being 1·056 = thirty-four feet per second nearly, earth as unity.

Notwithstanding a bulk eighty times that of the earth, the distance of Uranus is so great that he can scarcely be distinguished by the naked eye: though when the sky is serene and his place well known, a practised gazer will soon detect him, sometimes as a star of the sixth magnitude, and at others, under the best circumstances, of the fifth. His light is rather subdued, whence he is sooner lost in the solar rays than a small star; and his disc presents a uniform grayish tint, without any discernible spots, belts, or rings. He often appears distinct and well-defined in the telescope, and high magnifying powers readily raise his disc; but it requires very favourable circumstances to admit of his being satisfactorily observed, and my own observations upon him were necessarily confined to the southern portion of his orbit. His diameter of 4″ never seems to vary, owing to the comparative smallness of our orbit as compared with his: yet at the distance of the sun from us, the same apparently insignificant diameter would subtend 74″. So Mercury, under the same condition would appear to be 6″·6, Venus 16″·5, Jupiter 3′ 07″, Saturn 2′ 58″, and his ring 6′ 41″, showing, says Delambre, that the magnitudes bear no relation to their distances, and that their united diameters are far below that of the sun (32′); and it therefore follows, that he alone could be the true centre of the system, if the celestial motions are the result of a primitive impulse, and of a constantly acting central force. The sun's diameter, as seen from the planets of our system, is thus:

☿	♀	⊕	♂	⚳	♃	♄	♅
80′	46′	32′	21′	11′	6′	3′	1′·3

And, as seen from the sun, the planetary diameters are:

☿	♀	⊕	☽	♂	♃	♄	♅
16″	30″	17″·2	4″·6	10″	37″	16″	4″

From the statements of Sir W. Herschel, it seems that there are six satellites to Uranus; and moreover there is a suspicion of two rings at right angles to each other across his orb, but this curious circumstance has not been confirmed; "the observations," he remarks, "which tend to ascertain the existence of rings not being satisfactorily supported, it will be proper that surmises of them should either be given up, as ill founded, or at least reserved till superior instruments can be provided." The question, however, must be treated with caution. On account of the extreme delicacy of these objects, and because for a few years nobody else had succeeded in fishing them up, several continental astronomers were pleased to doubt whether Uranus had any satellites at all. But they must have had but a meagre notion of Sir William's powerful means, his skill in their application, and his method of deliberate procedure. A reference to the published descriptions of his discoveries must have convinced the most sceptical of the doubters; and there can be no misgiving in the mind of him who reads the papers in the 77th, 78th, 88th, and 105th volumes of the *Philosophical Transactions*, of the actual existence of objects, which the planet's approaching elevation to the northern portion of its orbit, and Lord Rosse's powerful telescope, will shortly confirm. Nor could Herschel himself gain the slightest glimpse of them until he laid aside the small speculum, and introduced the *front-view*, or method of using the reflecting telescope by looking with the eye-glass placed a little out of the axis, directly in at the mouth or front of the instrument without the interposition of a speculum: by this method a large accession of light is gained. Yet with all his ready adaptations, mark his care and judgment in "verifying a suspicion." He had caught a sight of some questionable objects on the 11th January, 1787, and he relates: "The next day, when the planet returned to the meridian, I looked with a most scrutinizing eye for my small stars, and perceived that two of them were missing. Had I been less acquainted with optical deceptions, I should immediately have announced the existence of one or more satellites to our new planet; but it was necessary that I should have no doubts. The least haziness, otherwise imperceptible, may often obscure small stars; and I judged, therefore, that nothing less than a series of observations ought to satisfy me, in a case of this importance." So far from doubting there being six satellites, because everybody cannot see them, it is highly probable that there are still more; but as Sir William Herschel says, "we shall probably not obtain a sight of them, for the same reason that the inhabitants of the Georgian planet perhaps never can discover the existence of our earth, Venus, and Mercury."

The satellites of Uranus move in a plane which is nearly perpendicular to that of the earth's orbit; and as far as has yet been ascertained, their nodal motions and the variations of their inclinations, if any, are very small. They appear to revolve, not in ellipses, as other satellites do, but in circles around the planet, so that they seem to glide around its poles instead of its equatorial parts. From what has been gathered among the attempts to investigate their movements, it is inferred that these minute moons seldom suffer eclipses; but as the plane in which they move must pass through the sun twice in the year, eclipses of them may happen at those times, and add variety to the appearance of the Uranian nocturnal firmament. But this is rather an analogy than a known fact, for their light has to traverse so vast an extent of space, as to be greatly enfeebled before it reaches us. To the surprise of all astronomers, their motion is retrograde, or contrary to the order of movement of all other bodies yet noticed; a phenomenon which damps every hypothesis relative to the primal cause of planetary actions. Elements for the whole were, however, computed, although those of the second and fourth being founded on real measurements; and the rest only conjectured. The inclinations are 89° 30′ or 90° 30′; and the ascending node will be 5^s 21°, or 8^s 9°, according as we select the first or second inclination. Laplace conceives that the first five of the Uranian satellites may be retained in their orbits by the action of its equator, and the sixth by the action of the interior satellites; hence he concludes, that the planet revolves about an axis very little inclined to the ecliptic, and that the time of its diurnal rotation cannot be much less than that of Jupiter or Saturn. The following table shows his estimate of their several sidereal revolutions, in mean solar days:

and by taking for unity the semi-diameter of the planet, equal to 1″·9, supposed to be seen at the mean distance of the planet from the sun, their distances result:

Herschel's Satellites.	Sidereal Revolution.		Mean Distance.
I.	5^d 21^h 25^m 20^s	5^d·8926	13·120
II.	8 16 57 47	8 ·7068	17·022
III.	10 23 02 47	10 ·9611	19·845
IV.	13 10 56 29	13 ·4559	22·752
V.	38 01 48 00	38 ·0750	45·507
VI.	107 16 39 56	107 ·6944	91·008

Sir William Herschel remained the sole authority for the existence of these moons and their anomalous peculiarities, for forty years; but Sir William was a host. In 1828, his son was the next who gained a view of them, after having prepared himself by keeping his eye in utter darkness for a quarter of an hour; and these two, with a third, were caught up by M. Lamont, with the gigantic refractor at Munich, in October, 1837. But they are indeed terrible objects to attack, and the utter hopelessness of seeing them with my means may be inferred from what is related under β^2 Capricorni, in the second volume of this work. When, however, I received a letter from Sir John, announcing to me his achievement, I was nearly as much gratified as he could have been, on thus breaking the blank in their history. His observations are detailed in an able paper, which is printed in the VIIIth volume of the *Memoirs of the Royal Astronomical Society;* and the periodic times of the second and fourth satellites, may now be safely depended upon, they being:

	Herschel I.	Herschel II.	Lamont.
II.	8^d 16^h 56^m 05^s	8^d 16^h 56^m 31^s·3	8^d 16^h 56^m 28^s·5
IV.	13^d 11^h 08^m 59^s	13^d 11^h 07^m 12^s·6	13^d 11^h 07^m 06^s·3

The enormous distance of 1,822,000,000 miles, has of course hitherto prevented the attainment of any very accurate knowledge of this planet's constitution. The principal physical circumstance brought to light, is one noticed by the elder Herschel, namely, that the satellites and small stars lose much of their lustre in the neighbourhood of the planet, and disappear when they arrive within a few seconds of it. This cannot depend on the atmosphere of the planet, since the phenomenon happens whether the satellite is before or behind it,—in the nearest half of their orbits, or in that which is furthest from us. No satisfactory cause has, as yet, been assigned for these disappearances; still Sir William's idea, that such dim objects may be rendered invisible by contrast when within the sphere of the planet's illumination is as good as any. The first and fourth satellites are subject to great variations of light; this cannot be owing to the changeable nature of the air, for Sir William says, that by comparing the brightness of one satellite with that of the other when they are seen together, the state of the air must be of equal clearness to both. From analogy, it may be presumed that they all rotate on their axes; but owing to the difficulty of observing them, we may long remain without any positive knowledge of their masses and motions.

§ 13. Comets ☄.

The discovery of these erratic bodies, and the determination of their paths, are so peculiarly within the scope of the amateur astronomer, that he will excuse my dilating a little upon them.

The term *comet*, from κόμη, hair, is applied to a heavenly body in the planetary region, moving in an ex-centric orbit, with a motion sometimes direct and at others retrograde, as it approaches to and recedes from the sun. Being generally surrounded by a faintly luminous vapour, in the form of a border of hair, to which the name of *Coma* and *Crinus* was given, the appellation has remained through all ages, but at times has been applied to mere atmospheric meteors*. Pliny says that comets were subdivided, according to their distinctive forms, into twelve classes, of which the principal are, *Pogonias*, bearded; *Lampadias*, torch-like; *Xiphias*, sword-like; *Pitheus*, tun-like;

* Some of our early writers mention *shode stars:* they mean comets, the word *shode* being a provincial term for hair.

Acontias, javelin-like; *Ceratias*, horn-like; *Disceus*, quoit-like; and *Hippias*, horse-mane-like.

Cometology can only be classed as a very recent branch of astronomy, since comets have heretofore been generally deemed occasional meteors, and the heralds of divine anger, by the *sages* of all nations and persuasions—worshippers of "Jehovah, Jove, or Lord." The uncertain periods of their occurrence, together with the seeming irregularity of cometary phenomena, have given a difficulty and even mystery as to their nature, which has perplexed philosophers from 4004 B.C. to 1844 A.D. The Chaldeans seemed to be of opinion that they were permanent bodies, which had stated revolutions as well as the planets, but in orbits considerably more extensive; on which account they are only visible when near the earth, and disappear when they ascend into the higher regions. It is also pretended that the Chaldeans were able to predict the appearance of these erratic bodies; but this is more than questionable, since the same authorities state that they could also, by the same art, foretell earthquakes; and Epigenes, the Babylonian astrologer, declared that his countrymen thought comets were caused by storms, an opinion from which he dissented. Anaxagoras, Apollonius Myndius, Epigenes, Democritus, and Zeno, considered comets as produced by the conjunction of many stars or planets in clusters; and the Pythagoreans held them to be nothing more than planets, which re-appear after long intervals, in the lower parts of their orbits, and which, at the vertex of the curve described, approach as near the sun as is the planet Mercury. Yet Aristotle, the very man who records this rational conjecture, gave a death-blow to Greek cometology, by teaching that comets consist of mundane exhalations raised to the upper regions of the air and there ignited; which homely origin for these magnificent celestials, obtained with the Peripatetics, and endured for ages, insomuch that there is not a word in Ptolemy's *Almagest* concerning comets, though there is enough, and more than enough, in those secondary works, the *Quadripatitum* and *Centiloquium*.

There were, however, as Pliny tells us, some among the ancients "who had juster notions," who took these visitors to be perpetual, and who believed that they move in proper orbits, but are never seen unless when left by the sun. Seneca, who was one of the most sagacious of the ancient cometologists, intimates that he thought comets were above the moon; that by their rising and setting there was something in common between them and the stars; and he declares his belief that, instead of being casual fires, they are among the eternal works of nature. "But why," asked he, "do we wonder that comets, so rare a spectacle in the world, should not yet be understood, or that their courses remain unknown, when they go and return after such prodigious intervals of space and time? It is now fifteen hundred years since the Greeks numbered and named the glittering stars: even now there are many nations who, to this day, know not the heavens but by sight, and are as yet ignorant why the moon wanes, or undergoes eclipses; and even among us these things have been but lately reduced to certainty. A time will come when those things which are now concealed shall be brought to light, by time and diligence, in future ages. A century is too short for searching those secrets, and all the years of man are required in the contemplation. Is it not grievous that we divide this brief span between serious and frivolous occupations? The time shall come, when our posterity will wonder that we were ignorant of things so manifest." And in a still more remarkable spirit of prophecy does his penetration, in *Quæst. Nat.*, l. vii., c. 26, thus predict the coming of a Newton: "Erit qui demonstret aliquando, in quibus cometæ partibus errent; cur tamen seducti a cæteris errent, quanti qualesque sint."

This promising state of inquiry fell into the decline which all knowledge experienced, in the dark ages that accompanied the fall of Rome, when imposture and superstition, taking advantage of ignorance, leaped into the high places. Thus it was that the Middle Ages became the birth-time of the terror inspired by the presence of comets: those strange visitants being then universally regarded as the harbingers of the great, more especially the calamitous, events of nations. Ammianus Marcellinus mentions, that among the Romans, comets were deemed portentous; but there is nothing in the more ancient writings to authorize a conclusion that they were regarded as objects of alarm in the earlier ages of the world. To be sure, Pope makes

Homer say, in describing Minerva's rapid descent from heaven, to break a truce between the Grecians and Trojans:

> As the red comet from Saturnius sent
> To fright the nations with a dire portent,
> (A fatal sign to armies on the plain
> Or trembling sailors on the wintry main,)
> With sweeping glories glides along in air,
> And shakes the sparkles from its blazing hair.

Now it so happens that there is not a word about a comet in the original; but the simile evidently alludes to a falling star. The Prince of Poets says, "And she rushed in haste from the peaks of Olympus, as the brilliant star emitted by the son of the sage Saturn, either as a sign to seamen, or to a broad array of hosts, and from which numerous sparks proceed." Pope, save his *trembling sailors*, makes a fine picture; but the passage is another instance showing that

> Our translators view
> In Homer more than Homer knew.

Superstition revelled triumphantly till Bacon, by his *Novum Organum*, and other splendid features of the *Magna Instauratio*, boomed off the quiddities of the Irrefragable Doctors, and placed intelligence again in the van. Still, while most other branches of science were resuscitating, the cometary phenomena were consigned to the prurient imaginations of moon-struck marvellers, crafty astrologers, and bigoted men of skill. They were long and largely regarded as the prodromi of plague, defeat, famine, floods, wrecks, and other desolating disasters; and they were held to be in amicable alliance with astrology, magic, geomancy, and all the other branches of mystical imposture; nor have the mists of superstition and prejudice yet wholly evaporated, as may be seen by referring to page 23. Paracelsus, that eccentric and bombastic *spagirist*, gravely insisted that comets were composed by angels, or spirits, expressly to foretell good or bad events. In a fine Norman Chronicle transcribed in the fifteenth century, recently showed to me by Mr. Thorpe, there is a curious exposition of the divine right of William to invade England: "How a star with three long tails appeared in the sky; how the learned declared, that such stars appeared only when a kingdom wanted a new king; and how the said star was called a *comette*." The opinions of M. Bodin, a learned French lawyer of the sixteenth century, were, if possible, yet more absurd; for he maintained that comets are spirits, or souls of illustrious men, which have remained upon the earth many ages as guardian angels, and being at last arrived on the confines of death, celebrate their last triumph, and are called to the firmament as flaming stars. "Cometes," saith Leonard Digges, in his *Prognostications* for 1556, "Cometes signifie corruption of the ayre. They are signes of earthquakes, of warres, of changying of kyngdomes, great dearthe of corne, yea a common death of man and beast." And he was well seconded by the astrological school. "Experience," quoth old John Gadbury, "is an eminent evidence, that a comet, like a sword, portendeth war; and an hairy comet, or a comet with a beard, denoteth the death of kings." The latter events seem to have formed the principal occupation of these mazy messengers*, for the aforesaid sage gives us a chronological register of their announcements for upwards of six hundred years; an account which he sums up thus, but in large Roman capitals: "As if God and Nature intended, by comets, to ring the knells of princes, esteeming the bells in churches upon earth not sacred enough for such illustrious and eminent performances." Many, who disregarded the uniform sublimity of the azure expanse in general, were startled at eclipses, meteors, and cometary bodies; and the full bearings of so evil an omen, as expressed by an old poet, were sufficient to make them quail:

The blazing star,
Threat'ning the world with famine, plague, and war:
To princes, death; to kingdoms, many crosses;
To all estates, inevitable losses;
To herdsmen, rot; to ploughmen, hapless seasons;
To sailors, storms; to cities, civil treasons.

And Milton, who lived after the days of Tycho Brahé and

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* Shakspeare, although he makes the Duke of Bedford suppose that comets import a change of rulers and states, introduces Calphurnia saying,

"When beggars die, there are no comets seen."

Cardinal Mazarine, when on his death-bed, being informed that a comet had appeared, exclaimed, "La comète me fait trop d'honneur."

Galileo, and was at once learned and philosophic, thus fans the popular prejudice:

> Satan stood,
> Unterrified, and like a comet burned,
> That fires the length of Ophiuchus huge,
> In th' arctic sky, and from its horrid hair
> Shakes pestilence and war.

Whiston and King, attempting to combine philosophy with religion, teach that the sun is the abode of the blessed, gathered from all the planets of the system; but they suppose that comets, which they ought to have made the carriers of their scheme, are so many places of punishment for the wicked, where, in the words of Milton,

> At certain revolutions, all the damn'd
> Are brought; and feel by turns the bitter change
> Of fierce extremes, extremes by change more fierce,
> From beds of raging fire, to starve in ice
> Their soft ethereal warmth, and there to pine
> Immovable, infix'd, and frozen round,
> Periods of time, thence hurried back to fire.

The last comet which was astrologically put before the public by an orthodox astronomer, was that mentioned on p. 23, when Messier concocted his noted treatise on the comet which attended at the birth of Napoleon. On the 4th of July, 1816, Dr. Pennada actually read, to the Institute at Padua, a detailed memoir showing "that the most remarkable political events have always been preceded, accompanied, or followed by extraordinary astro-meteorologic phenomena."

The Aristotelian doctrine of comets being meteors existing in our atmosphere, was prevalent till the days of Tycho Brahé. That excellent astronomer supported a true hypothesis on the subject: he proved by observations that the comet of 1577 had no sensible diurnal parallax, and therefore was not only far above the regions of our atmosphere, but much higher than the moon; that as *daughters of the planets*, they therefore participate in their nature; that few have come so near the earth as to show any such index, yet they all exhibit an annual parallax; the orbital revolution of the earth causes their apparent motion to appear very different from what it would be, if viewed from the sun, which demonstrates that they are much nearer than the fixed stars, which have no parallax. These conclusions were based on the comet of 1577, which was simultaneously observed by Tycho at Uraniburg, and Thaddeus Hagecius at Prague; these two places being nearly on the same meridian, and about 6° apart. Both astronomers measured the distance of the comet from a star in its vertical, and found their distances the same, consequently they both viewed the comet in the same point of the heavens, which could not have happened unless the comet had been in a higher region than the moon. Such was Tycho's opinion; but Hagecius considered it so bright and agreeable (*elegans et venusta*), as therefore to be sublunary. Delambre cannot see why it should be less beautiful for being nearer the earth: "Ici l'on pourrait, n'en déplaise à Tycho, trouver un reste de péripatétisme; car, pourquoi la comète serait-elle moins belle si elle était plus près de la Terre?" Tycho, indeed, was in some measure preceded by Kepler; but though the latter supposed comets to move freely through space, he could not precisely determine the tenour of the motion, and moreover ran a little wild as to their origin. He was followed by Hevelius, who, from his own accurate observations, concluded that they moved in parabolic trajectories.

James Bernouilli, the head of the celebrated knot of Swiss philosophers of that name, a man who "traversed the stars against his father's inclination," formed a new conjecture upon these wanderers. He viewed comets as the satellites of some most distant planet, which, either from its remoteness or smallness, is invisible to us; but that several satellites move round it, some of which descend so low as the orbit of Saturn, and become visible in their perigæum. Hevelius thought that comets are formed and condensed out of the grosser exhalations of the solar body. Descartes, to suit the general motion of his atomic universe, advanced another opinion: he held that comets are only stars which were fixed, like the rest, but becoming gradually covered with spots, and at length wholly deprived of their light, cannot keep their places, but are carried off by the vortices of the circumjacent stars; and in proportion to their magnitude and solidity, move in such a manner as to get within the reach of the sun's rays, and thereby become visible. Still comets confounded the Cartesian plenum, for they traversed the vortices in all directions without being affected by their imaginary currents.

But the insufficiency of these hypotheses is now proved by the more accurate scrutiny which was instituted by our illustrious countrymen, Newton and Halley. According to the theory of the former, comets are compact, solid, and durable; in fact, a species of planet, which moves in very oblique and excentric orbits in every direction with the greatest freedom, persevering in its motions even against the course and direction of the planets. Comets move in ellipses, having one of their foci in the centre of the sun, and by the radii drawn to the sun, describe areas proportionate to the times. As to their magnitudes, the estimates are not sufficiently accurate to be depended upon; for it does not appear that a proper distinction has yet been made between the nucleus and its atmosphere. It is true, that obstacles have presented themselves to baffle inquiries which were purely theoretical; but by legitimate hypotheses, which approximate to the truth, results are approached which, if not strictly true, are sufficiently correct to be acted upon.

The variety which occurs in the form of the cometary orbits, in their angular inclination to the plane of the ecliptic, in their ex-centricity, and in the direction of their movement, forms a striking circumstance in the solar system; and one from which it has been inferred that different final causes must have presided over the formation of the planets and the comets. In the determinations to which the former are subject, it is seen that their orbits are nearly circular, and but little inclined; that all of them, both primary and secondary, move from west to east, and all those the rotation of which we have been able to observe, turn on their axes in the same direction. "Thus," says Laplace, "the planetary system displays to us forty-two movements in this direction; and it is four millions of millions to one, that this arrangement was not owing to chance."

The principal orbital difference between comets and planets, is the great elongation of the former, and their much greater variety of inclination, while in the latter it never exceeds 35°. In some of their physical characteristics, such as size and nebulosity, comets resemble the asteroids; and that of 1682 was said even to exhibit phases. Hevelius estimated one as having a diameter equal to that of the moon. The celestial prodigy of 1472 described an arc of 120° in one day, if we are rightly informed. As a comet approaches the sun, the coma becomes brighter, and at length shoots out with a long train of luminous transparent vapours, keeping in a direction opposite to the sun; and this train is called the tail. When a comet makes its appearance, it is only for a very short period, seldom exceeding a few months, and sometimes only a few days. On retiring from the sun, the tail decreases; and those comets which never approach very near to the centre of our system, have nothing but a coma or nebulosity round them during the whole time of their continuance in view. The length and form of the tail are very different; sometimes it extends only a few degrees, and at others to more than 90°; for that of 1618 is said to have subtended an angle of 104°, so that while the body might have dipped below the horizon, the tail would still reach over the zenith, and beyond it. In others the tail consists of diverging streams of light. One which appeared in 1744, consisted of six of these streams, all proceeding from the head, to a distance of nine millions of miles, and all a little bent in the same direction; but the well-known drawing of this phenomenon by M. Chézeaux, though honoured with the adoption of Delambre, bears internal evidence of a difference of opinion between nature and the artist.

The comet of 1811 was the most beautiful that had been seen for many years; and I remember it with pleasure, as having relieved the monotony of many a night-watch in a line-of-battle ship under Lord Exmouth off Cape Sicie, when blockading the French fleet at Toulon. This splendid object was extremely interesting, not only from its appearance, but from the length of time it remained visible, nearly ten months, which was longer than any other on record; and, therefore, none has afforded such certain means of information with respect to its aspect, and its orbit, especially during the time it was circumpolar, and therefore in constant apparition. Both Sir William Hershel and Schroeter inferred that it shone by inherent light, from the variations in the brightness of its nucleus, and the rapid coruscations of its tail; but that opinion was not generally received. When this comet was in perihelion, its distance from the sun was about 98,000,000 of miles, and 140,000,000 from the earth. The gaseous envelope of its head was 30,000 miles thick, and the centre of the nucleus was separated from the interior surface of the surrounding discus, the *head veil* of Schroeter, by a space of 36,000 miles; while its central brilliant spot was estimated at 500 miles in diameter. Its tail was composed of two diverging beams of pale light, slightly coloured, which made an angle of fifteen or twenty degrees, and sometimes much more; both of these were a little bent outward, and the space between them was comparatively obscure. This tail varied at its greatest extension, from nearly as long as the distance of the sun from the earth to 130,000,000 of geographical miles in length; and some observations made it even longer. Sir William Herschel, in the 102nd volume of the *Philosophical Transactions*, p. 122, thus describes its elastic atmosphere:

In every instrument through which I have examined the comet, I perceived a comparatively very faint or rather darkish interval surrounding the head, wherein the gradually diminishing light of the central brightness was lost. This can only be accounted for by admitting a transparent elastic atmosphere to envelope the head of the comet.

Its transparency I had an opportunity of ascertaining the 18th of September, when I saw three very small stars of different magnitudes within the compass of it; and its elasticity may be inferred from the circular form under which it was always seen. For being surrounded by a certain bright equidistant envelope, we can only account for the inequality of the distance by admitting the interval between the envelope and the head of the comet to be filled with an elastic atmospherical fluid.

The apparent difference in the length and lustre of the tails of comets, has given rise to a popular division of these singular bodies into three kinds; viz. *bearded*, *tailed*, and *hairy:* but this division rather relates to the successive circumstances of the same comet, than to the phenomena of different ones. Thus, in general cases, when the comet is east of the sun, and seems to move from him, it is said to be bearded, because the light precedes it in the fashion of that crinite appendage; when it sets after the sun, it is said to be tailed, because the train of light follows it in that form; and when the sun and comet are diametrically opposite, the earth being between them, the train or tail is hidden behind the body of the comet, except the extremities, which being broader than the body, appear to surround it like a coma, or border of hair, and on this account it is called hairy. Tail, however, is a misnomer, since the train thus designated sometimes precedes the comet, and points directly towards the sun. The conjectures which have been advanced respecting the nature and cause of these appendages, are curious, and in many instances equally plausible and ingenious. The illustrious Dane, Tycho Brahé, supposed the tail to be occasioned by the rays of the sun passing through a diaphonous nucleus. Kepler thought it was an atmosphere driven behind the comet, by the force of the solar rays. Newton maintained that the tail was a thin vapour, furnished by the atmosphere of the body, ascending by means of the sun's heat, as vapour does from the earth. This hypothesis was founded on the supposition which then prevailed, that the sun was a vast wilderness of fire; but as the truth of this supposition was soon afterwards doubted by some, and abandoned by others, the notion was never stoutly advocated. The principal objection to Newton's inference appeared to be the difficulty of supplying such prodigious vapours from the atmosphere of a comet: this he removed by a computation which he made on the expansive power or force of an elastic fluid; whence it followed, that a cubic inch of common air, at the distance of half the earth's diameter, would necessarily expand itself so as to fill a space larger than the whole region of the planets: even "to the very sphere of Saturn, and far beyond." Euler was persuaded, that the tail is produced by the impulse of the solar says driving the atmosphere from the comet; and that, therefore, there is a great affinity between these tails, the zodiacal light, and the aurora borealis. Indeed, they often increase with extraordinary rapidity; that of the comet of 1680, being emitted from the comet's body to the length of twenty millions of leagues in two days. Most reasoners seem now to consider them as consisting of electric matter; and this would account for the undulations and other appearances which have been noticed, as, for instance, that extraordinary one seen by M. Chladni, in the comet of 1811, when certain undulatory ebullitions rushed from the nucleus to the end of the tail, a distance of more than ten millions of miles, in two or three seconds of time! Yet its substance is so extremely rare, as to pass over celestial bodies without any diminution of their splendour; and these tails have a very faint and languid appearance in the telescope. The comet which traversed our system in 1824, exhibited the extraordinary phenomenon of two tails, diametrically opposite to each other; that towards the sun being smaller and fainter than the one in the opposite position. P. Bienewitz, better known as Apian of Ingoldstadt, concluded, from what he ascertained in the instance of the comet of 1531, that the tails are always opposite to the sun, and in the direction of a line joining the centres of the sun and the comet; but more exact observation shows that as comets approach their perihelion, the tails are gradually bent more or less towards the region they have left, as if there were a resisting medium. The tail of the comet of 1689 assumed the form of a Turkish scimetar; and that of the comet of 1744, was bent like the quarter of a circle. Seneca is the earliest observer whom I remember to have recorded the stars' having been seen through them.

But comets have been observed, whose disc has been as clear, round, and sharply defined, as that of a planet, without either tail, beard, or coma. Some of these appeared of the magnitude of the bright stars, and some immensely larger. That which Hevelius viewed in 1652, did not seem to be less than the moon, though it was very deficient in splendour; and Seneca relates, that one which appeared after the death of Demetrius, king of Syria, was but little inferior in magnitude to the sun himself; being a circle of red fire, sparkling with such a light as to surmount the obscurity of the night. And he describes an enormous one which he himself saw, in the "happy reign of Nero," for six months together. Most comets, however, have dense and dark atmospheres surrounding their bodies, weakening the solar rays which fall upon them; but within these the nuclei appear, which, though sometimes nebulous, are often of sufficient splendour to justify a belief in their corporeity. Yet this is a point upon which it may be said, in round but distinct terms, we know nothing: the nuclei may be altogether gaseous, or, in many instances, solid and opaque; which, as we shall presently see, is nearly the conclusion at which M. Arago, after a strict investigation, arrived. The physical composition of comets is, therefore, still a mystery, but will henceforth be the object of earnest study. I have seen none, except Encke's and Biela's, which have not had a condensed spot in the head; but I never pursued the study of them with sufficient means and attention, to enter upon the inquiry, as to whether these spots were luminous in themselves, or shining only by a borrowed light,—a question which the detection of phases in a comet would satisfactorily set at rest. Sir John Herschel regards them as vast masses of vapour, susceptible of being penetrated through their whole substance by the solar beams, and reflecting them alike from their interior parts and their surfaces. "Nor will any one," he continues, "regard this explanation as forced, or feel disposed to resort to a phosphorescent quality in the comet itself, to account for the phenomena in question, when we consider the enormous magnitude of the space thus illuminated, and the extremely small *mass* which there is ground to attribute to these bodies. It will then be evident that the most unsubstantial clouds which float in the highest regions of our atmosphere, and seem at sunset to be drenched in light, and to glow throughout their whole depth as if in actual ignition, without any shadow or dark side, must be looked upon as dense and massive bodies compared with the filmy and all but spiritual nature of a comet." Yet he owns that a minute stellar point *has* been seen in some, indicating the existence of a solid body. As to the assertion of stars' having been seen through the nucleus, were it not for the remarkable instance recorded by Professor Struve, in 1828, I should say that the fact had never yet been absolutely proved, since it is next to impossible to define the precise limit of a nucleus in an increasingly dense nebulosity; and, as in the case of the projection of a star on the lunar disc, alluded to in page 133, some effect of refraction, or incidence of light, may represent a star as being on the disc of a comet, which is actually behind it. It is not a little singular that, on the very night when Struve saw a star of the 11th magnitude through the central part of the comet, M. Wartmann, at Geneva, saw the same body eclipse a star of the 8th magnitude: the instrument of the latter, however, bore no comparison with the Dorpat telescope.

Comets have been seen to transit the disc of the sun like dark spots, of which the instance described by Gambart is one of the most remarkable. That gentleman had calculated, that a comet which he had observed would pass across the sun on the morning of the 18th of November, 1826; and both he and M. Flaugergues were successful in witnessing the phenomenon. From all the evidence upon this point, M. Arago deduces the following conclusions:—1. That there exist some comets destitute of the nucleus. 2. That there are other comets, the nuclei of which are transparent. 3. That there are also comets which are more brilliant than the planets, the nuclei of which are probably solid and opaque.

Long before anything was known of the nature of the cometary orbits, observers, who were not even provided with tolerable instruments, had noted various particulars respecting them; such as the point in the heavens where the comet most nearly approximated the sun, the inclination of its orbit to the ecliptic, its distance from the sun, the time of its perihelion, the precise point where its orbit crossed that of the earth or the ecliptic, and whether its motion were direct or retrograde. Halley, prompted by the incident related at p. 54, and moreover induced by Newton's hint in his *Principia*, l. iii., prop. 41, set about the laborious task of examining the scattered notices given by ancient and modern writers respecting comets, amounting in number to about four hundred. Of these, twenty-four only had been observed with the degree of accuracy necessary for his inquiry, from the earliest record to his own time: he then collated all the accounts, and framed elements which in the end proved equally satisfactory and singular: with few exceptions, it appeared that these bodies had passed within the earth's shortest distance from the sun, and the greater portion of them had moved in a retrograde or opposite path to the planets. "I find nothing," said he, "that can be of any service in this affair before the year 1337, at which time Nicephorus Gregoras (a Constantinopolitan historian and astronomer) did pretty accurately describe the path of a comet among the fixed stars, but was too lax as to the account of the time; so that this most doubtful and uncertain comet only deserves to begin our catalogue, because of its appearing upwards of four hundred years ago."

In the month of December, 1680, a great comet appeared above the horizon of London, which particularly fixed the attention of astronomers, it being the finest which had been seen since the revival of learning; it carried a train of vast extent, but was then already retreating from the sun, and after four or five months ceased to be perceptible. Halley is said to have been the first who saw this, being then between Calais and Paris, and it seems to have been that for which he began his elliptical calculations, since he says, in the well known *Astronomiæ Cometicæ Synopsis*, "compos factus methodi qua calculus in orbe elliptico quantumvis eccentrico accurate et perfacile absolvitur." This ex-centric comet had been observed at Weida, in Germany, by the intelligent George Dörfel, in the preceding November, when it was approaching the sun; and from the data which his observations furnished, he proved that it was the same which was soon afterwards seen returning from the sun; in the words of Montucla, "the same which, after approaching the sun and losing itself in his rays, had again appeared in moving from him; and, aided by the light of Hevelius, Dörfel showed that its course was a parabola having the sun in its focus." From a similarity of aspect and the place it occupied in the heavens, Halley inferred that this was the fourth recorded appearance of the comet which astonished Rome at the death of Cæsar, and had since revisited us at intervals of 575 years; and by trying back, it was found that remarkable comets were noted to have been seen 44 years B.C., and 531, 1106, and 1680 A.D. These intervals were equal; and to verify the possibility of the objects being the same, Halley calculated a new table which was necessary for an ellipse, whose major-axis corresponded to a revolution of 575 years; and from the dimensions of this ellipse, it was calculated that the comet, when in the perihelion point, was at a distance from the surface of the sun less than one sixth of the semi-diameter of that luminary. Halley had a very strong feeling as to the perils of a cometary collision, and was alarmed on discovering, that had this terrific body come but thirty-one days later to its perihelion, it would have been scarcely as far from our globe as the quantity just mentioned; and he earnestly paints the consequences of a shock, in reducing this fair earth to its primeval confusion, unless Divine Providence should avert them: "Collisionem vero vel contactum tantorum corporum ac tanta vi motorum (quod quidem manifestum est minime impossibile esse) avertat Deus O.M.; ne pereat funditus pulcherrimus hic rerum ordo et in chaos antiquum redigatur *." Through all apprehensions, however, the arduous computation advanced: by the aid of his table, Halley found nineteen places between the 3rd of November, 1680, and the 9th of March, 1681, which did not differ from those which had been observed by more than $-2' 31''$ of longitude, and $+2' 29''$ of latitude, the mean of the whole errors being $-35''$ in longitude, and $-6''$ in latitude. Now whether this remarkable accordance were accidental or not, it had the effect of giving spirit to the laborious inquiry.

I must here beg permission to digress for a moment. The discussion as to whom we are indebted for the first idea of comets moving in a parabola, or in an ellipse, is not complete without recollecting that, in a letter from Sir William Lowër to his "especiall good friend Mr. Thomas Harryot," dated the 6th of February, 1610, the intelligent knight mentions that he has just been reading Kepler—a meritorious undertaking for a country gentleman in those days—and incidentally makes the lucid remark that he is in love with the elliptical *iter planetarium*, "for methinkes it shewes a way to the solving of the unknown walkes of comets. For as his ellipsis in the earth's motion is more a circle, and in Mars is more longe, and in some of the other planets may be longer againe, so in those commets that appeare fixed the ellipsis may be neere a right line." This extraordinary allusion is, I think, greatly undervalued by the late excellent Professor Rigaud, who, in his *Supplement to Dr. Bradley's Miscellaneous Works*, will not admit of such an observation's being a discovery,

* Though this idea was so strong in Halley's mind, that he published two essays on the Deluge, yet the feeling of the astronomer peeps through his argument. He thought that in F. Duillier's suggestion, of determining the solar parallax from the motion of comets which might approach very near the earth, the opportunity was rather to be wished for than deprecated.

saying, "The Georgium Sidus was seen by Flamsteed, Mayer, Lemonnier, and Bradley, but no one would claim for either of them the discovery of the planet, in preference to Sir William Herschel." But surely this instance only alludes to an occurrence so entirely accidental, that Sir William himself took the object to be a comet; while Lowër's remark is the result of an exertion of mind, and at least anticipates the celebrated G. A. Borelli, who has been supposed to precede Newton in the conception of cometary orbits by fifty-four years. My friend, moreover, in his warmth to vindicate Oxford, and his anger against Baron de Zach, has assuredly borne hard upon Harriot, and he confesses that there are still many manuscript papers of his in the British Museum, which he had not time to investigate, as well as that the Baron had access to others which he had not seen. I had perused Rigaud's written statement, and was able to suggest an explanation or two; and when it was afterwards printed, he wrote to me, on the 28th of October, 1833, saying, "I know you are an old correspondent of the Baron de Zach; I must, therefore, endeavour to disarm any hostility which you may feel against any remarks on him, which I now venture to send to you. If you take the trouble of reading them, which we will leave an open question, I beg you will keep in mind, that my attack is purely defensive. I have done my best to beat him off, but I have not retorted by carrying war into the enemy's country."

Under this friendly premonition, I read the *Supplement* with pleasure and instruction, although I cannot but look upon the negative established, as a positive proof of the strong claims of Harriot. I admitted, at p. 174, that Professor Rigaud had confuted Baron de Zach's assertion, that Harriot had discovered the satellites of Jupiter; but the Baron appears, by Rigaud's showing, only to have mistaken the application of a date upon one of the papers. The satellites were not seen, it seems, till the 17th of October, 1610, instead of the 16th of January of that year; but the regular observations of them from thence to the 28th of May, 1611, are extremely valuable, as being actually the earliest original manuscripts on the subject. Harriot was remarkable for unremitting diligence in the pursuit of knowledge, and seems to have been the first who systematically observed the solar spots. It is shown that he had, previously to 1610, thrown out the idea, from analogy, of the possibility of secondary bodies' moving unseen about the superior planets; and on the 4th of March, 1611, Sir William Lowër, in writing of the *Joviall starres*, says, "That you have made so manie excellent observations of them I am most glad of, for you have gotten the starte of all in limitinge their periods." Harriot was a leader in the introduction of Algebra, preceded Ghetaldi on specific gravity, and wrote a book on *The Doctrine of Nautical Triangles.* He examined the surface of the moon with his "trunk," or "perspective cylinder, of $\frac{20}{1}$ of 14′ dyameter," in July, 1609; and, from his agency, telescopes were sold in London in 1610. But his claims to esteem cannot be better summed up than in an incidental passage of one of Sir William Lowër's letters, erroneously ascribed by Zach to Lord Percy:

Kepler I read diligentlie, but therein I find what it is to be so far from you. For as himselfe he hath almost put me out of my wits, his aequants, his sections of excentricities, librations in the diameters of Epicycles, revolutions in Ellipses, have so throughlie seased upon my imagination as I doe not onlie ever dreame of them, but oftentimes awake lose myselfe, and power of thinkinge with too much wantinge to it, not of his causes, for I cannot phansie those magnetical natures, but aboute his theorie which methinks (although I cannot yet overmaster manie of his particulars) he establisheth soundlie, and as you say overthrowes the circular astronomie. Doe you not here startle, to see every day some of your inventions taken from you; for I remember long since you told me as much, that the motions of the planets were not perfect circles. So you taught me the curious way to observe weight in water, and within a while after, Ghetaldi comes out with it in print. A little before Vieta prevented you of the gharland for the greate invention of algebra. All these were your deues and manie others that I could mention; and yet too great reservednesse hath robd you of those glories.

To return to the great comet of 1680. It is supposed to have approached nearer to the sun than any other that is known, while its aphelion distance had not been less than twelve billions of miles, or 127,000 times the earth's distance from the sun. It descended from the regions of space towards the sun with a surprising velocity, being at the lower apsis at a rate of 880,000 miles per hour, almost in a straight line, and ascended in a similar manner, remaining in sight four months, with a tail 120,000,000 of miles in length! Had the centrifugal or projectile force been arrested at its perihelion point, which must have been in a dense portion of the solar atmosphere, this tremendous body was then so close, only 584,000 miles from the sun's centre, and 144,000 from its surface, that it might have fallen upon that luminary in less than three minutes: and appearances indicate that this may one day be its fate. It was by this comet that Sir Isaac Newton proved the fallacy of the hypothesis which supposed such bodies to consist of solar exhalations; for the heat of the sun is as the density of its rays, or reciprocally as the square of the distances of places from that luminary. Wherefore, since the distance of the comet, on the 8th of December, was observed to be to the distance of the earth from the sun as 6 to 1000; the sun's heat in the comet at that time, was to his heat with us at midsummer, as 1,000,000 to 36. Now the heat of boiling water being little more than three times that of our dry earth, when exposed to the midsummer rays; and assuming the heat of red-hot iron to be above three or four times that of boiling water, Newton concluded that the heat of the body of the comet, in its perihelion, must be near two thousand times as great as that of red-hot iron; and it followed, that a globe of red-hot iron, of the dimensions of our earth, would scarcely cool in fifty thousand years. Let, then, the comet be supposed to cool a hundred times as fast as that metal, yet, since its heat was two thousand times greater, if it were of the same magnitude with the earth, it would not cool in a million of years. This comet seems to have been particularly studied by Newton, who, however, steered a little wild as to replenishing the sun and stars by means of such wanderers; for instance, in the remarkable conversation which took place between him and his nephew in 1724, in the eighty-third year of the philosopher's age, Mr. Conduitt says:

I asked him, why he would not publish his conjectures as conjectures, and instanced that Kepler had communicated his; and though he had not gone near so far as Kepler, yet Kepler's guesses were so just and happy, that they had been proved and demonstrated by him. His answer was, "I do not deal in conjectures." But, upon my talking to him about the four observations that had been made of the comet of 1680, at 574 years' distance, and asking him the particular times, he opened the *Principia,* which lay on the table, and showed me there the particular periods, viz., first, the Julium Sidus, in the time of Justinian, in 1106, and in 1680.

And I, observing that he said there of that comet "incidet in corpus solis," and in the next paragraph adds, "stellæ fixæ refici possunt," told him I thought he owned there what he had been talking about, viz., that the comet would drop into the sun, and that fixed stars were recruited and replenished by comets when they dropt into them; and, consequently, that the sun would be recruited too; and asked him, why he would not own as freely what he thought of the sun, as well as what he thought of the fixed stars. He said, "That concerned us more;" and laughing, added, "that he had said enough for people to know his meaning."

While the sagacious Halley was incessantly occupied with his problema *longe difficillimum*, the comet of 1682 fortunately made its appearance; and he observed it with such skill as to determine its orbital inclination, the position of its line of nodes, together with the longitude, distance, and time of its perihelion. With these valuable elements, he soon detected the striking resemblance between its orbit, and that of the comets which he had tabulated for 1607 and 1531; he therefore came to the conclusion that they were one and the same body revolving in an elliptical course round the sun, in a period of seventy-five or seventy-six years. This is the comparison:

Elements.	1531.		1607.		1682.
Longitude of ascending node - -	49° 25′	..	50° 21′	..	51° 16′
Inclination of orbit - -	17° 56′	..	17° 02′	..	17° 56′
Longitude of perihelion - -	301° 39′	..	302° 16′	..	302° 52′
Perihelion distance, earth as unity -	56° 700′	..	58° 680′	..	58° 328′
Perihelion passage - -	Aug. 24.	..	Oct. 16.	..	Sept. 4.
Distance from perihelion to ascending node	107° 46′	..	108° 05′	..	108° 23′
Motion - - -	*retrog.*	..	*retrog.*	..	*retrog.*

From these records it appeared, that there existed a difference in their returns which required investigation: the interval between the perihelion passages of the first and second comet being fifteen months longer than that between the second and third. At the time that Halley made this comparison, the theory of gravitation was in its infancy, and the laws of planetary disturbance had not received a general assent. In this dilemma Halley happily conjectured what had not yet been proved, that the orbit might have been influenced by the attraction of the remote planets; and after making an allowance, *lævi calamo*, for the effect of Jupiter, he boldly predicted that the comet would re-appear towards the end of 1758, or the beginning of the following year. He was so satisfied that his assumption was upon sound principles, that he desired, when the comet should return, all would remember that the author of the investigation was an Englishman: "Hoc primum ab homine Anglo inventum fuisse non inficiabitur æqua posteritas*." This announcement was received with extraordinary interest, as a test for deciding whether these bodies obeyed the general laws of nature, with permanence and regularity; and the consequent triumph of the Newtonian doctrines, proved that design is manifested in the infinity of the Creator's power:

> At His command, affrighting human kind,
> Comets drag on their blazing length behind:
> Nor, as was thought, do they at random rove,
> But in determined times, through long ellipses move.

It was now no longer doubted, that the comet observed in each of these years was the same, although its aspect was very different at each apparition. In trying back for the preceding epochs of this body, the earlier appearances are only connected, by somewhat unequal intervals, with the celestial phenomena alluded to in historic records; and this recurrence is the sole test of their presumed identity. It is thus conjectured that the frightful and exaggerated comet, exceeding the sun in splendour, which heralded the birth of Mithridates, about 130 years B.C., may have been Halley's. So also with another, which was seen for forty nights in China, about the year 248 A.D.; and it may have been that which appeared in Virgo in 324. The year 399 was a calamitous epoch, and the historians mention the comet which then appeared, with terror, as a celestial monster of prodigious magnitude and horrible aspect, dashing as it were its hair on the earth: both this, and the one which appeared for twenty nights in 855, agree with Halley's intervals. In 930, it returned, in compliment, as the chroniclers think, to the

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* It must be remarked, that Halley confesses his calculations are derived from the views which Newton, *Geometrarum Princeps,* had explained in his *Principia.* "Tanti viri vestigia insecutus," ait, "eandem methodum calculo arithmetico accomodare aggressus sum, nec irrito conamine." But so large an amount of intelligence, assiduity, and practice, was required to accomplish this "arithmetical computation," that Mr. Airy thinks Halley was probably the only person in the world who was competent to the task.

redoubtable Countess Marozia, who elevated her natural son to the papacy. In 1006, this comet was seen by 'Alí Ben-Rodwán, making its appearance with an immense curved tail, which was compared to a scythe; but though it seems to have been seen in 1155 and 1230, no exact particulars of its aspect, by which it could be identified, are recorded, except that the Chinese writings describe it as prodigious at the latter date. The comet re-appeared in 1305; but so far from bearing heat, as popular prejudice supposes these bodies to do, Germany, France, and Italy, were suffering under intense cold; while in England, a severe frost in June destroyed the corn and fruits. In 1379, a comet became visible, which had strong pretensions to be Halley's; and M. Biot has shown that it was methodically observed in China. In 1456, it came with a tail of 60° in length, and of a vivid brightness; which splendid train affrighted all Europe, and spread consternation in every quarter. To its malign influences were imputed the rapid successes of Mahomet II., which then threatened all Christendom. The general alarm was greatly aggravated by the conduct of Pope Callixtus III., who, though otherwise a man of abilities, was but a poor astronomer: for that pontiff daily ordered the church-bells to be rung at noon-tide, extra *Ave Marias* to be repeated; and a special protest and excommunication was composed, exorcising equally the Devil, the Turks, and the Comet. By the way, while the *cometa monstriferus* was still in sight, Hunniades, the Pope's general, gained an advantage over Mahomet, and compelled him to raise the siege of Belgrade; the remembrance of which Callixtus immortalized, by ordering the festival of the Transfiguration to be religiously observed throughout the Christian world. Thus was established the custom, which still exists in Catholic countries, of ringing the bells at noon; and perhaps it was from this circumstance that the well-known cakes made of sliced nuts and honey, sold at the church-doors in Italy on Saints' days, are called *comete*.

We have now approached the time when the returns of Halley's comet are identified to a certainty, although its aspect has varied at each appearance. When it was seen in 1531, in Cancer, it was of a bright gold colour; in 1607 it was dark and livid; in 1682, it was again bright; and in 1759, it was pale and obscure. In 1607, it was examined in the "perspective cylinders" of Sir W. Lowër and Harriot; but all the gazers were not equally instructed, for it was accused of causing inundations and severe frosts; and is thus described by a sage of that day: "Its head was not of an equal roundness, but here and there exuberating. Its apparent magnitude greater than that of any of the fixed stars or Jupiter. Its light was pale and waterish, like that of the moon. Its tail was somewhat long and thick, like a flaming lance or sword. The effects that followed this comet: The Duke of Lorraine died. A great war between the Swedes and Danes." In 1682, it seems, the comet only betokened "woe to all those of the shaven orders," with a hint that the Turks were to take Venice.

While the multitude were thus *reasoning* upon comets, Halley's confident prediction had caused very different speculations among geometers. That energetic philosopher, however, did not live to see the verification of his noble prophecy; having sunk, full of years and honours, seventeen years before the event. Others worked after a fashion upon cometary orbits, but Halley alone went methodically upon the Newtonian principles; and he was succeeded by Bradley, in the proper method of calculating these intricate phenomena. This method, however, was not practised out of England till 1743, when Maraldi first had the courage to separate himself from the strong Cartesian faction, which held French science in bondage. In the meantime a triumvirate of illustrious mathematicians, Clairaut, Euler, and D'Alembert, had engaged themselves in investigating the question of the "three bodies;" that is, to determine the paths described by three bodies, projected from three given points, in given directions, and with given velocities; their gravitating forces being directly as their quantities of matter, and inversely as the squares of their distances. The object of this problem, is to find their disturbing effects upon each other. Having succeeded in obtaining a solution, Clairaut, in 1757, undertook the severe task of computing the effect of the perturbations of the principal planets through a period of 150 years; and, extending Newton's application of his theory, applied the results to detect the influences of Jupiter and Saturn upon Halley's comet. The operose calculations necessary for the several conditions which Clairaut was investigating, were undertaken by M. Lalande, though Bailly has omitted to name him in his account of the undertaking; and he was assisted by Madame Lepaute, wife of a Parisian watch-maker of that name: "During six-months," writes Lalande, "we calculated from morning to night, sometimes even at meals; the consequence of which was, that I contracted an illness which changed my constitution for the remainder of my life. The assistance rendered by Madame Lepaute was such, that without her we never should have dared to undertake this enormous labour; in which it was necessary to calculate the distance of each of the two planets, Jupiter and Saturn, from the comet, separately for every successive degree, for 150 years." The result was, that the comet would be retarded 100 days by the attraction of Saturn, and 518 by that of Jupiter; so that in November 1758, when the comet was already expected, Clairaut announced that it would arrive at its perihelion on the 13th of April, 1759. Aware of the numerous imperfections of calculation which he necessarily laboured under, he admitted the possibility of his prediction's proving erroneous to a few days, one way or other: "Any one may think," said he, "with what caution I venture on this publication, since so many small quantities, unavoidably neglected by the methods of approximation, may very possibly make a month's difference." By subsequent corrections, this error was reduced to nineteen days in the seventy-six years; and Laplace has shown that it would have been thirteen days only, had the mass of Saturn been as well known as it is now. That the comet, as will presently be seen, appeared in December, 1758, and reached its orbital point nearest the sun on the 13th of March in the succeeding spring, or thirty days before the presage, only inspires reverence for the profound computation, and the prodigious pains employed; and when we recollect that the computers did but approximate to the force of Saturn, and were not aware of the existence of Uranus, the successful labours on this comet may be classed among the greatest intellectual victories of man.

Such of my readers as have contemplated this matter only through the medium of Lieutenant Stratford's unrivalled Appendix to the *Nautical Almanack* for 1839,—where a singularly accurate amount of all the perturbations, the variations of the elements, and the equations of condition for Halley's comet, are brought to his hand,—may not view this undertaking as one of such laborious difficulty. But to comprehend the delicacy of these inquiries, even at present, it must be recollected that, besides the slight angle of their orbital planes, the planetary ellipses are of exceedingly small ex-centricities, so that they approximate very nearly to a circle; but the elliptic orbit of a comet may lie in an infinite variety of positions in respect to the sun, and yet in all those have its focus in him. In the ordinary theory of the planetary perturbations, therefore, the ex-centricity and inclination being small, it is convenient to expand the expressions into infinite series of co-sines of multiples of the mean longitudes,—the co-efficients proceeding by powers of the ex-centricities and inclinations: but in the case of a comet, where these elements are so considerable, a finite expression must be used; and this can be obtained only by keeping one in the form of a function of the true longitude and radii vectores. But the accurate integration of all the consequent expression is hardly possible, and the computer therefore resorts to the method of integration by quadratures. For this purpose, the value of the differential co-efficients is calculated for small intervals of time, each is multiplied by the length or number of units which that interval contains, and all the products are added. When the result is gained, it is not as with the changes of the planetary orbits which must return in certain cyclical periods for ever. what the cometary system is at any given time, it is very unlikely ever to be again, so that the geometer also must perpetually change his plan of proceeding. It will be seen that it requires the full energy of an elevated mind to undertake these intricate operations, for the use of the few who derive real pleasure from such abstruse subjects, and of the still smaller number of persons who can follow their recondite reasonings.

Clairaut is considered as having published his announcement somewhat prematurely, from fear of being anticipated by the arrival of the comet, his calculations being read to the Academy of Sciences, on the 14th of November, 1758. And he was but just in time, for on the Christmas night following, the wanderer was detected by George Palitzch; not, however, as stated by Delambre, with the naked eye, but with an 8-foot telescope. Indeed, there has been altogether a mistake about this gentleman: instead of being a shepherd or peasant as usually represented, he was a substantial farmer, and an able amateur-astronomer, in the neighbourhood of Dresden. He had, however, according to Baron de Zach, who knew him personally, a strong sight, and was in the habit of surveying the heavens with his naked eye. A few days after he had made the discovery, the comet was caught up by an observer at Leipzic, who, unwilling to have rivals, kept it secret. Within a month after this, it was seen by the conductors of all the principal observatories in Europe; but it was so pale and obscure, as well as being in an unfavourable position, and without a tail, that there is no actual record of any one's having seen it with the naked eye, before it plunged into the sun's rays. Indeed, it was so near the horizon that Messier, who, misled by Delisle, had been searching for it nearly two years, saw it with some difficulty in his 4½ foot Newtonian reflector: it afterwards became a little brighter, but, though tolerably large, was still faint and ill-defined. When it had doubled the sun, and emerged from its rays, towards the end of March, it became of the size of a large star, but still without any appearance, to European observers, of that tail which had formerly startled all nations. However, during the month of April, when that appendage ought by analogy to have been the longest, the comet was far from the earth, and only appeared in the twilight, which may have eclipsed its faint light. But it is now known that the same comet may, at successive returns to our system, sometimes appear tailed, and sometimes without a tail, according to its position with respect to the earth and the sun; and there is reason to believe that comets in general, from some unknown cause, decrease in splendour in each successive revolution. The position or place of the observer, too, has considerable effect, for we have the authority of two French astronomers, who watched it carefully,—namely, Cœur-Doux, at Pondicherry, and La Caille, at the Isle of Bourbon,—in stating that its tail was distinctly visible to the naked eye, under a length varying from 10° to 47°.

While on this subject, a remark is perhaps necessary. Delisle and Messier were certainly ill-paired for running together, and the mystery they made of this affair excited the derision of the scientific world. Delisle also, being the commanding officer, inflicted silence on Messier with respect to a comet which he caught up in January, 1760; but, says Delambre, he soon after abandoned science to devote himself to prayer, and left comet-hunting to Messier, who dearly loved to ferret them out. Of this, Laharpe gives a very characteristic anecdote: "Messier is at all events a very good man, and simple as a child. He lost his wife some years ago, and his attendance upon her death-bed, prevented his being the discoverer of a comet, for which he had been lying in wait, and which was snatched from him by Montaigne de Limoges. This made him desperate. A visitor began to offer him consolation for his recent bereavement: when Messier, thinking only of the comet, answered, 'I had discovered twelve; alas! to be robbed of the thirteenth by that Montaigne!' and his eyes filled with tears. Then recollecting that it was necessary to deplore his wife, he exclaimed, 'Ah! cette pauvre femme!' and again wept for his comet."

By the confirmations of 1759, a new body was finally added to our solar system, and this being determined, analogy assumed cognate conditions for all other comets. But the work upon Halley's comet was not terminated, nor is it likely to be, since it must form the *experimentum crucis* of cometary trajectories. And well it may, when we remember that it moves in so vast an orbit as to be about 3,400,000,000 of miles in length, by 850,000,000 of miles in breadth; so that its successive returns, under accurate observations, will afford such exact comparisons between the computed and actual orbit of the comet, as effectually to show the existence of any causes of variation to future astronomers.

A quarter of a century has now elapsed, since geometers sounded the note of preparation, for the re-appearance of Halley's comet at its late welcome return; a return which it was a great happiness to witness. It was now a nice task to predict the perihelion place for 1835; which, together with the improvement of methods for computing the perturbations, induced the Academies of Turin and Paris to offer prizes on the subject. The comet had passed within the attraction of Uranus, Saturn, Jupiter, and the Earth. Of these, Jupiter, from being of greater magnitude, has had by much the greatest effect in disturbing its motions. The tendency of his attraction has been to increase the length of the comet's path, consequently to augment the time of its revolution, whereas the attraction of Saturn, Uranus, and the Earth, acting in a contrary direction, has tended to shorten the comet's path, and to diminish the time of its revolution. The real change produced is therefore the difference of the two; so that the disturbing action of these four planets has still enlarged the comet's orbit, and augmented its periodic time. These disturbing forces not being well understood in Halley's age, that astronomer had merely observed, that Jupiter's attraction would, upon the whole, increase the comet's absolute velocity, and would, therefore, by lengthening the major-axis, increase its periodic time; a conclusion which, accurate as it is, Lalande professed his inability to understand. The task of applying the corrections was a severe one. In 1817, the Baron Damoiseau gained the Turin prize, and in 1833, that of Paris was adjudged to M. de Pontécoulant. Sir John Lubbock computed an orbit, wherein he applied Pontécoulant's perturbations to the elements for the year 1759, computed by himself. All those computers agreed pretty nearly in the perihelion time, their differences being entirely imputable to the inaccuracy of the data: still, notwithstanding all the known and unknown causes of derangement, the comet appeared about the very time, and in the exact spot that was predicted; and its actual passage at its perihelion, differed from its computed passage by only eight or nine days in a period of seventy-six years*. The following are the elements alluded to, and to

* It was concluded that the comet would re-appear in 1835; but my friend Sir Thomas Macdougall Brisbane, a strenuous cultivator of astronomy, circulated an ephemeris which he received from Germany, by which that remarkable body was to visit us in December, 1834. This excited great curiosity at the moment, and occasioned me a little loss of time. After much

these are added those of Lieutenant Stratford, which were approximately corrected during the comet's re-appearance, from fifty-six roughly reduced right ascensions and declinations, made by various observers between the 20th of August and the 19th of October, 1835; his longitudes are from the mean equinox of November the 15th, 1835:

	Pontécoulant.	Damoiseau.	Lubbock.	Stratford.
Perihelion passage, 1835	Nov. 7·2, *Paris mean t. from noon.*	Nov. 4·32, *Paris mean t. from midn.*	Oct. 30·42, *Paris mean t. from midn.*	Nov. 15·93546, *Greenw. mean astron. t.*
Place of perih. on orbit	304° 31′ 43″	304° 27′ 24″	304° 23′ 39″	304° 32′ 09″·2
Long. ascending node	55° 30′ 00″	55° 09′ 07″	55° 03′ 59″	55° 08′ 21″·2
Inclination of orbit	17° 44′ 24″	17° 41′ 05″	17° 42′ 50″	17° 45′ 56″·7
Ex-centricity	0·9675212	0·9673055	0·967348	0·9675509
Semi-axis major	17·98705	17·9852	17·98355	18·0779386

In addition to the above labours, Dr. Lehmann computed the elements of an orbit by the method of quadratures by equal intervals of time; and his results are published in the *Astronomische Nachrichten.* But the most elaborate calculations were made by M. Rosenberger, who computed the whole of the perturbations from 1682 to 1835; pointing out the effects of Venus and other planets, hitherto neglected by geometers. This enormous labour was duly appreciated by the Council of the Royal Astronomical Society; and I had the gratification of receiving their gold medal for him, at the general anniversary meeting, held on the 10th of February, 1837, after an eloquent and luminous exposition of all the bearings of the case from the President, Mr. Airy. In strongly recommending this address to the reader's careful attention, I cannot but extract his allusion to the opinions of Laplace and the elder Herschel—who both ascribe the origin of comets to the nebulous matter that is scattered throughout space—because it affords food for reflection:

There are, however, other points of view in which the subordination of this body to the general law of gravitation is extremely interesting. It is not merely that its period is long, and its orbit extensive, but that it is a body of a different kind, and moving in an orbit of very different proportions, from any

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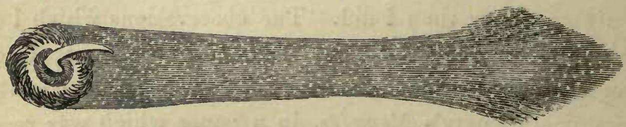
patient fishing in and around the predicted place, I was able, in January, 1835, positively to assure my astronomical correspondents that it was *not* in sight,—an announcement by which I at least proved a negative. I had also some severe searches in February and March, in consequence of Dr. Olber's interesting remarks in No. 268 of the *Astronomische Nachrichten.*

of those which mankind had been accustomed to regard as belonging to our system. The most striking consideration is that derived from the contemplation of the nebular hypothesis; a theory which if not certain, is plausible, and accounts, in a most remarkable degree, for the phenomena that seemed to require some single cause to explain their general similarity. Is it true that this system of sun, planets, and satellites, was once a nebula, whose slow rotation and gradual condensation at length formed a number of bodies, bearing in their form and motions no trace of their original state? And is it true that comets are detached portions of nebula, which the want of mass has saved from the extreme degree of condensation that the planets have experienced, which, by the attraction of our sun, have at first been made to describe parabolas; and which, in some instances, perhaps from the effects of resistance when our system abounded with uncondensed nebular matter, have been made to return in orbits of limited extent? If these things be true, then I say that the subordination of these bodies to the law of gravitation is a most striking fact. They are a link, at the same time connecting the past with the present state of our system, and its present state with the state of those curious bodies, which we find dispersed in all parts of the heavens. And their obedience to the law of gravitation affords a very strong presumption that this law has been unaltered since our system was one nebular chaos; and that it now holds in the nebulæ which preserve their state yet unaltered.

Astronomers of every grade were on the alert, and it is very probable that the heavens were never attacked by a more earnest body of gazers, or with so many telescopes. The comet was first caught a glimpse of at Rome, on the 5th of August, by M. Dumouchel, Director of the Observatory of the Roman College. Most observers, however, waited for the waning of the moon in that month, and then it was almost simultaneously perceived by those who were in possession of powerful telescopes: those with inferior instruments had to wait a week or two longer. I did not look for it till the 24th of August, when I almost immediately saw a faint nebulous patch near ζ Tauri, which soon proved to be the returning wanderer. From its easy visibility, I felt sure that I might have gained a sight of it at least two or three nights sooner than I did. The observations which I then carried on, their reductions, and the mean apparent places of the comet, will be found in the ninth volume of the Royal Astronomical Society's *Memoirs*, in a paper which was read on the 10th of June, 1836. But though I refer the reader to that volume for the details alluded to, I feel that it is necessary to make an extract here, both as relating to a very remarkable phenomenon, and also to give a nearer representation of it than that which is there annexed. The designs of the comet's appearances which I sent, were complimented in the Society's *Monthly Notices*, and my method of scraping the lights from a black field was strongly recommended for adoption. But so badly were these copied upon the stone, that they bear but a slight resemblance to the *monochromatic* drawings, and more especially that of the 11th of October, where the whole centre seems to have been torn up on the stone; which, indeed, in no way agrees with the text. I therefore submit the passage, with a more faithful diagram of the surprising aspect of the comet.

10th. A very fine evening till midnight, when the greater part of the atmosphere clouded over. The comet was now racing along with a motion apparently as rapid as that of the moon, yet, to the *senses*, its passages over the ring were well taken. The position and time were so favourable, that I obtained two several sets of measures with the annular micrometer, at an interval of two hours, with capital meridian observations between them. Wind, N.W.; Barom. 29·22; Therm. 45·3; Hygrom. 556.

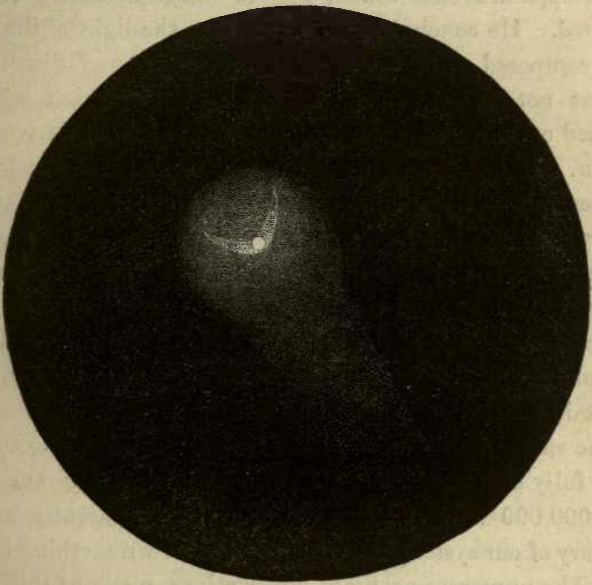
The comet, in this evening's examination, presented an extraordinary phenomenon. The brush, fan, or gleam of light, before mentioned, was clearly perceptible issuing from the nucleus, which was now about 17″ in diameter, and shooting into the coma; the glances at times being very strong, and of a different aspect from the other parts of the luminosity. On viewing this appearance, it was impossible not to recall the strange drawing of the "luminous sector" which is given by HEVELIUS, in his *Annus Climactericus*, as the representation of HALLEY's comet in 1682, and which had been considered as a distortion. As this sector is a feature of the utmost importance, I beg to submit the original passage, with a copy of the engraving: "Toto apparitionis tempore lucidius, ac etiam aliquanti majus caput exhibuit, quàm præcedens iste anno 1681, ut ut hicce multò longiorem Caudam retulerit. In ipso Capite, beneficio longioris Telescopii, non nisi unicum nucleum figuræ ovalis et gibbosæ constanter notavimus; nisi quòd die 8vo Septembris, ex dicto nucleo clarissimus simul radius, ex parte etiam incurvatus in caudam exiret*: quod ut notari meretur (cùm ejus generis faciem in nullo adhuc Cometâ, quantum memini, observaverim) sic lubens volui faciem Capitis et Caudæ delineatam dare: uti ex figurâ subsequente suo loco videbis." (p. 123.)



Facies Cometæ, Anni 1682.

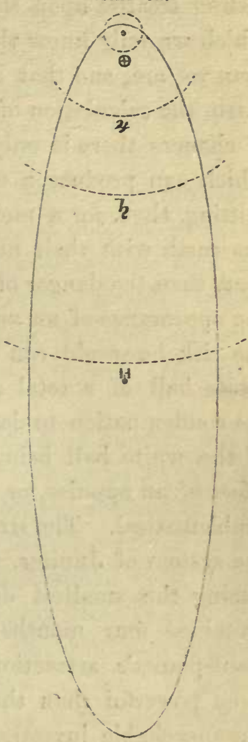
* The comet observed by CORNELIUS GEMMA (son of FRISIUS), Nov. 28 and Dec. 3, 1577, was somewhat like this. If the drawing of LEMONNIER be correct, the comet of 1680 also presented a curious sector of light on the nucleus.

11th. A tolerably fine evening, with the wind at N.W. At about eight, the comet formed the apex of a triangle, of which δ and ϵ Ursæ Majoris were the base, the whole presenting a beautiful object; and the measures were taken with the annular micrometer, as well as on the meridian. The tail was increasing in length and brightness, and, what was most remarkable, in the opposite direction to it, there proceeded from the coma across the nucleus a luminous band, or lucid sector, more than sixty or seventy seconds in length, and about twenty-five broad, with two obtuse-angled rays, the nucleus being its central point. The light of this singular object was more brilliant than the other parts of the nebulosity, and considerably more so than the tail; it was, therefore, amazingly distinct. On applying as much magnifying power as it would bear, the nucleus appeared to be rather gibbous than perfectly round; but with the strange sector impinging, it was a question of difficulty. Barom. 29·70; Therm. 44·9; Hygrom. 502.



This is a singular and striking feature. In the masterly treatise which M. Arago published, he states that when a comet has a tail, the luminous ring generally seen round the nucleus is closed, or complete only on the side next the sun, and forms but a semi-circle: the two ends or horns of this semi-circle being the points of departure from which the tail emanates. But here a tail was gradually streaming forth under a contrary disposition, for the luminous sector gleamed towards the sun. This singular phenomenon seems only to be accountable for under Bessel's hypothesis of the forces of polarization; and in a letter from him, of the 19th of January, 1844, he says, "I do not consider it improbable that the sudden developement of light, and the throwing out of a tail, are appearances connected with each other. I wish for nothing more than that a comet as instructive as Halley's was, and still more that of 1744, might give me the opportunity of proving these opinions." On the 23rd of October, 1835, M. Arago applied his new instrument to Halley's comet, to determine photometrically whether its light were inherent or reflected. He directly saw two images presenting the complementary colours, red and green: by turning the apparatus half round, the red image became green, and *vice versâ*. He concluded, therefore, that the light of the comet is not composed of rays possessing the property of direct light, at least not the whole of it; but consists of that which is polarized or reflected specularly, that is, of light derived from the sun. It has been suggested, that perhaps the nebulosity becomes extremely dilated on approaching the sun, even to being wafted to the opposite side by the solar rays, thus explaining the apparent alteration of its direction whilst the nucleus doubles, or winds round that luminary in its perihelion. Tycho thought that the tail of the comet in 1577, avoided even Venus; for explaining which, surmises may be made as to the cause, but no certain conclusion has yet been attained.

The value of this erratic body to human knowledge cannot yet be fully estimated; but its periodical trips from the sun to 1,600,000,000 miles beyond the otherwise apparently extreme boundary of our system, must help us to know something by-and-bye. The numerous accurate observations, made at this its last apparition, have revealed most of the peculiarities of this comet's motion; and the time of its return to its perihelion in 1911, will be exactly ascertained. It is a wonderful condition that this body, throughout the whole of its course, extending nearly 3,500,000,000 of miles from the sun, never escaped the sensible attraction of Jupiter; and he was only one of the disturbing bodies. When Clairaut pondered upon the influences which interfered with the deduced orbit, he considered that there might exist forces yet unknown, such as the action of other comets, "ou même de quelque planète toujours trop distante du soleil pour être jamais aperçue." It is true that since this remarkable observation was made, the planet Uranus has been discovered, and it seems sufficiently remote to form the outer verge of the system, as it had heretofore been thought Saturn did; but who can place his compasses here? There may exist bodies still undiscovered of a planetary or cometary nature in those remote regions where Halley's comet, reduced in velocity, as common with all others in their aphelia, obeys the then superior influence of the sun's attraction, and returns to that object which, from the appearance of a star, he must approach till the apparent magnitude of it is several times greater than as seen from the earth. The annexed diagram shows the proportions of the vast trajectory, the small circle at the perihelion being that of the earth's orbit.



In the present state of astronomy, the cometary phenomena are those most likely to lead to new results respecting the constitution of the universe. We are satisfied that comets obey the Newtonian laws; but the perturbations of their orbits, though we are now more familiar with them than in the days of Clairaut and his colleagues, are still open to many inquiries, and are computed with such difficulty that their theory is yet in its infancy, however Herculean that infancy may be. Still less do we understand their physical modifications; and whether they be actually permanent bodies, or whether they are occasionally generated by the collapse of nebulous matter, is a question which posterity may decide. All that hath yet been discovered with certainty is, that their masses are so small as to render the influence of their attractions altogether insensible. A knowledge of this fact, in some degree removes alarm for the safety of the terrestrial orbit and axis of rotation: yet it cannot be denied, that though a collision is so improbable that the chances are nearly as 300,000,000 to one against it, such a shock is still possible*. But, says M. Arago, in his elegant and interesting treatise upon these bodies, "let us suppose a comet, of which we only know that at its perihelion it is nearer the sun than we are, and that its diameter is one fourth of that of the earth, the calculation of probabilities shows that of 281,000,000 of chances there is only one unfavourable, there exists but one which can produce a collision between the two bodies. Admitting, then, for a moment, that the comets which may strike the earth with their nuclei would annihilate the whole human race, then the danger of death to each individual, resulting from the appearance of an *unknown* comet, would be exactly equal to the risk he would run if in an urn there was only one single white ball of a total number of 281,000,000 balls, and that his condemnation to death would be the inevitable consequence of the white ball being produced at the first drawing." The effect of an appulse, or even of a concussion, is, of course, most problematical. The strange comet of 1770 passed twice through the system of Jupiter, without deranging his satellites, or producing the smallest disturbance in their motions, though it remained four months each time within the sphere of that giant-planet's attraction, which was then two hundred times more powerful than that of the sun; but there is proof from unimpeachable investigation, that its own path was lengthened

* As a specimen of the remoteness of the probability of such a catastrophe, Olbers computed, that after a lapse of 83,000 years, a comet will approach the earth to the same proximity as the moon; after 4,000,000 years it will reach within 7,700 miles; and then, if its attraction equals that of the earth, the waters of the ocean will be elevated 13,000 feet, and cause a second deluge. After 220,000,000 years, it will clash with the globe; but whether it would, even then, reduce this beautiful frame to its original chaos, remains to be felt. We may add that, in the present instance, weighing all the elements, 2500 years must elapse before a *near approach* to Biela's comet is probable; but many thousands of years may pass without its happening, leaving *collision* out of the question. This reasoning, however, applies only to particular comets; but among such numbers we are entirely dependent on the will of an Almighty Agent for existence: the very next might prove fatal.

by proximity to so vast a body. Nor is it possible to form any idea of the amazing number of these erratic cruizers: almost all those which become visible arrive within the orbit of the earth; but they traverse the heavens so rapidly, that long before the period of the year when that portion of the sky again answers for observation, they are gone. By crossing that part of the heavens only which is then above the horizon in the day-time, many escape observation altogether; and a curious fact is related by Seneca, that during a great solar eclipse, 60 years B.C., a large comet was seen very near the sun. Some, however, have been bright enough to be seen at noon-day, as those of 44 B.C., and 1402, 1532, and 1843 A.D. If it be assumed that they are equally distributed in space, the number actually recorded would lead to the inference that not fewer than 250,000 of them approach nearer to the sun than the planet Uranus! We shall presently return to this subject.

The comet of 1770, which was discovered by Messier, but is usually named Lexell's from the eminent mathematician who investigated its orbit, is too important an object to be passed by with so slight a mention of it. This comet, the elements of which were also computed by Pingré, Prosperin, Widder, Slop, Lambert, Rittenhouse, and Burckhardt, was very brilliant, and the diameter of its head was supposed to be thirteen times as great as that of the moon. Of all those bodies yet seen, it passed nearest to the earth, being only about six times the distance of the moon from us, and moving almost in the plane of our orbit; yet it went by without even affecting our tides, or altering the lunar librations*. This approach enabled us to ascertain a limit of its quantity of matter. Laplace computed that, if its

* Arago remarks that the shock of a comet on the moon, would have disturbed the harmony existing between the motions of rotation and revolution, and consequently have caused the greater axis of the moon to be displaced from the line directed towards the centre of the earth. He also notices the legend stating that the Arcadians believed themselves older than the moon, a tradition which generated the belief of that satellite's having been a comet. The partisans of this opinion, he says, will have some difficulty in explaining why the moon has no atmosphere, or gaseous envelope: "if she is an old comet, what has she done with her hair?"

mass had equalled that of the earth, it would have shortened the length of our sidereal year by one ninth of a day, or $2^h\ 47^m$. Now it has been ascertained, by the computations of Delambre on the Greenwich observations of the sun, that the length of the year did not perceptibly change; and thence Laplace concluded, that the mass of that comet was less than $\frac{1}{5000}$th of that of the earth. By Lexell's computations, it appeared that the orbit was changed by the action of Jupiter, from a parabola, or infinitely elongated ellipse, to an oval of short period, $5\frac{1}{2}$ years; and even this seems to have been altered by the earth's perturbation. From remaining invisible to us, many thought that by again passing too near Jupiter, it became so much deflected that it had been driven away from the system; but Burckhardt considered that it might have become a satellite to Jupiter, at which distance it consequently would be lost to terrestrial observers. The disappointment of Lexell at the mysterious disappearance of his comet surprised many, and provoked dull attempts at witticism from others. Such was the state of the question, when it was announced by Professor Henderson, of Edinburgh, by a letter dated the 10th of February, 1844, that the comet recently found by M. Faye, and presumed to have a period of about seven years, was the missing object: "In several respects this comet is very remarkable; and it may afford room for speculation regarding its identity with the lost comet of 1770. The orbit resembles more nearly the elliptical orbits of the planets than those of the periodic comets yet known. In its aphelion and perihelion it approaches nearly the orbits of Jupiter and Mars; and must occasionally experience great perturbations from the former. It also passes within comparatively small distances of the orbits of the minor planets." M. Valz, of Nismes, in a paper read to the French Institute on the 22nd of April, 1844, has also recognised the comet of Faye as that of 1770; and though he abuses Jupiter as the tyrannical dominator of our system and the overpowering transformer of planetary orbits, he shows such strong probabilities for the identity, that curiosity must be anxious for its predicted re-appearance in the spring of 1851.

Of all the comets of recent years, none so suddenly startled the world as the great one in 1843, which seemed at once to start into apparition with a lengthy tail. There is a strong presumption that this is the same as the one which appeared in 1668; and Professor Henderson says there is considerable likelihood for the supposition: "I am in possession of a map," adds he, "representing the apparent track of the latter in the heavens as seen at Goa, in the East Indies, from the 9th to the 21st of March, 1668." From this valuable document he derived elements which, compared with those of 1843, seem to establish the case. While upon this comet the reader will probably excuse an extract from a letter which I received from the energetic Mr. Maclear, since it gives a lively impression of an astronomer in distress: it is dated at the Cedar-berg, near the Cape of Good Hope, 12th of November, 1843.

Of the casual observatory phenomena, the grand comet of March takes precedence; and few of its kind have been so splendid and imposing. I remember that of 1811: it was not half so brilliant as the late one. Immersed in the ravines of the Cedar-berg, with high and precipitous ranges on each side of me, I made strenuous efforts to reach the Snew-berg station, to command a view of the sudden visitor. The theodolite was separated, each piece being folded in elastic packing for safe carriage, for none of us could have anticipated such a surprise. In the first instance I sent off a dispatch to your son at the observatory, requesting him to devote his entire attention to the observations for position. Those unacquainted with the character of the Cedar-berg, cannot form a conception of the difficulties I had to encounter; for seventeen days we toiled on, tantalized every evening by seeing a portion of the tail over the mountain tops, and sometimes a sight of its bright head, as openings in the mountains permitted. When at length we reached the top of Snew-berg, and put up the theodolite, the wires were too fine to be seen without lamp illumination, and the latter extinguished all trace of the comet. The thermometer was at the freezing point, and the piercing wind blew so strong, that I doubted if the station would be tenable. I could only console myself that other observers would have better luck.

The sudden apparition of this comet strongly recalls the bursting upon sight of the third comet of 1819, in the Lynx. I was then surveying the shores of the Adriatic Sea; and on the 5th of July, being in the Corzola Channel on the coast of Dalmatia, Lieutenant Malden informed me that he had seen a comet in the night. From the unexpected tenour of the tidings, and the description of the stranger's light, we were inclined to rank it as a mere temporary meteor; but in the evening we had ocular proof to the contrary, for it was so conspicuous as to make me imagine we had kept a bad look-out. Such neglect, however, was not very likely to happen on board H. M. ship *Aid;* and we could only suppose the comet had been coming from the south, and had just escaped the solar rays, on its passage towards its higher apsis. At about six bells in the first watch, or 11 P.M., it was 27° 40′ following Capella, and a line projected from the Pole-star over it, passed just under Castor and Pollux. I mention the ship-time to show how roughly we observed it; because as we were going into Lissa, I thought we should have an opportunity of watching it closely, and therefore only took a sextant angle, which was just read off when the bell struck. We stood into the harbour of Lissa, and fitted up my astronomical tent on the isle of S. Giorgio. On the 9th the comet was looking very bright, with a diverging tail, and a defined nucleus, presenting in aspect somewhat of that of 1811 in miniature: it was then exactly on an imaginary line between Dubhe and Betelgeuze, and nearly in mid-distance, where it was crossed by another line drawn from Polaris to Pollux. We now made preparations for a close attack, and constructed a rude equatorial mounting for my largest telescope, a description of which would make a Dollond, a Troughton, a Simms, or a Jones, smile: we, however, were highly gratified with it. But human happiness is liable to many crosses: on the night of the 13th, the wind, instead of subsiding at sunset as usual, increased in strength, the sky was overcast, and the lightning, which had been playing about the horizon during the two preceding evenings, now flew up to the zenith, and became incessant. I was on shore with some of the officers, and had to provide for the safety of the instruments, when about one o'clock A.M., the wind suddenly changed from south-south-east to a Bora from the north, and settled the fate of our comet scrutiny. I afterwards saw it at Zara, on the 1st of August, nearly midway between Dubhe and Castor, progressing towards the Pointers in Ursa Major.

Besides Halley's, and that of 1680, there are two other comets of long trajectories, of which something like a periodicity has been traced. One of these passed the summit of its orbit nearest the sun in July, 1264, and again in April, 1556; so that, on a period of 292 years, we must soon begin to look out for it again. The second, whose identity has been inferred, appeared in 1532, and again in 1661, denoting a period of about 129 years; but in 1790, though three comets were visible, none of them bore the stamp of the one expected. Of the six or seven hundred comets which are on record, about one hundred and forty have had their orbits computed, and a long list of the elements of most of them is inserted in Delambre's *Astronomie Théorique et Pratique*, vol. iii., ch. 33. A period of 3383 years was assigned by Bessel for the fine comet of 1811; but it has been reduced to 2888 by Argelander: both predictions must remain for verification. Such an excursion reveals much on the extent of solar attraction; but what is that compared with the comet of 1763, which has an assigned period of 7334 years! The comet of 1819, which appeared in Leo, was expected to return in a very short period, but has not been seen again: it was very near us when observed, passing between us and the sun. Still we cannot reason upon these as instances; for as comets travel far into unknown space, and the determination of the length of the major-axis is liable to very great uncertainty, their time of revolution, as well as the form and position of their orbit, cannot be sufficiently established to be implicitly relied upon: nor can we presume to estimate how these *incipient worlds* may be affected by physical causes, beyond the limit of our present knowledge.

In this dilemma, it has most opportunely happened, that two comets of short periods have lately been discovered and reduced to law; and as both of them have only yet been seen by the telescope, are found amenable to gravitation—of which they are a consequence and confirmation—and have appeared at their predicted returns with unerring punctuality, these interesting discoveries may be proudly placed in the van of modern astronomy. Though now duly recognised bodies of the solar system, they both seem to be mere masses of vaporous matter, of extreme tenuity, barely corporeal, and but slightly luminous; and it is not a little wonderful to see such dim mists, "whose parts," says Sir John Herschel, "can have no more cohesion than the floating particles of the lightest fog," borne along despite of their inertia, and commanded by their gravity, with all the exact regularity of the denser planets. It is, therefore, with more poetry than science, that Lord Byron says,

> A *pathless* comet and a curse,
> The menace of the universe.

The first of these familiars is stamped with the name of the indefatigable Encke, who considered the elements of its orbit in 1818, and ascertained the period of its revolution to be about 1208 days, a result which occasioned great astonishment and a degree of doubt. By the researches which he then instituted, he identified it with the comet found by Messrs. Méchain and Messier, in 1786, in Aquarius; but these gentlemen having observed it only twice, were unable to furnish materials for computation. It was then detected by Miss Herschel at Slough, in 1795, in the constellation Cygnus; and her brother perceived a small star through its middle, with very little diminution of brightness. In 1805 Pons, Huth, and Bouvard, discovered it on the same day. In 1818, Pons caught sight of it again; and Bouvard computed an orbit for it. Hitherto it was supposed that the four comets were different ones; but Encke not only pointed out their identity, but also showed that an oval orbit agreed better with each set of observations than a parabola. The investigations of the diligent professor enabled him to foretell its reappearance in 1822, and to state the probability of its not being observed in our latitudes. This anticipation was realized by the fortunate incident of our then having a ruler of a colony in the southern hemisphere, who is at once a distinguished officer and a profound philosopher; and but for whose appointment, the phenomenon had been lost, to the probable injury of the whole cause. I allude to my friend Lieutenant-General Sir T. M. Brisbane, who, being Governor of New South Wales, had fitted up an observatory at Paramatta, and appointed Mr. Charles Rumker to be his assistant. To the gratification of all the astronomical world, the comet was seen by the latter on the 2nd of June, 1822; and the accurate observations which were made, afforded Encke the means of reconsidering its elements, and, with additional confidence, to predict its return in 1825. It has since been very generally observed, at its successive epochs, and though never yet seen by the naked eye, is, astronomically speaking, a well-known object. Its orbit is an ellipse of comparatively small dimensions, almost in the plane of the ecliptic, and wholly within the march of Jupiter, one extremity reaching a little beyond the orbit of Pallas, and the other extending to that of Mercury.

Nothing could be more satisfactory than all this; but the period of 3 $\frac{3}{10}$ years was found to be accelerated* about two days in each revolution. The possible derangement which the comet would suffer from planetary influences, had been duly calculated; yet, at each re-appearance there was a difference between the prediction and observation, and always on the same side. This was directly imputed to the resistance of some ethereal fluid, or modification of light and heat, and constituted what Sir John Herschel aptly termed the residual phenomenon. As this seemed to be a revival of Aristotle's fifth element, the *quinta essentia* of after times, and the Leibnitzian doctrine of ether, the question was approached with delicacy; and it is only now, that it may be deemed orthodox to believe in the existence of a resisting medium. It was advanced, that no motion could be more equal, constant, and accordant, than that of the planets round the sun; but a medium which may impress no appreciable opposition to the solid and weighty mass of a planet, may produce a very perceptible difference in the time of the revolution of a gaseous wanderer. Hence Dr. Olbers has said: "The exemption of the dense and solid bodies of the planets from any sensible effects of resistance, in the interplanetary spaces, proves nothing with respect to comets, which occupying, perhaps, a volume 1000 times as great, may have masses 1000 times smaller." Newton himself—albeit often brought forward as the advocate of a *vacuum*—supposed that a *spiritus subtilissimus* was diffused through space, diminishing in the inverse ratio of the square of the sun's distance; and if this ether, said he, should be supposed to be 700,000 times more elastic than our air, and above 700,000 times more rare, its

* It may appear paradoxical, that the resistance of an ethereal medium, which would make a body of such tenuity move slower, should have the effect of causing its revolutions to be performed more quickly. But by moving more slowly, it is the more drawn towards the centre, and therefore its path shortened: which is the converse of the proposition on p. 237.

resistance would be about 600 billion times less than that of water, a resistance which would scarce make any sensible alteration in the motions of the planets in 10,000 years. "If any one would ask," he adds, "how a medium can be so rare, let him tell me, how an electric body can by friction emit an exhalation so rare and subtile, and yet so potent? And how the effluvia of a magnet can pass through a plate of glass, without resistance, and yet turn a magnetic needle beyond the glass?" The magnitude of the retardation is a quantity too large to be a doubtful case, the supposition, therefore, that the heavens oppose a gaseous ether to the motion of bodies, became necessary to reconcile these anomalies; and it is seen, that this fluid only retards the progress of the comet, without altering its course. This subject has been ably treated by M. Mossotti, in the *Memoirs* of the Astronomical Society of London, a society which had shown the liveliest interest in the matter, and which awarded their gold medal to Professor Encke, Sir T. M. Brisbane, and Mr. Rumker, in acknowledgment of their services in the cause. The return of Halley's comet in 1911, will solve several questions of deep interest connected with the ethereal medium. An opinion prevails, that this fluid has a rotatory motion about the sun from west to east, communicated to it by the incessant gyrations of the planets. Should such a rotation exist, it must have a widely different effect upon Halley's comet, which moves from east to west, from that which it produces upon Encke's and Biela's comets revolving in a contrary direction. These points, comparatively speaking, will soon be settled.

Thus does this obscure, tail-less object, seem to have revealed the secret of a rare medium filling space, of which the planets gave no indication, they performing their evolutions as in a perfect vacuum. Besides this, it is weighing one world and registering the experiment to another, for it will enable us to obtain the mass of Mercury, which is as yet but hypothetically known; and it may yet open other views of importance and grandeur. The constant decrease in the size of its orbit consequent upon the resisting medium, may possibly precipitate it on the surface of the sun, if, before that event takes place, the perpetual diminution of its mass does not either dissipate it or condense it into a solid state. The question is a very singular one. Hevelius had boldly given his opinion, that the diameters of cometary nebulosites increased in proportion as comets receded from the sun; an opinion in which he was somewhat tardily joined by Pingré, although it was difficult to believe that a mass, plunging into colder regions, should expand rather than condense. But the truth of the theory was proved by the variations which the real diameter of Encke's underwent in 1828. It was found that on the 28th of October, the comet was nearly three times further from the sun than on the 24th of December, but that, notwithstanding this, the diameter of the nebulosity was about twenty-five times greater at the first date, than at the second; a dilatation and contraction placed beyond dispute, by M. Arago's table, where the numbers in the second column are compared with the earth's distance from the sun as unity:

Dates.	Distances of Encke's Comet from the Sun.	True Diam. of the Nebulosity in semi-diam. of the Earth.
28th October - - - -	1·4617	79·4
7th November - - -	1·3217	64·8
30th November - - -	0·9668	29·8
7th December - - -	0·8473	19·9
14th December - - -	0·7285	11·5
24th December - - -	0·5419	3·1

The second comet of short period, is that known as Biela's. In 1805, Professor Gauss found that one of the comets of that year, appeared to complete its revolution in 1731 days; and though no prediction was made, it seems to have been conjectured. On the 27th of February, 1826, Captain Biela, of Johannisberg, discovered a telescopic comet which "he had partly expected;" and it was seen ten days afterwards by the late M. Gambart, at Marseilles, who computed its path, and concluded that it accomplishes its revolution in 6¾ years. As this announcement encouraged the anticipation of much astronomical knowledge, it promoted immediate inquiry, and the comet was found to possess similar claims to attention to those of Encke's. Having established its periodicity, it became necessary to substitute elliptical elements for parabolic, in order to determine the time of its revolution to rigid accuracy. In this calculation an anomaly appeared in its return, which at first puzzled the computers, as one interval was found to be of 2460 days, and the other 2469; but this was soon found to be owing to the action of Jupiter, near which the comet had passed in 1782, 1794, and 1807; allowing for these influences, and a similar one in May, 1831, the elements showed that its period is 6·7 years. It was now seen that it would cross the plane of our ecliptic a little within our orbit*, at midnight on the 29th of October, 1832, about a month before us. The announcement of this in Paris, a city which had shown especial excitement on the advent of Lexell's comet, raised considerable apprehensions in some, and spread so great an alarm among others, that even the talents of M. Arago were called into requisition to allay the public dread. "Popular terrors," observed a Professor in Paris, "are productive of serious consequences. Several members of the Academy may still remember the accidents and disorders which followed a similar threat, imprudently communicated by M. Lalande, in May, 1773. Persons of weak minds died of fright, and women miscarried. There were not wanting people who knew too well the art of turning to their advantage the alarm inspired by the approaching comet, and places in Paradise were sold at a very high rate. The announcement of the comet of 1832, may produce similar effects, unless the authority of the Academy apply a prompt remedy; and this salutary intervention is at this moment implored by many benevolent persons."

Another metropolis was also in a ferment; some dreaded a deluge or a conflagration, and others the comet's impinging upon the earth, and dashing it into pieces. Some of the terrified thought of taking refuge in caverns, others longed to be afloat, and a third class thought most wishfully on the Jura range, the Pyrenees, the Alps, and the Himalayas:

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* In more express terms, it passed a point in our orbit, at about 2⅓ diameters of the earth's distance, that is, something more than 18,000 miles; and it glided along with an hourly motion of 102,300 miles. But the alarmists did not recollect that this orbit is not a material bound; and there was no harm in crossing it, while we were not making use of it.

Terruit urbem:
Terruit gentes, grave ne rediret
Sæculum Pyrrhæ, nova monstra questæ:
Omue cum Proteus pecus egit altos
Visere montes:
Piscium et summa genus hæsit ulmo,
Nota quæ sedes fuerat columbis:
Et superjecto pavidæ natarunt
Æquore damæ.

And all the damage was to be performed by the agency of an indiscrete object, which was to pass more than two hundred times the moon's distance from us; which must unheeded have crossed the earth's path one thousand seven hundred times since creation; and which is of so faint a constitution, that it can only be seen in telescopes of extraordinary size and power. As to myself, aided by Mr. Henderson's Ephemeris, and Sir John Herschel's advice, I *fished* for it; but though it must assuredly have been in the field of my instrument, I cannot affirm that I actually made it out. Sir John attacked it with his 20-foot reflector, with a newly-polished mirror, and caught sight of a vapoury cloud $2'\frac{1}{2}$ or $3'$ in diameter. It passed directly over a small cluster of most minute stars, of the 16th and 17th magnitudes; and when on the cluster, presented the appearance of a nebula resolvable, and partly resolved, the stars of the cluster being visible through the comet: "a more striking proof," he observes, "could not have been offered of the extreme translucency of the matter of which this comet consists. The most trifling fog would have entirely effaced this group of stars; yet they continued visible through a thickness of the cometic matter, which, calculating on its distance and apparent diameter, must have exceeded fifty thousand miles, at least towards its central parts. That any star of the cluster was *centrally* covered, is indeed more than I can assert; but the general bulk of the comet might certainly be said to have passed centrally *over the group*." Yet this is the redoubtable object which excited such positive alarm only twelve years ago, among the less informed! Dr. Olbers, indeed, as far back as the 24th of April, 1826, had publicly given his opinion upon this very subject: "It may be scarcely necessary to remark, that this *possible*, but not probable, contact between our globe and the comet, need occasion no fear, if ever it take place, of any unpleasant consequences to the earth, or its inhabitants. It can only have a very insignificant influence on the climate." It should be added that, on the 29th of October, 1832, Biela's comet cut the terrestrial orbit in a point where the earth arrived a month after, but from which it was then distant more than 55,000,000 of miles; in 1805 the same comet passed us unheeded at the distance of about 5,500,000 of miles! To Encke's and Biela's must now be added the comet of Faye, already spoken of; but its claim cannot be confirmed till it has returned to its prediction.

Numerous and plausible, as well as wild and visionary, have been the cogitations about the object and uses of comets. We have glanced at the fear and trembling which pervaded the superstitious herd on the coming of such portentous harbingers, as well as at the terrors of the uninstructed; and we have now to notice the speculations of superior minds, which also owned the power of dread, though from different motives,—the apprehension of a physical injury to our globe. But Sir Isaac Newton, after showing the immense atmosphere of comets, and its dilatation, thinks that when the vapours are thus rarified and diffused through space, they may gradually, by means of their own gravity, be attracted down to the planets, and become intermingled with their atmospheres. By this, the moisture spent in vegetation would be recruited; "and I suspect," adds the immortal philosopher, "that the spirit which makes the finest, subtilest, and the best part of our air, and which is absolutely necessary for the life and being of all things, comes principally from the comets. So far are they from portending any hurt or mischief to us, which the natural fears of men are apt to suggest, from the appearance of anything which is uncommon and astonishing." Another use which, without any reasonable analogy, he conjectured comets may be designed to serve, is that of recruiting the sun with fresh fuel:

To shake
Reviving moisture on the numerous orbs
Through which the long ellipsis winds; perhaps
To lend new fuel to declining suns,
To light up worlds, and feed the eternal fire.

Whiston, who, though rather too whimsical, was both a learned man and a mathematician, considered comets as intimately connected with the world. His opinion was, that the great comet of 1680 was instrumental, at the earth's cosmogony, in giving the globe its diurnal rotation, by striking it obliquely; that afterwards a near approach of the same body enveloped us in its tail, and occasioned the deluge; and that by another advance, after being heated to an incalculable degree in its perihelion, it will cause the final consummation of all things, by a general conflagration; a persuasion which has pervaded both Christians and Heathens, the former from the supposed testimony of sacred writings thus interpreted, and the latter from very early tradition. M. Villemer has doggrelized the impression:

> Tremble, Mortel pécheur! Ce corps de feux errans,
> Du céleste pouvoir est un des instrumens,
> Cette Comète en feu peut te faire descendre
> En un de ces volcans, pour t'y réduire en cendre.

But notwithstanding the ingenuity, and even probability, of these and other hypotheses, there is yet little in any one of them to entitle it either to implicit confidence, or estimation above the others; and until multiplied observation shall have added to the imperfect knowledge which we at present possess of these bodies, it is perhaps better not to give a decided preference to any. Pingré thought comets as old as the rest of the solar system, but without assigning a reason; while Herschel imagined that new ones might be continually forming. Piazzi did not suppose their formation to be contemporaneous with that of the planets: he was rather of opinion that they were occasionally formed in the immensity of space, in which they are afterwards dissipated, nearly like those globes and luminous meteors which are generated and disappear in the terrestrial atmosphere. Some astronomers see no great cause for apprehension in our encountering a comet. The learned and illustrious Euler, in a treatise, *De periculo a nimiâ Cometæ appropinquatione metuendo*, has investigated the changes which would be made in the elements of the earth's orbit by a comet, its equal in bulk, coming almost in contact with it; and he concluded, that the attraction of such a comet would indeed alter the length of our year, but only by the addition of seven hours. The utmost of the effects resulting from the comet's attraction at the time of its appulse, would be greater than would be inferred from the total result of its attraction, after its final departure; for the changes occasioned during its approach, would be in a great measure undone during its retreat. But even at their maximum, such changes would not be very great, because the mass of a comet is generally so small, that there is little chance of the earth or planets' being deflected from their course; while from the rapidity of the comet's motion, time would be wanting to complete them. Much, of course, would depend on its bulk and distance, as well as on the liability to a direct shock. A comet merely grazing the earth would be incompetent, Euler says, to produce even a deluge on our continents, unless the shortness of its stay were compensated by its great magnitude of volume. The comet which came nearest to the earth is that of 1577, which Tycho Brahé observed to be within three times the distance of the moon, that is, 720,000 miles from the centre of the earth; but as nothing has been recorded to have happened in consequence, probably it had no sensible effect. The comet of 837 remained four days within 3,700,000 miles of the earth's orbit, without any perceptible influence; and Lexell's comet approached to within six times the distance of the moon from us. Its own period was diminished more than two days by the action of the earth; but the re-action of the comet, which ought in like manner to have lengthened our orbital revolution, did not even affect our tides. Indeed, comets move so rapidly, that even were their attraction greater than it is, there is not time for a sufficient accumulation of impetus to produce any sensible effect on the ocean.

Some comets have certainly approached very near the earth, particularly one which appeared in 1472, and another in 1760. The former of these, it is said, moved over an arc of 120° in one day, having a parallax twenty times greater than the sun's; and the latter 41° in the same space of time. Such extraordinary variations can scarcely be accounted for, on any other principle than their proximity to our globe. Yet neither these, nor even one which, according to rather vague accounts, approached so close to the earth in 1454 as to eclipse the moon, produced any sensible effect upon us. Cardan describes a comet seen in open daylight at Milan, in 1532; and that of 1774 is said to have been more resplendent than Sirius when it first appeared, and in three weeks to have been nearly equal to Venus in splendour. But Lexell's comet, which passed within 1,800,000 miles, is the nearest approach of which we possess trustworthy record. Hitherto, however, none has threatened the earth with a closer appulse than that of 1680; for, by calculation, Halley found that at six minutes after one o'clock on the 11th of November of that year, the comet was not above one semi-diameter of our globe to the northward of our path; at which time, had the earth been in that part of its orbit, the wanderer's presence would have been serious indeed. Where all is motion, space, and matter, such a shock is not at all impossible. As for the probable consequences, no conjecture can be well offered, except that from the extreme tenuity observable in these bodies, we may presume that the danger seems to depend principally upon the force of attraction; so that whether we should be shivered into asteroids, or merely transported outside Uranus, is a problem. Olbers calculated that a comet only the two thousandth part of the earth's mass, which yet would form a globe 520 miles in diameter, and of the density of granite, meeting us with a velocity of about forty miles per second, would amply suffice to shatter us to pieces. Laplace agrees with Euler in supposing that, from the rapidity of their passage, the effect of their attraction must be diminished; but he gives rather an uncomfortable view of the effects of a collision with a giant comet: "The axis and rotatory motion being changed, the seas abandon their former position, and rush to the new equator; great part of the men and animals are drowned in this universal deluge, or destroyed by the violent stroke on the terrestrial globe; entire species annihilated; all the monuments of human industry swept away: such are the disasters which might ensue."

As to the old notion of a conflagration from their fiery properties, the details already submitted, and the fact of many of the unnucleated ones being so transparent as not to hide the stars whose disc they pass over, go far to prove their comparative insignificance. They have not exercised the slightest influence

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upon us, since astronomy has been able to prove our relative positions in the system; nor is there a trace of the existence of such effects upon any authentic record. Another well-established fact is, that though, as in that of 1811, it is commonly supposed that harvests are aided by the calorific presence of comets, insomuch that "comet wines" have had distinct bins allotted to them in cellars, yet they have no power whatever in imparting heat. Some sages were led to suppose that the equilibrium of our atmosphere was slightly disturbed in 1811; but they could hardly have been aware that even the intruder's tail, lengthy as it was, never approached nearer the earth than some millions of miles; that its light was not equal to a tenth part of that of the moon; and that all the efforts to concentrate its rays did not produce the slightest effect on the blackened bulb of the most sensitive thermometer. M. Arago instituted a comparison of the registers kept in the observatories of Europe, and found that neither this, nor any other comet, could possibly have had any effect on our seasons. "The year 1808," he observes, "may be reckoned among the cold years, although few have produced so many comets; and 1831, in which there was no comet, enjoyed a much higher temperature than 1819, when there were three comets, one of which was very brilliant." Of the one hundred and thirty-seven comets, the orbits of which were known in 1831, he classified the number which came to the perihelion point in the different months, thus:

January	14	July	10
February	10	August	8
March	8	September	15
April	10	October	11
May	9	November	18
June	11	December	13

The preponderance here observable in the winter months, is owing, most likely, to the long and dark nights admitting of a better look-out. The greater number of the selected hundred and thirty-seven have their paths out of the direction of those of the planets, so that there is but little chance of collision; and their passages have been made through very different parts of the solar system. With regard to the magnitude of the perihelion distances, it was found that thirty of the comets had their perihelia nearer than Mercury; forty-four between Mercury and Venus; thirty-four between Venus and the Earth; twenty-three between the Earth and Mars; six between Mars and Jupiter; and none beyond the orbit of Jupiter. The probable number of these and other bodies amenable to the Newtonian law, is truly astonishing. M. Lambert held, that universal space is replenished with as many globes as it can contain, so as to move with freedom and security within the circumference of the universe. On this point M. Arago thinks, that if the perihelia are distributed throughout the system as between the sun and the orbit of Mercury, the volumes of the two spheres being to each other as the cubes of their radii, there would be three and a half millions of comets within the sphere of Uranus; but there are many considerations which, on the same hypothesis, would greatly increase that number. Such are the comets; and they will offer matter of speculation to many successive ages.

§ 14. Concluding Remarks.

Having thus taken a *giro* through the wondrous Solar System, a few words may generalize its elements. We have traced astronomy from the time that man, independently of instruction, was naturally* led to adopt means for exactly determining that important period the year, and its seasons; and from thence the science has been progressively brought to its full bearings, as the brightest result of human investigation. It has been shown that the relations of the sun and planets are inseparably connected, that no single body can be regarded as an independent sphere, and that all must be reckoned as portions of a whole. But here two or three considerations arise, which will probably be better

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* The word *naturally* is introduced here, because this system of measuring time was not confined to the Chaldeans, and other early people of the old world. If reliance is to be placed upon Josef Acosta, and on Gemelli Carreri, both the Peruvians and Mexicans had practices which corresponded nearly with those of our ancients, especially in their gnomonic observations of the equinoxes and solstices; and we are informed in the *Polynesian Researches*, vol. i., ch. iv.; that the Otaheitans measured time by the year, which consisted of twelve or thirteen months.

treated by him who writes an astronomical treatise in the year of our Lord 2844, than they possibly can be at present.

One striking and obvious circumstance is, that the rotatory motions of all the planets on their respective axes, and all their revolutionary motions round the sun, with those of all the satellites—except the attendants of Uranus—round their primaries, are in one and the same direction, namely, from west to east; and they are all maintained in this movement by the attraction of their central bodies, which restrains the corresponding revolving bodies from flying off. Each planet is acted upon by the attraction of all the rest, under the law of universal gravitation; and it is perceived, that the smaller the planet, the larger is its ex-centricity. To prove that all this results from design, attention has been strongly drawn to the demonstrable facts, which were not a little aided of late by the singular theorem of Bode, given in page 156, that the interval between the orbits of any two planets is about twice as great as the inferior interval, and only half the superior one: or, if a be the distance of Mercury from the sun, and $a + b$ that of Venus, then $a + 2b$ is that of the Earth, $a + 4b$ of Mars, $a + 8b$ of the Asteroids, $a + 16b$ of Jupiter, $a + 32b$ of Saturn, $a + 64b$ of Uranus. To this empirical rule, which tallies very nearly with the actual numbers, the parity as to the length of the day in planets so various in respect to their years, is a singular condition, especially on noting that the more rapid succession of day and night is a modification confined to the distant planets. The following table exemplifies this:

Planets.	Length of Day.	Length of Year.
Mercury - -	24^h 05^m 28^s	0^y 2^m 28^d
Venus - -	23 21 07	0 7 15
Earth - - -	24 0 0	1 0 0¼
Mars - -	24 39 21	1 10 21
Ceres - - -	*rot. unknown*	4 7 11
Jupiter - -	9 55 50	11 10 17
Saturn - - -	10 29 17	29 5 24
Uranus - -	9 30 (?)	84 0 27

The numerous and unquestionable evidences of an all-wise plan, in the planetary arrangements, utterly defeated the few remaining advocates for chance; but a new point of attention arose, as to the stability or instability of the system; and this great question occupied the best mathematicians of Europe for the greater part of the last century. Some feared the consequences of the moon's approaching us at the rate of a degree in two thousand years, until Laplace relieved them by showing the self-correction of that ominous movement. The planes of the planetary orbits are subject to a variation of place; but, after certain periods, they return to the positions from whence they departed. The figure of the earth's orbit is now approaching to that of a circle; but it will afterwards recede from that figure, without subjecting the length of the year to any change, or the mean temperature to any alteration. The obliquity of the ecliptic is diminishing; and hence it has been supposed, that seed-time and harvest, summer and winter, might hereafter assimilate; but that obliquity will afterwards again increase, and return to its former state; and the variation will be restricted to such limits, that the seasons will never be sensibly affected by it. Lagrange had discovered that the mutual perturbations of Jupiter and Saturn, by making their nodes retrograde on each other's orbits, cause the intersections of both orbits with the ecliptic to advance and retrograde alternately about a mean point on the latter; the inclinations of the orbits to the ecliptic, were also found to oscillate within certain limits about a mean state. These delicate investigations engaged the continued exertions of able mathematicians for many years; but it was not till 1786 that Laplace discovered a true explanation of these difficulties, and announced the discovery as a fresh triumph of the Newtonian theory. Lagrange had conceived that the acceleration of Jupiter was owing to a secular, or long-period-equation; but Laplace, weighing the dependence of the position of the bodies on each other, was led to look for an equation of more frequent occurrence. As twice the mean motion of Jupiter was very nearly equal to five times that of Saturn, he concluded that the arguments expressed by the difference of these mean motions, might become sensible by integration, though they should be multiplied by such quantities as the cubes of the ex-centricities and of the inclinations of the orbits; retaining, therefore, such terms in the investigation, the result justified his conjecture, and reconciled, in some measure, the apparently discordant details of Halley and Lambert. In a word, he found that there existed in the motion of Saturn an inequality, the period of which is nine hundred and twenty-nine years, and in the motion of Jupiter a corresponding inequality, which is affected with a contrary sign, and whose period is nearly the same, the difference between the two scarcely amounting to a degree in a thousand years. This was balm to the apprehensions of the philosophers, for all fears as to the probable disorganization of the frame of nature evaporated; and the explanation of Laplace produced the true *ἀποκατάστασις*, by which ancient astronomers signified the restitution of things to their former state.

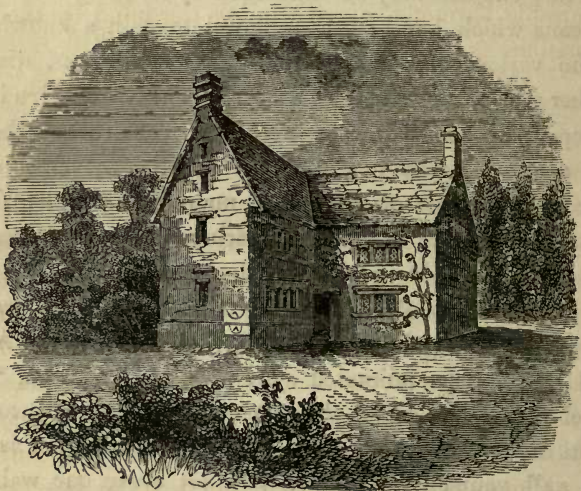
While, therefore, the stability of the system appeared to be confirmed beyond question, the progress of Encke's telescopic comet, by revealing the existence of ether, again spread alarm through the minds of the scientific. As no speculation is admissible which would govern the material universe by the mere doctrines of necessity, the whole truth became evident. The projectile impulse which produced planetary motions, might continue unimpaired in void space; but if those motions are, through space occupied by matter, however thin and weak that matter may be, they must be continually enfeebled and diminished till the motive power, except such as depends upon gravitation, becomes quiescent. Astronomy enables one to divide, as it were, eternity into intelligible periods, and the period may require millions, or millions of millions of years in its consummation; but the catastrophe which threatens can be pronounced upon—the celestial orbs may not endure for ever. A resisting medium is now known to exist, and however faint that resistance may be, or however vast the period of the retarding action, the visionary eternity of the planetary movements is dispelled, and finite duration indelibly stamped: unless, indeed, such medium be eventually attracted into the sun. A ray of hope also gleams through the despondency of the view, in that, whatever may betide the comets which are stemming the ether-tide on the opposite tack, the eternal planetary action may have caused that medium to rotate along with the planets, and therefore to offer no obstruction.

The existence of a resisting medium, and the recognition of the Nebular Hypothesis, which will presently be alluded to, have certainly opened new and wide views of the Activities which pervade the Universe. The innumerable components of the vast creation, appear to have a closer affinity in characteristic peculiarities of structure and operations of law, than the dreamers on cosmogony have hitherto suspected. Thoughts upon time, space, and infinity, with considerations on the vast mechanism connected with the former condition, actual state, and future destiny of the constituents of the firmament, cannot but occupy the mind even to bewilderment. The Majestic Design, although now ascertained to be so much more wonderful than formerly supposed, is more than ever inexplicable to human reason.

But as, to apply an old saw, the solar system will "last our time," this chapter may be concluded by alluding to the artificial means which have been employed to gain a knowledge of it. The various orreries, planetariums, satellitians, diagrams, and other similar contrivances, are so obviously defective in scale and proportion, that, however ingeniously constructed, they give hardly a more correct notion of the celestial movements, than the smell of tar does of a first-rate man-of-war. The Vicomte de Vaux proposed to represent the scheme on a large grass-plat in the Isle of Wight, with a pavilion for the sun, and gravel walks for the orbits of the planets; the latter in cars drawn by soldiers, to the regulated strains of Lydian music. Another plotted a still more animated system: "Let," said he, "a tree on level ground be called the sun, and let several persons, at different distances from this tree, be called the planets, as one of which, call yourself the earth; now let every one walk their regular pace round the tree in the same direction, keeping nearly at the same distance from it [*sic in orig.*], and those persons will represent the annual movements of the planets about the sun; and if in the same direction you keep turning round as you walk, the latter will represent the diurnal rotation; and a small person very near you, walking round you in a like direction, is to be called the moon." As this round-about proposition almost makes one feel giddy in the very wording of it, let us look to the better conception of Sir John Herschel:

Choose any well levelled field or bowling green. On it place a globe, two feet in diameter; this will represent the sun; Mercury will be represented by a grain of mustard-seed, on the circumference of a circle 164 feet in diameter for its orbit; Venus, a pea, on a circle 284 feet in diameter; the earth also a pea, on a circle of 430 feet; Mars, a rather large pin's head, on a circle of 654 feet; Juno, Ceres, Vesta, and Pallas, grains of sand, in orbits of from 1000 to 1200 feet; Jupiter, a moderate-sized orange, in a circle nearly half a mile across; Saturn, a small orange, on a circle of four-fifths of a mile; and Uranus, a full-sized cherry, or small plum, upon the circumference of a circle more than a mile and a half in diameter.

This gives a notion of the proportions of the solar system; and if, from the mimic orbit of Uranus, a line of five thousand miles be carried out, the distance of the nearest fixed stars will be represented, according to the scale of the rest.



The House in which Newton was born, showing the Sun-Dials which he made when a Boy.

Chapter III.

A GLANCE AT THE SIDEREAL HEAVENS.

Ces variations des étoiles sont bien dignes de l'attention des observateurs curieux. . . . Un jour viendra, peut-être, où les sciences auront assez d'amateurs pour qu'on puisse suffire à ces détails.—Lalande.

Quitting the solar system for the inerratic sphere, it is necessary to overleap a vacuity, so vast that the interplanetary spaces dwindle into insignificance. Yet inconceivably distant as it is, we are here presented with a scene at once stupendous and magnificent, displaying the wisdom of God in the dazzling splendour of His power. Here we discover objects rising above each other to an incomprehensible infinity of space, and suns and systems of suns, as yet untold save by their mighty Maker, in admirable harmony, overwhelming the mind by their varied combinations and interminable succession:

> And canst thou think, poor worm! these orbs of light,
> In size immense, in number infinite,
> Were made for thee alone?

The due consideration of this conveys a withering idea of insignificance; for if the earth were annihilated and blotted out of space to-morrow, it could never be missed by the astronomers of the myriads of worlds around us, even had they telescopes better than those of Herschel, Fraunhofer, and Rosse, since they never yet caught sight of us. Still is our minute sphere benignly noticed by the eye of Omniscience, who, at once the Creator, Governor, and Preserver of the Universe, and of every portion of it, has beneficently shown that, amid the surrounding grandeur, man is not overlooked, and that he is—"sic parvis componere magna,"—as much belonging to the fleet when in a cutter as on board a three-decker.

The Cycle which follows will contain my examination of these wonders as far as it went; but some preliminary remarks may be necessary for the tyro, even at the risk of repetition.

§ 1. The Fixed Stars.

While our knowledge of the solar system shows the height to which human reason, guided by unerring principles, has ascended; our ignorance of the stellar masses reveals how small a portion of the universe is open to human intelligence. To the eye of the common observer, the stars appear to preserve their relative distance in the heavens, the angle subtended by any two of them, being the same in all parts of the earth. From this apparent coherence they were designated *inerrantes*, to distinguish them from the planets, or *errantes*, which were seen to change their positions: hence also they were generalized as the Fixed Stars, though, as we shall presently see, the term is not exactly correct. The ancients had some strange notions of these glorious bodies. Anaximenes considered the stars as merely ornamental, and nailed like studs in the crystalline sphere; and his views, however puerile, cannot be said to have yet expired. Pythagoras, indeed, pronounced each star to be a distinct world, with its own land, water, and air; but the Stoics, Epicureans, and almost all the ancient schools of philosophy, held that the stars were fires that required *pabulum*, and that therefore they were perpetually nourished by the caloric, or igneous matter, which incessantly streams from the centre of the universe. Callimachus describes the circumpolar stars as feeding on air; and Lucretius, pondering on the nature of things, and not doubting the fact, asks, "Unde æther sidera pascit?" Anaxagoras deemed that they were stones whirled upwards from the earth by the rapid motions of the ambient ether, the ardent property of which kindles them into stars; and this opinion prevailed very widely, though opposed to the notion of their being spiraculæ, or breathing holes of the universe. In later times they were designated the Eyes of Providence. Astronomers and astrologers were constantly pestered, with inquiries as well respecting the nature as the use of those bodies; just with as much reason as Nebuchadnezzar required his soothsayers not only to interpret his dream, but to relate the dream itself, which had escaped his royal memory.

The contemplation of the order and harmony of our own system, has induced numbers of astronomers to neglect the stars, as objects of secondary importance. This, however, is a serious error. Hipparchus gave a noble proof how well he understood the question. Copernicus left earnest advice to his scholar Joachim, to apply himself to the fixed stars, without which there could be no hope of *attaining* to the true places of the planets: and Tycho Brahé, "Danorum celeberrima gloria gentis," undertook a new and more accurate survey of the sidereal host. Keill declares, "It is upon the observation of the fixed stars, as upon immovable pillars, that the whole science of astronomy is erected, and by them it is sustained." But no one has shown their use more forcibly than Sir John Herschel, who, in pronouncing the award of the Astronomical Society's gold medal to Mr. Baily for his Sidereal Catalogue, with admirable eloquence thus expressed himself:

The stars are the land-marks of the universe; and amidst the endless and complicated fluctuations of our system, seem placed by its Creator as guides and records, not merely to elevate our minds by the contemplation of what is vast, but to teach us to direct our actions by reference to what is immutable in His works. It is indeed hardly possible to over-appreciate their value in this point of view. Every well-determined star, from the moment its place is registered, becomes to the astronomer, the geographer, the navigator, the surveyor, a point of departure which can never deceive or fail him, the same for ever and in all places, of a delicacy so extreme as to be a test for every instrument yet invented by man, yet equally adapted for the most ordinary purposes; as available for regulating a town clock, as for conducting a navy to the Indies; as effective for mapping down the intricacies of a petty barony, as for adjusting the boundaries of transatlantic empires. When once its place has been thoroughly ascertained and carefully recorded, the brazen circle, with which that useful work was done, may moulder, the marble pillar totter on its base, and the astronomer himself only survive in the gratitude of his posterity: but the record remains, and transfuses all its own exactness into every determination which takes it for a ground-work, giving to inferior instruments, nay, even to temporary contrivances, and to the observations of a few weeks or days, all the precision attained originally at the cost of so mnch time, labour, and expense.

It had long been an axiom that the stars were too numerous to be counted by man. The number of those seen by the naked eye at once, is seldom much above a thousand; though from their scintillation, and the indistinct manner in which they are viewed, they appear to be almost infinite. Indeed, albeit the keen glances of experience might do more, the whole number that can be generally perceived by the naked eye, taking both hemispheres, is not greatly above three thousand, from the first to the sixth magnitudes, in about these proportions:

I.	II.	III.	IV.	V.	VI.
20	70	220	500	690	1500

Riccioli asserts, that he who should say that there are above 20,000 times 20,000 stars in the "militia of the heavens," would say nothing improbable: this is vast, but we may now safely declare that nearly one hundred millions of suns are within telescopic reach, and every optical improvement reveals more*. If we cannot call them infinite, we must agree with Halley's apparent paradox, that they are more than any finite number, and some of them more than at a finite distance from the others; at least we must come to the conclusion that they are beyond expression innumerable, and that the most ardent imagination can set no bounds to the extent of the universe.

However much the stars are further from the sun than the remotest planet, they are yet found to shine much brighter than such planet; and since we know of no other luminous body besides the sun, whence they can derive their light, it follows, that they shine by their own native light: indeed, no other conclusion can be drawn, since notwithstanding distances immeasurable, they are comparable to the sun in brilliancy. There is a direct mean of putting this question beyond all doubt, namely, the stellar light, like the solar, shows itself wholly unpolarized; while every reflected light, celestial or terrestrial, betrays itself as such by properties acquired through polarization.

The scintillation, twinkling, or apparently agitated emission of light, above alluded to, is owing to sudden changes in the refractive power of the air, which would not be sensible if the stars, like the planets, had discs; but the telescope takes off the scattered rays which cause the radiation to our vision, and, under high powers, raises a spurious disc. I have found the twinkling to be more powerful in low than in high altitudes,

* When M. Chambre broke a lance with the astrologers in 1653, he ridiculed them for limiting the number of stars to 1028, wherewith they had to consult the destinies of the world; for he declared that the eight spheres, properly packed, would stow no fewer than 71,209,600.

which shows that much of it depends upon atmospheric density, as well as on the effect of the emitted rays of light on the retina. The cause was long an exercise for the opinions of philosophers. Aristotle ascribed the scintillations of the stars to their excessive remoteness; Gassendi considered them as *tremulations* of their primigenial light; and Hevelius attributed them partly to axical gyration, and partly to an *evibration* of their lucid matter, their luminous property being ever considered as innate; "omnes stellas lumine lucere suo," said Macrobius.

The stars are divided into orders or classes according to their apparent magnitudes. Those that appear largest to the naked eye, have been called stars of the first magnitude; those that appear next largest, of the second magnitude; and so on to the sixth, which comprehends the smallest stars visible to the naked eye. All those which can only be perceived by the help of a telescope, are called telescopic stars. This classification, however, is, up to the present hour, a mere conventional and arbitrary usage, formed by observers according to the brightness or apparent quantity of light which comes from those bodies; and until a systematic standard shall be established, we may acknowledge with Schickard, "veras illorum magnitudines verè ignoramus." The very term Magnitude was not general, and we find old Leonard Digges speaks of "Starres of the first lyghte." In the present confusion, the stars of each class are not even of the same apparent brilliance. In the first class, or those of the first magnitude, there are scarcely two that appear of the same size, and the intermediates through the artificial classing, are numerous and often perplexing. The elder Herschel observes, that "the inconvenience arising from this unknown, or at least ill-ascertained standard, is such, that now our most careful observations labour under the greatest disadvantage. If any dependence could be placed on the method of magnitudes, it would follow, that many of the stars had undergone a change in their lustre or apparent magnitude, even since the time of Dr. Flamsteed. Not less than eleven stars in the constellation of Leo, for instance, have undergone a change of lustre." Now such a supposed change must be attributed to the uncertainty of the standard of magnitudes, rather than to any real alteration in the brightness of the stars. As we know scarcely anything of the star's distance from us, its absolute magnitude, or its intrinsic brightness, all conclusions must in some measure be conventional: photometry promises to lend a powerful assistance, and under such aid something may yet be done, although but little attention has been hitherto paid to the proposal of a prize for a successful photometer by the Royal Astronomical Society, in 1824. M. Steinheil, and the compilers of the Berlin zones, are said to be now occupied with the subject, and will probably wipe off the discredit of leaving so many experiments unconfirmed. My son, Charles Piazzi Smyth, now at the Cape of Good Hope, has recently suggested a method of observing the apparent magnitudes of stars, which is explained in the following extract from the *Monthly Notices* of the Astronomical Society, 8th of December, 1843:

He proposes to employ telescopic vision, and to measure the degree of brightness of every star by means of the obscuration which is necessary to make it vanish. By this means, the necessity of direct comparison between stars taken two and two is avoided, and an absolute zero is established.

For producing the obscuration, he proposes, in the first place, a long wedge of blue-coloured glass, (with its prismatic qualities counteracted by a similar transparent wedge,) made to slide between the object and eye-glasses, a little way out of focus. This wedge might be fixed on the eye-end of the telescope, mounted either in a micrometer frame, or made to move in the manner of a barometer scale.

Another plan is, to have a coloured *disc* of glass in the tube, capable of sliding up and down in it, by which means the object will be differently obscured, on account of the variation of the diameter of the pencil of rays at different distances.

The author then dwells on the method of observation, the means of getting rid of the atmospheric effect, the establishment of a common unit of comparison, and the obviation of the practical difficulty of obtaining a uniform rate of obscuration.

Many stars have been noticed to be periodically changeable in brightness, and are therefore called *Stellæ versatiles*, or variable stars. Comparatively little attention has been devoted to this class of bodies till recent times; those who have most cultivated this branch of astronomy being Montanari, Fabricius, Maraldi, Kirch, Goodricke, Pigott, Harding, and the two Herschels. Of one of these M. Lalande reported, in the fourth volume of Montucla's *Histoire des Mathématiques*, "Dans les Pays-Bas Autrichiens, actuellement Français, l'astronomie ne paraît pas avoir été cultivée; le seul observateur de ce pays est un gentil-homme Anglais, M. Pigott qui, après avoir passé à Caen plusieurs années occupé de l'observation, et en ayant fait de fort curieuses sur les étoiles changeantes, s'était fixé, en 1772 et 1773, dans les Pays-Bas, pour y coopérer à un grand travail désiré par le gouvernement, qui consistait à rectifier la carte du pays, *ce qu'il a fait gratuitement et même à ses frais.*" It is singular that this unaccountable neglect should have fallen on a branch which is so admirably adapted for the amateur.

Various hypotheses have been stated for these changes: some suppose that the periodical stars have vast dark spots, and very slow rotations on their axes, by which means they disappear when the dark side is turned toward the earth; others are of opinion that the luminous surfaces of these bodies are subject to perpetual change; and there are those who ascribe the transient variation in the vivacity of their light, to the interposition of large planets which revolve round them, and thus intercept the rays when in conjunction. Another opinion is, that their swift rotation generates a very oblate spheroid in the orb itself, and consequently, when the plane of its equator coincides with the line of vision, the light appears at its minimum. Maupertuis seems to have started the notion, of some being so flattened as to acquire the figure of millstones. Our ignorance, however, of the nature, constitution, and local conditions of those remote masses, utterly precludes our arriving at any definite conclusions; and indeed the periods differ so greatly in duration, that the same cause is hardly assignable to the whole. The elder Herschel considered, that of all the stars which are singly visible, about one in thirty is undergoing an observable change. The variable stars attain a certain maximum of brightness, and by degrees suffer a diminution of it, in some instances vanishing entirely; but the increase of light takes place in almost every case more rapidly than the diminution. About twenty stars are now pretty well established as variable, and upwards of fifty are strongly suspected of being so. Some of these objects are treated of in the Cycle, to the extent of all that is yet known, so that it is only necessary here to state, that the most remarkable in our hemisphere are:

Star.	Change of Magnitudes.	Period.
β Persei (*Algol*)	2 to 4	$2^{d}\ 20^{h}{\cdot}7$
δ Cephei	3 to 5	5 8·5
β Lyræ (*Sheliak*)	3 to 5	6 9
η Antinoi	3 to 5	7 4·3
a Herculis (*Ras Algeti*)	3 to 4	60 6
In Sobieski's Shield	5 to 8	62 0
3 Leonis	6 to 0	78 0
18 Leonis	5 to 10	311 23
o Ceti (*Mira*)	2 to	334 0
χ Cygni	5 to 11	396 21
γ Hydræ	3 to 10	494 0
ψ Leonis	6 to 0	many years.

Some of the stars appear to be in a great degree out of the reach of the attractive force of other stars, whence Sir William Herschel, from analogy, considers them as centres of extensive systems like our own. Among them, with probably many others, are:

The Sun	Sirius	Menkab
Lyra	Canopus	Schedir
Capella	Markab	Algorab
Arcturus	Bellatrix	Propus (1 Gemin.)

Many of the changes among the stars must, for some time to come, be imputed to wrong entries in the registers, mistakes in reading off subdivisions, and other liable errors of observation; yet there does not seem to be a reasonable doubt but that some stars have actually disappeared, and that new ones have come into sight. It was a phenomenon of the latter nature, which made so great an astronomer of Hipparchus; and it is related that a star blazed near Altair, A.D. 389, which remained for three weeks as bright as Venus, and afterwards disappeared. The extraordinary apparition of the new star which astonished Tycho in 1572, will be found in the Cycle under 55 Cassiopeæ, p. 55; and that discovered by the scholars of Kepler in 1604, at p. 387. A star of the third magnitude was found by Dom Anthelme, a Carthusian of Dijon, in December, 1669, close to the Swan's Bill; which, after undergoing some singular fluctuations of light unexplained by the *Burattina* telescopes of the day, disappeared, and has not since been seen. On the other hand, several stars which have been distinctly observed, and enrolled in authentic catalogues, are completely lost, or have undergone such changes that they can no longer be found: such are 80 and 81 Herculis, both of the fourth magnitude; 19 Persei, 108 Piscium, 73 and 74 Cancri, 8 Hydræ, and others. On the 10th of October, 1781, Sir William Herschel distinctly saw Flamsteed's 55 Herculis, a star of the fifth magnitude, and noted that it was *red:* on the 11th April, 1782, he again observed it, but nine years afterwards it was not to be found. My search after 42 Virginis, which Sir John Herschel missed in May, 1828, is detailed in the CYCLE under ε Virginis, p. 292. Geminiano Montanari, as far back as 1670, was so struck with the celestial changes, that he projected a work to be intituled the *Instabilities of the Firmament*, hoping to show such alterations as would be sufficient to make even Aristotle—were he alive—reverse his opinion on the incorruptibility of the spangled sky: "There are now wanting in the heavens," said he, "two stars of the second magnitude, in the stern and yard of the ship Argo. I and others observed them in the year 1664, upon occasion of the comet that appeared that year. When they first disappeared I know not; only I am sure that on the 10th of April, 1668, there was not the least glimpse of them to be seen." Startling as this account is—and I am even disposed to question the fact—it must be recollected that Montanari was a man of integrity, and well versed in the theory and practice of astronomy; and his account of the wonder will be found—in good set Latin—in page 2202 of the *Philosophical Transactions* for 1671.

The distance of the stars is a most momentous question, but it is one on which some welcome light is now thrown by Bessel, Struve, Henderson, and Maclear. When Seneca, meaning to hint that immortality was not attainable by common efforts, said that there is no easy way from the earth to the stars—*Non est ad astra mollis à terris via*—he was pronouncing a great astronomical truth; the hunting for the assigned distances between them having long been reckoned among the *pseudo-eurekas*, or mare's-nests of astronomy. Pliny considered such investigation as little better than a piece of madness; and Riccioli prefaced his discourse with these words, "parallaxis et distantia fixarum non potest certa et evidenti observatione humanitùs comprehendi." Leonard Digges, however, a mighty diver into the τό πᾶν, or abyss of space, saw no great difficulty in the matter: for in his *Prognostication Everlasting*, (1556,) he gives the distance of the stars to the greatest nicety, and adds: "Here *demonstration* myght be made of the distance of these orbes, but that passeth the capacite of the cōmō sort." These are his results:

From the earthe to the moone	- -	15,750 myles
„	moone to Mercurie - -	12,812
„	Mercurie to Venus - -	12,812
„	Venus to the sunne - -	23,437½
„	sunne to Mars - - -	15,725
„	Mars to Jupiter - - -	78,721
„	Jupiter to Saturne - -	78,721
„	Saturne to the firmament - -	120,485

Whence it clearly follows, that from the city of London to the star Sirius, it is exactly 358,463½ miles.

These *computations* were, however, far from settling the question. The hypothesis of Digges's great cotemporary, Copernicus, began to be discussed, and it brought forward the striking astronomical inferences, that as the enormous displacement of the spectator's site which the Copernican system supposed was not supported by a corresponding change in the positions of the fixed stars, either they were at infinite distances, or the earth was motionless. As the latter view soon succumbed before the Copernican hypothesis, the attention of astronomers was strongly drawn to the subject, and Hook, Flamsteed, and Cassini made many attempts to trace the parallax. Römer and Horrebow ascribed parallactic effects to certain stars, but it is now seen that their means must have been quite inadequate to the solution of so nice a problem; where the angle appears even as yet to be almost inappreciable with the most perfect instruments ever yet invented. Römer discontinued his inquiry, on account of a certain variation which he detected in the declinations of stars, which can neither be attributed to refraction nor parallax: Bradley then took the field with better instrumental means, and by his discoveries of aberration and nutation, explained the apparent anomalies which had perplexed the discoverer of the gradual transmission and finite velocity of light. Still the wished-for stellar distance eluded every attempt to detect it, until very recently, when the brilliant success of practical science has put us in possession, or nearly so, of this important element: yet in the course of the Catalogue, I have occasionally adverted to the exertions of the great astronomers on this important element, especially as it is thereby seen how they all gravitate towards one decisive conclusion. Among these, however, the *episode* of the dispute between Dr. Brinkley and Mr. Pond must not be overlooked, since it led to wonderful exactness of method in seeking to deduce the value of parallax from meridian observations, where the quantity sought is actually less than that arising from the uncertainty of refraction. Dr. Brinkley prosecuted his observations with the Dublin 8-foot altitude and azimuth circle: Mr. Pond with the Greenwich 6-foot mural circle: the first contended that he had established the parallax of Wega, Deneb, and Altair; while the second maintained that no sensible parallax was shown in any of those stars. The controversy lasted several years, and, as usual, there were partisans on both sides, who, provided they actually read the able expositions produced on either hand, must have been instructed as well as interested in the discussion. We *now* know that Dr. Brinkley was mistaken, and that Mr. Pond was right in his conclusions; but the Royal Society availed itself of an excusable latitude, and awarded their Copley Medal to each of the disputants.

A tolerable notion of the effect of the parallactic change may be obtained, by taking the angles of distant objects from various parts of a measured circle only a few yards in diameter. The observer will find in every different position, a different reading; and circular instruments are constructed of such nicety, that their several readings would give differences in the angles observed, even when the distance of the observed objects was at least a hundred thousand times the diameter of the circle itself. Now—as Sir John Herschel has pointed out—instruments of this perfect kind have been employed to observe the angular distances of the stars from opposite points of a great circle of the earth; but, however effective the method and principle have been in determining the diurnal parallax of the sun, they have never yielded a trace of the *vera causa* sought. It would therefore follow, that the distance of the stars is more than a hundred thousand times the diameter of the earth; but how insignificant is this distance, when even the angle formed by two lines drawn to a fixed star from diametrically opposite points of the earth's orbit, which in round terms may be assumed a base of nearly 200,000,000 of miles, is too small for observation. Yet as we know that, if the earth's orbit subtended at the nearest fixed star the angle of a single second, the parallax could not have escaped detection; the least assignable distance would be 4,800,000,000 radii of the earth, an expression of no common unit, each radius being equal to 4000 of our miles. The task was evidently too delicate for meridional circles, and every attempt at it by way of declination and right ascension broke down, till the late attacks of Messrs. Henderson and Maclear upon *a* Centauri. Sirius seems to be upon the point of yielding, but *a* Lyræ, after showing terms of capitulation to M. Struve, has again entrenched itself in the vastness of space, from which our Astronomer-Royal cannot dislodge it by any meridional operations.

Under a totally different treatment, and with a heliometer of hitherto unheard-of dimensions and properties, M. Bessel betook himself to that extraordinary star 61 Cygni, with the success I have recorded in page 496 of Vol. II. As those researches answer the most crucial test of examination, his actual discovery of parallax is acknowledged by the most experienced astronomers. It may here be recapitulated, that he found the star to be 657,700 times the distance of the sun from us, or 62,481,500,000,000 miles, an expanse of which the mind is utterly incapable of grasping a correct conception. Even light, the *anima mundi*, which flies along at the rate of almost 12,000,000 of miles per minute, would be nearly ten years in reaching us from such a distant object. Such wonderful numbers induce Sir John Herschel to conclude, that when we observe a change in any of the smaller stars, we are reading its history of a thousand years ago! But his father's views are truly startling and magnificent. In theorizing, that gifted man assumed that the stars were all of the same size, and that they are uniformly distributed through space; which assumptions, though not proved to the strict letter, are sufficiently so for taking the aggregate of many thousands of those bodies. He thus supposes that the stars of the second magnitude are removed as far from stars of the first magnitude as the latter are from the sun. Sirius, for example, the brightest star in the heavens, would become a star of the second class if removed to double its actual distance from us; at three times that distance, it would be reduced to the third magnitude; and at ten times that distance to the tenth magnitude. This being premised, he found with his 20-foot telescope, that he could *gauge*, and penetrate into space, seventy-five times further than with his naked eye; ninety-six times further with a 25-foot instrument; and with his great telescope 192 times the distance reached by unassisted vision. Now since the naked eye can discern stars of the seventh magnitude, it follows that stars of the 1344th order of distances were rendered visible by the 40-foot telescope. Light would be nearly 14,000 years coming this distance to the earth, though ever travelling at the known rate of 192,000 miles in a second of time. Consequently, if such a body were extinguished, its light would yet continue to be seen from the earth for 13,440 years*!

Such wondrous conceptions, which are scarcely beyond the bounds of probability, offer a wide field for contemplation. Those vast luminaries were not created merely to ornament the spacious canopy of heaven, or called into existence for the purpose of uselessly lighting up the solitudes of space; and it cannot be doubted, that the Eternal Mind has an end in view corresponding to the magnificence of the means employed. "Surely," says Herschel, "not to illumine *our* nights, which an additional moon of the thousandth part of the size of our own would do much better; nor to sparkle as a pageant void of meaning and reality, and bewilder us among vain conjectures. Useful, it is true, they are to man as points of exact and permanent reference; but he must have studied astronomy to very little purpose, who can

* Huyghens believed that there may be stars at such inconceivable distances, that their light has not yet reached the earth since its creation. Laplace started another condition: he held that a luminous star, of the same density as the earth, and having a diameter 250 times that of the sun, would exercise such an attraction over the rays of light emitted from it, that they could never reach us; and that consequently the largest luminous bodies in the universe are invisible to us. This can hardly be admitted, if we adopt the Undulatory Theory.

suppose man to be the only object of his Creator's care, or who does not see in the vast and wonderful apparatus around us, provision for other races of animated beings." Indeed it checks pride to recollect, that if our sun, with the whole system of planets, asteroids, moons, and comets, were to be removed from a spectator to the distance of the nearest fixed star, not one of them would be visible, except the sun, which would then appear but as a star of perhaps the second magnitude. Nay more, were the whole system, of which our globe forms an insignificant member, with its central luminary suddenly annihilated, no effect would be produced on those unconnected and remote bodies; and the only annunciation of such a catastrophe in the sidereal "Times" would be, that a small star once seen in a distant quarter of the sky had ceased to shine.

While at this point a remark may be made, as to the custom of noticing these bewildering and inconceivable distances in miles, instead of referring them to larger units. For this—as there is an inability in the mind to conceive a very high number—there is perhaps no better excuse than that which was made by Dr. Derham, in his *Astro-Theology*, saying, it is "for the sake of such as are not very conversant in astronomical matters and dimensions; who can better understand you, when you say that it is so many miles, than so many degrees, minutes, or seconds,—or semi-diameters of the earth or other planets." But the numerals shown by astronomers, are not so awful in quantity as those of the circle-squarers and $9^{(9^9)}$-men; and even now we see that the homœopathists recommend opium to be taken by the *decillionth* of a grain! Let the Chinese look to this.

Though the relative situations of stars have a high degree of permanence, the phrase *fixed* is rather comparative than absolute. Strictly speaking, there is perhaps not a fixed star in the heavens. When their apparent motions are cleared of the effects of aberration, nutation, and precession, all of which depend on the mundane motions, as well as of the grand diurnal revolution, they have still a slow motion in a given direction through space; a motion which will inevitably mingle the constellations in a few billions of ages. In demonstrating the universality of gravitation, and consequent motion, Laplace observes, "Toutes les étoiles, en vertu de la pésanteur universelle, doivent graviter les unes vers les autres." It is true that the delicacy of this quantity rendered it impossible for anything to be known of its existence in former ages, by observation, and therefore the data hitherto afforded, are insufficient for yielding definite conclusions in all cases; but the proper motions of so many are now before us, that a short time will show whether they are real or apparent. Halley, on comparing the observations of Hipparchus with those of Flamsteed, had found incongruities which, after strict reductions, could not well be ascribed to errors of observation alone; though the nature of the early records was not such as to preclude doubt. When, however, Bradley's exact results were compared with those of Piazzi, these differences became palpable; and other astronomers have pursued the inquiry with the diligence it deserves and demands. The prospect is promising; for even if many of the results now registered shall prove to be the effect of inaccurate observation, and be swept from the list, the remaining ones, the movements of which become confirmed, will be wonderfully enhanced in interest.

Halley conceived the whole solar system, together with all the stars, to be in motion around some unknown point in the firmament, which is the common centre of gravity of the whole. Scintillations of this notion had long, though vaguely, glimmered in philosophy, as expressed by Lucretius, *De Rer. Natura*, lib. i., and it was thought that but for such a motion, all the celestial bodies must have collapsed and formed a chaos. Halley's suggestion as to the proper motions of stars, was followed up by Le Monnier and Cassini; but Tobias Mayer, by a comparison of the mean apparent places of eighty of Römer's stars with his own determinations, confirmed the suspicion; and he also considered that the changes thus brought to light, might be produced by a progressive translation towards a certain quarter of the heavens. The elaborate Alsatian philosopher, J. H. Lambert, in his *Cosmologische Briefe*, (1761,) suggested that all the stars in the universe are collected into systems; that all these systems are in motion; that the individual stars of each system move round a common centre of gravity, which may possibly be a large opaque globe; and that all the systems of the universe, as one related system, revolve about some grand centre, common to the whole*, which alone, of the whole universe, can be at absolute rest. The possibility of a solar motion was treated upon theoretical principles by Dr. Alexander Wilson, of Glasgow; and M. de Lalande deduced the same opinion from the rotatory motion of the sun, by supposing that the same mechanical force which made it revolve round its axis would also displace its centre, and give it a motion of translation in absolute space.

Sir William Herschel now took up the question, and treated it with his usual zeal and ability: he saw that if the sun really has a motion directed towards a particular point, the stars in that quarter must appear to recede from each other during such advance, while those in the opposite region must seem to close as the sun left them. By a process which he has fully detailed in the seventy-third and ninty-fifth volumes of the *Philosophical Transactions*, he arrived at the conclusion, that the sun is actually gravitating towards the constellation Hercules, in some grand path, the nature of which it is necessarily reserved for after-times to discover. But notwithstanding Laplace and Prevost received this conclusion, Maskelyne, Bessel, Biot, and Lindenau opposed it; and though the recent and laborious investigation of M. Argelander upon 560 stars—390 of which are strictly scrutinized—go far to confirm it, there is still a cloud of doubt and objection to be removed. Practical astronomy, however, is hardly sufficiently advanced to yield a full and satisfactory conclusion upon so delicate an inquiry: a large number of the proper motions must be decided in amount and course; and centuries may yet be required for its demonstration. "If we theorize too soon," observes Sir William, "we run the risk of wandering from the truth; yet if, on the contrary, we heap observations on observations without endeavouring to perceive their laws, we labour blindly."

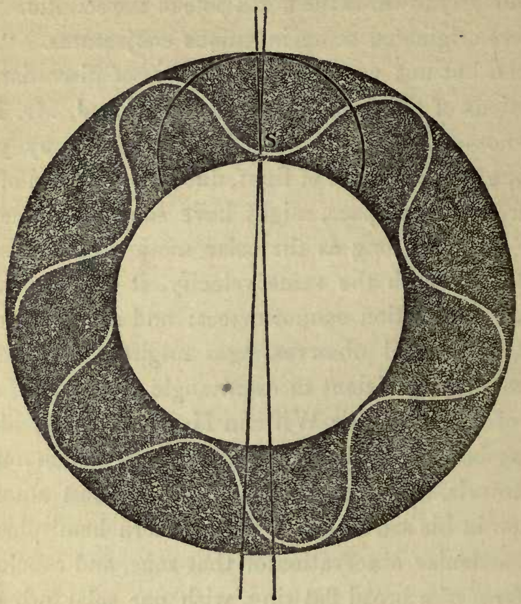
* Pascal, that "paradoxical individuum of the human species," as Bayle sarcastically designated him, thinking of the immensity of creation, made the happy expression that its centre is everywhere, and its circumference nowhere. His great contemporary, Milton, said:

"As God in heav'n
Is centre, yet extends to all."

Still the majority of practical astronomers must be convinced that the solar system is actually moving through space, at the rate perhaps of 0″·1 annually (1° in 36,000 years); and that its motion is directly towards the north pole of the ecliptic. This *fact* has therefore originated some ingenious conjectures. "Amongst the possible, but not very probable, causes of discordance in the proper motions of the fixed stars," said my friend, Mr. Pond, the late Astronomer-Royal, "it occurred to me, many years ago, that perhaps the aberration of light, due to the motion of the solar system through free space, might have some influence on their positions." But as long as the solar motion continues uniform and rectilinear, with the same velocity, it must be a constant effect which observation cannot detect; and even under different conditions, Mr. Pond observes, ages might elapse before data could be collected sufficient to disentangle the effect of one cause from that of another. Sir William Herchel's noted idea of the Milky Way being a thin stratum of stars, in which our central luminary travels, has received countenance almost amounting to confirmation in his son's visit to the southern hemisphere, where he made particular observation of that zone, and concludes it to be in the form of a broad flat ring, with our solar orb ex-centrically placed therein.

This wonderful view—with Argelander's confirmation of the solar translation—attracted the deep attention of Professor Mossotti, of Corfu; and he kindly forwarded to me his results. As the assumed system agrees well with the laws of geometry and perspective, he sought whether it was equally reducible to those of mechanics. The process ingeniously suggested that our sun and its system follow a serpentine course in this broad ring, alternately visiting its inner and outer edges, in meanders which are expressed in the following figure; where, supposing the sun to be at S, in the inner edge of the *quoit*, it will be seen where radii passing laterally through the annulus from it, will present the greatest glow. The serpentine course results from bodies under reciprocal action being confined within the limits of a ring, where the prevailing attraction will be seated in a line passing between its inner and outer margins; the durability of which must be tested by Laplace's fine theory founded on

Saturn's ring, and Plana's doctrine of the attraction of bodies of various forms. From the latter we deduce, that a body presented to the interior or exterior edge of a broad ring, will be



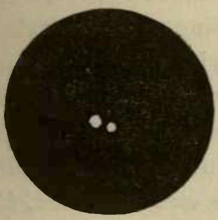
attracted to the central line, but will not remain there, because in consequence of its velocity it will shoot beyond it, and though decreasing in speed will reach the opposite boundary; or at least will proceed till its progress is counterbalanced by the attraction of the central region. Being now dragged backwards, as it were, it will begin to return, and increasing in velocity as it re-approaches the point of attraction, it will again overshoot its mark, and then relaxing in speed, will not only feel the central attraction resume its influence, but will also, while velocity and attraction are both weak, be more susceptible of the first impulse of projection given it; which impulse, on the inference that we are gravitating towards Hercules, we are authorized to take for granted. These united elements thus produce an oscillating meandering motion, which may be repeated indefinitely in the course of a whole revolution throughout the circumference of the Milky Way: as to the time requisite to perform the grand *annus magnus*, only myriads of centuries can possibly suffice.

§ 2. The Compound Stars.

The most remarkable of these wondrous bodies are pretty largely discussed in my sidereal Catalogue; but it may be necessary to give a general view of our knowledge respecting them.

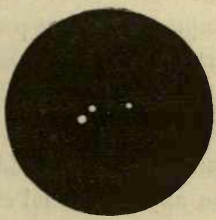
In examining the celestial bodies, many of those stars which appear single to the naked eye, when examined with the telescope, are found to consist of two or more stars, and are termed double, triple, quadruple, or multiple, according to the number of individuals of which the group consists. Thus *a* Geminorum, Castor, which is cited by the Greek, Arabian, and Middle-age observers as single, with a sufficient optical power, proves to be a beautiful pair of stars of the third and fourth magnitudes; ζ Ursæ Majoris, Mizar, the zenith-point of Paris, was long observed before its doubleness was suspected*; and ε Lyræ, which to unassisted vision seems an elongated star, under telescopic treatment is found to be a double-double star. Of the first, or *double* class, ε Boötis, *a* Herculis, ξ Aquarii, 36 Andromedæ, ω Leonis, λ Ophiuchi, and π Aquilæ, may be instanced as fine specimens; of the *triple*, ζ Cancri, 11 Monocerotis, γ Andromedæ, 12 Lyncis, ξ Libræ, and ψ Cassiopeæ; of the *quadruple*, π^2 Canis Majoris, β Lyræ, and 8 Lacertæ; and of the *multiple* order, β Capricorni, σ Orionis, and β Equulei. The following diagrams of objects, greatly separated by high magnifying powers, will illustrate the statement:

Double.



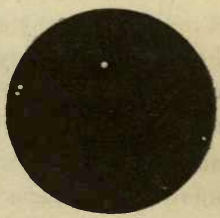
γ Leonis.

Triple.



ξ Libræ.

Quadruple.



178 P. xx. Delphini.

* It is asserted that Mizar was noted as a double star on the 7th of September, 1700, by Godfrey Kirch; as well as by his celebrated and scientific wife, Mary Margaret.

The first recorded application of the term *double* to stars in juxta-position is the διπλοῦς which Ptolemy gave to ν Sagittarii. His example, however, was so rarely followed, and so little were

such subjects specially observed, that so lately as 1754, when Sir John Hill published his *Astronomical Dictionary*, the word "double-star" did not obtain a place in it. This was owing to its having long been supposed that the contiguity of compound stars was merely an optical deception, arising from both components having a fortuitous opposition from being nearly on the same visual line drawn from the earth, as in the annexed diagram, where stars seen as on the small circle, may be actually only posited as shown below them. This phenomenon, however, had not escaped the notice of Galileo, who soon considered it to be a means by which the long-wished-for stellar parallax might be obtained: and the notion was just in its conception; for if the composite objects were composed of independent members at a great distance from each other, it is clear that the quantity of annual parallax, would be very different for the two stars; and consequently, from being unequally affected by this cause, they will appear at one time to recede from, at another to approach towards, each other according to laws dependent on their relative positions and distances,—the subtended angles showing the parallactic displacements. Hook, Flamsteed, Molyneux, and Bradley, severally attempted this most promising of all methods; but the insufficiency of the means hitherto employed still leaves it open. At length Sir William Herschel, among other great and as yet unparalleled astronomical labours, directed his continued attention to the compound stars, and added more largely to our knowledge of them than any individual of his own, or indeed, of any other age. When he commenced his important inquiries, he was not aware of more than *four* stars that came exactly under the description of double stars; but, as he emphatically expresses it, he opened the Great Book of Nature, and drew so largely from it, as to offer a vast arena to speculation relative to the structure of the universe. His first measurement seems to have been that of the well-known trapezium in the nebula of Orion, in 1776.

Sir William was induced to apply himself particularly to the compound stars, in the hope that by observing them from the opposite parts of our orbit, Galileo's suggestion might be realized, and the desideratum detected. His means were vastly more powerful than those of his predecessors; and as he could measure the apparent distance of two neighbouring stars from each other, the problem of parallax was thus reduced to that of finding a double star in which a variation of distance is observable, when following the law which the earth's change of place requires. Many brilliant stars have an inferior companion so close, as not to be easily separated with small telescopes; but if the opening should apparently increase for six months of the earth's progress in its orbit, and again diminish during the next six months, the variation of this small angle must ultimately lead to an important determination. Sir William gave the formulæ requisite, and a considerable list of these small angles; yet not having applied any of them, it was thought that he did not consider the observations to have been taken under the required circumstances*. But, in truth, an unexpected consequence led him from the investigation of parallax to researches even yet more profound. While attempting Galileo's problem, there followed a most important result, one which vies in interest with the discovery of Saturn's ring,—the progressive motion of light,—the revolution of planets on their axes,—the phases of Mercury and Venus,—and the general laws of motion. It was found that, in general, when stars of nearly equal proportions appear very contiguous, they are so dependent upon each other, as to be kept together by their mutual gravitation; that the smaller one moves round the larger, or, to speak expressly, that they revolve about their common centre in circles, or in similar ellipses, the

* The case is fraught with serious difficulties: from the insensibility of the annual parallax, it is now thought that the objects chosen should be 3′ or 4′ apart; and even then the distance would be ascertainable only if it does not exceed that which light may traverse in twenty years!

dimensions of their orbits being proportional to their relative quantities of matter, under a law which has been assumed to be that of gravitation. This splendid conclusion was not founded merely on probabilities. From a series of fine observations at certain intervals of time, the great leader of modern observers detected the fact, that several of the double stars had actually changed their situations with regard to each other; the revolutionary motion of some being direct, while that of others was retrograde. Thus he discovered that Castor was running against the order of the signs at the rate of nearly a degree per annum; ε Boötis was revolving in accordance with that order about half a degree; and ζ Herculis, which he saw composed of two fine stars in July, 1782, appeared single twenty years afterwards, the one seen having actually occulted the other.

This last phenomenon, together with a similar one of δ Cygni, besides the singular nature of the transit or occultation, opened another view, since it was obviously a consequence of the line of junction of the two stars passing through the earth's orbit, which at that enormous distance is a mere point: in other words, the sidereal orbit is in the plane of our eye, for in instances of orbital verticality we can see both the revolving suns through the whole of their revolution. To meet the objection which might be started at a first glance, as to the degree of obliquity in which the distance is measured, interfering with the deductions for the real orbit, we may state that it hampers the projection in no way that is unprovided for. Indeed, where the distance is so minute as to render the measures difficult and inaccurate, from gravitation the orbit may be determined by means of the angles of position, and the corresponding times of observation, independently of the distance. With these elements, as Sir John Herschel has shown, a curve is graphically constructed, the tangential intervals of which will furnish the radii vectores on the known law of the apparent distances being equal to the square-roots of the apparent angular velocities. Either star may be assumed as the fixed one, the relative curve being the same for both. Astronomical observations generally show the movement of one merely with regard to the other, for, if we only collect the elements of a *relative motion*, the orbit thence deduced can only be relative;

that is, the curve which the smaller star would appear to describe to an observer placed on the larger, and fancying himself at rest. Nor is more done in determining the orbits of our own planet, for we refer their position to the sun without regarding whether he has or not a proper motion.

We may here allude to a striking instance of the utility of the doctrine of probabilities, when founded on inductive knowledge. So far back as 1767, the Rev. John Michell presented to the Royal Society his Inquiry into the probable parallax and magnitude of the fixed stars, estimated from the quantity of light which they afford us, and their particular circumstances of situation. In this document, the probabilities that no six stars in the whole heavens, of equal splendour to the faintest of the six bright Pleiades, would be within so small a distance from each other, are submitted to computation,—and the resulting odds are about 500,000 to 1. Extending the same argument to the smaller clusters,—as that in the hilt of Perseus's Sword, or the Præsepe,—the examples become still more conclusive. The author, therefore, predicts that one star may be found to go round another, and boldly pronounces that the Pleiades are not independent of each other. Having cited his analogies, he says, "We may hence, therefore, with the highest probability conclude, (the odds against the contrary opinion being many million millions to one,) that the stars are really collected together in clusters in some places, where they form a kind of system, whilst in other places there are few or none of them, to whatever cause this may be owing, whether to their mutual gravitation, or to some other law or appointment of the Creator. And the natural conclusion from hence, is, that it is highly probable in particular, and next to a certainty in general, that such double stars, &c., as appear to consist of two or more stars placed very near together, do really consist of stars placed near together, and under the influence of some general law, whenever the probability is very great, that there would not have been any such stars so near together, if all those, that are not less bright than themselves, had been scattered at random through the whole heavens."

Such were the lucid speculations of cultured genius; and the sagacious anticipator lived to see his predictions verified by the surprising exertions of the elder Herschel: in a letter to Mr. Cavendish, of May, 1783, inserted in the 74th volume of the *Philosophical Transactions*, he expresses his great delight at the result of those exertions, and, in a spirit of prophecy, says, "By far the greatest part, if not all of them, are systems of stars so near to each other, as probably to be liable to be affected sensibly by their mutual gravitation; and it is therefore not unlikely, that the periods of the revolutions of some of these about their principals, (the smaller ones being considered to be as satellites to the others,) may some time or other be discovered." That prediction has been fully realized; but it is to be regretted, however, that Mr. Michell soon afterwards discontinued his scientific inquiries, on succeeding to a benefice, for he was a man of unusual promise. He was one of the first who practically recommended Hadley's quadrant for the surveying of harbours; he proposed a method for measuring degrees of longitude upon parallels of the equator; he proposed the experiment followed by Cavendish for ascertaining the mean density of the earth; and he was one of the gentlemen "skilled in mechanics," chosen to adjudicate the parliamentary reward to Harrison for his time-piece. He also wrote a paper on the cause and phenomena of earthquakes, which was published in the 51st volume of the *Philosophical Transactions:* in this essay he displays original and philosophical views upon the structure and strata of the globe, and anticipates in a remarkable manner some of the geological theories which are now prevalent.

The grand discovery of the existence of binary sidereal combinations revolving about their common centre of gravity, was at first received with indifference or incredulity; while a still worse spirit was manifested by some, who considered their own reputation as undergoing an eclipse. A late professor at one of the universities was even wont to cool the zeal of the younger hands, by dilating upon the absurdity of drawing deductions from "viewing space through a highly-magnified medium," a phrase, which, however stultific, became habitual in his denunciations of the new celestial discoveries. A decennium of unaccountable neglect followed, during which nothing was contributed to the knowledge of those interesting bodies, except some occasional observations with meridian instruments; and Sir William Herschel's magnificent conceptions remained in abeyance. "Magna est Veritas, et prævalebit." The attention of various active astronomers was at last aroused, the means of examination were improved, and measures remarkable for their skill and accuracy were taken. Among the foremost who ascended this new step in science, were Sir John Herschel and Sir James South; their united operations were eminently successful in reviving the subject in the public mind, and were replete with interest. In the comparisons which necessarily ensued, it was found that some most extraordinary changes in the sidereal systems had taken place. That beautiful object, η Coronæ Borealis, had completed an entire revolution since Sir William Herschel first determined its angle of position, and was well advanced in a second rotation. It appeared that τ Serpentis, which Sir William had seen with a companion notably distinct from it, was so completely in one that the most powerful telescope could not then expose its duplicity; that the primary of ζ Orionis had become double, with its two small suns revolving around it; that in ψ Cassiopeæ, the two little stars probably revolve around each other, and then the two together about the large one. Moreover, the colours and magnitudes of some of them had undergone unaccountable changes; while η Coronæ, ζ Cancri, ξ Ursæ Majoris, and 70 Ophiuchi, revolved round their common centres of gravity with a motion so rapid, as to admit of the angular changes being measured from month to month!

Results of such importance could not fail to open the high road to discussion; and to M. Savary must be ascribed the merit of having first determined the elliptical elements of the path of a binary star from observation. In treating of ξ Ursæ Majoris, in the *Connaissance des Temps* for 1830, he announced the elegant geometrical property of four consecutive chords of an elliptic arc. He had previously shown how from the apparent ellipse the true one may be obtained, and thus the elements of the orbit; and he concluded that the dimensions of such an orbit might be determined by the known rate of the velocity of light, a suggestion more ingenious than applicable. M. Encke also gave a method on the same foundations, requiring four complete observations of position and distance to determine the relative orbit of two stars, which he applied to 70 Ophiuchi. But in 1832, Sir John Herschel published a singularly interesting investigation of the orbits of some of the revolving stars, in which, under the existing deficiency of exact data, he obtains the approximate elements of the orbit by an elegant graphical construction and numerical calculation: indeed, this "rich-in-sense" procedure is so simply clear and geometrical, as to be well adapted for the amateur. The subject-matter was, therefore, quickly called into action, and among other novel announcements, the *Nautical Almanac* for 1835 exhibited the ephemerides of ξ Boötis and γ Virginis*, under elements deduced from Sir John's valuable treatise. A very slight improvement in the present practice of observing binary systems, will enable astronomers to assign with exactness the duration of the ascending semi-revolutions, and the descending ones, of the stellar satellites, and the difference between their durations will be a step to their distances, when the distances will become another step to the determination of the masses of bodies which only present themselves, in the most powerful telescopes, as mere points of light without even appreciable dimensions! Application and zeal may supply these desiderata even in our own day; for in astronomical phenomena, precision of observation often balances length of period.

The algebraic formulæ by which these complicated motions are unravelled, rest on Newton's hypothesis, that the large and small star attract each other in an inverse ratio of their distance; and the computed orbits being proved by observation to obey the Keplerian laws, and approximate towards the fulfilment of prediction, is almost conclusive evidence, that the principle of gravitation extends into infinite space, and pervades the whole universe. It is true, that in some cases it is doubtful whether the apparent motion of these co-acting bodies, may not be produced by the movement of our system, supposing the stars to

* Professor Henderson, at my request, has recently computed an orbit for γ Virginis. His interesting letter to me on the occasion, will be found in the Appendix to this Volume.

be at different distances; but there are numbers which palpably show, that the forces by which they are mutually attracted vary like gravity inversely as the squares of the distances, and that the movements of these remote orbs are governed by the same laws as those of our own system. Until the relation, however, of their masses is known, this can only be advanced as a feasible speculation: ere long we shall probably know more about the matter. Whether the one individual move round the other, the latter round the former, or both round their common centre of gravity, will make no difference, so far as their relative orbits are concerned, where the stars are so distant as to undergo no sensible apparent parallactic displacement. In the ternary and multiple systems of these grouped suns, the most distant *comites* are usually found to be the smallest, while the nearest are often equal, or nearly so, to the primary star; our planetary system is governed on an opposite principle. But we are only on the threshold of a branch of the science, of which posterity will gain a glorious view; and there is no doubt but that the ephemerides of a future day will exhibit the reciprocal places of each member of that vast chain, with the same fidelity as they now show the places of the planets.

Those double stars which derive this appearance from their casual position in the same direction, are termed *optical;* in contradistinction to the *physical*, or such as are nearly similar in size and distance, and have been found to be binary or composite in motion and connection. Both classes are possessed of intrinsic interest: that of the binary and ternary systems in reciprocal dependence will be obvious; and where the proximity of the stars is merely accidental, the proper motions of the larger member may be readily watched, on the inference of the greater fixity of the small one from its remoter distance. Besides the optical power of the largest telescopes being brought to bear on such cases, micrometrical measurements are more to be relied upon for angles of position, than where they are deduced from differences of right ascension and declination taken by meridional instruments, as proposed by Mayer, *De Novis in Cœlo sidereo Phœnomenis*,—a work in which eighty objects, in pairs, were announced, that is to say, fixed stars with satellites, a somewhat daring term for his day. Indeed, it met with such contradiction and even ridicule, that he was obliged to write in defence of his theory, *Vertheidigung neuer Beobachtungen von Fixstern Trabanten;* Manheim, 1778. His object was to ascertain the proper motion of the stars by means of small ones that are placed near them.

Such I considered was the state of the compound stars in 1837, when the distinguished Professor Struve had the kindness to send me a copy of the extensive series of micrometrical measures which he had made in the Imperial Observatory at Dorpat: and this important work, as it must constitute a standard epoch and point of departure in the future progress of astrognosis, as well also from its being so constantly quoted throughout my observations, demands a particular mention here. It consists of a large folio volume, containing a luminous Latin Introduction of 180 pages, details of the observations in 332 pages, and a copious Index; which was printed at the expense of the Academy of Sciences at Petersburg, in the year 1837, and is dedicated to the Emperor Nicholas, under the title, *Stellarum Duplicium et Multiplicium Mensuræ Micrometicæ.* A glance over the introductory matter will explain the contents and value of a volume which is destined to be of the same importance to astrometers, as Bessel's *Fundamenta Astronomiæ* is to meridian observers.

On the appointment of M. Struve to the conduct of the Dorpat Observatory in 1813, he found a transit instrument of 8-feet focal length, and 4½ inches aperture, by Dollond,—and a portable telescope 5 feet long, with an object-glass of 3½ inches, which the author ascribes to Troughton; but as that artist only *fitted* telescopes, the optical portion was probably by Dollond or Tulley. The transit showed many stars with *comites*, which even Sir William Herschel had pronounced to be of difficult definition. The portable instrument was provided with a position micrometer, but had no means of measuring distances, and was in want of a parallactic mounting. Even with these imperfect means he worked very assiduously, and made some important remarks on the motions of α Geminorum, η Cassiopeæ, 70 Ophiuchi, ξ Ursæ Majoris. In 1820, he formed a Catalogue of 795 Double-stars, with their approximate places in Æ and declination, of which 500 were within 32″ of each other. Some of these were Herschel's, some Lalande's, and the rest his own. It must be observed that in this, as well as in his succeeding operations, he divides the stars into twelve magnitudes only, from Sirius to the *minimum visibile*.

Such ardour fortunately met with due encouragement, and in 1824, one of the most powerful and manageable instruments with which the heavens had ever been attacked, was placed in his hands by the munificence of his Sovereign. It consists of a superb refracting telescope with its equatoreal mounting, and clock-work motion, which gives the effect of observing in an immovable sky. The object-glass—justly esteemed the *chef d'œuvre* of the celebrated Fraunhofer—is 9·43 inches in diameter, with a focal length of about 14 feet; and every part—tube, eye-pieces, micrometers, and frame-work—is very admirably adapted to its purpose. It was, in fact, the most perfect optical instrument then in existence, whether for capacity, convenience, or the variety of its applications. "I stood astonished," said Struve, in a letter to that promoter of science, Mr. Francis Baily, "I stood astonished before this noble instrument, undetermined which to admire most,—the beauty and elegance of the workmanship in its most minute parts, the appropriateness of its construction, the ingenious mechanism for moving it, or the incomparable optical power of the telescope, and the precision with which objects are defined."

Armed with such ample means, M. Struve resolved on making an inspection of all the stars from those of the first to the eighth magnitude, which were visible between the north pole and the fifteenth degree of south declination. This was a difficult enterprise, and one well worthy of his instrument; and such was his assiduity, that in two years he reviewed and examined about 120,000 stars in the prescribed space. Among these he found 3112 close objects within 32″, of which 340 were on Herschel's list, and 447 in his own previous Catalogue.

Having previously received a meridian circle by Reichenbach in 1822, this diligent astronomer began observing the places of his double stars in right ascension and declination, and continued the operations till 1826, when he assigned that department to his assistant, M. Preuss. The 3000 stars above alluded to required each to be taken twice in both positions of the instrument; of which 12,000 meridian observations about 10,000 were already made by February, 1837: but several years of calculation have been requisite to deduce from these raw materials the mean apparent places, and then reduce them to one epoch. In consequence of this, the Catalogue now referred to gives only the result of micrometric measurements of distance and angular position, but with positions sufficiently approximate for finding and identifying the objects.

The book before us is therefore to be considered in relation to the progress of stellar combinations only, and as the fruit of twenty-three years' close application to that department, eleven of which were with imperfect instruments. Since the publication of the Catalogue of 3112 Stars, various rejections and additions have taken place, so that the total list now given to the public is only 2710. To these are appended, in a separate list, the positions and distances of 405 stars observed with the inferior means only, trusting that the anterior date may compensate in interest for their not being so precise as the later observations. It is, indeed, one of the peculiarities of celestial registers, that they become valuable by the lapse of time, and some only by the lapse of centuries, when they refer to bodies of very slow motion. Sir William Herschel, the founder of this branch of sidereal astronomy, now gives us a basis, but it is only of forty-two and sixty-two years' standing.

M. Struve has given the general results which he has endeavoured to draw from his observations, in the Introduction to the work; the particular ones in the body.

His Introduction is divided into fifteen chapters, in which the experiments tried during twelve years relative to the great telescope, will be useful to those who may acquire a similar instrument. It was desirable to submit the micrometric measurements to the severest examination, and no fewer than 10,000 angles of position, and 10,000 distances, were compared. The probable error in the mean of three measures of very close brilliant stars, is said to be $\frac{3}{100}$ of a second in distance, and only $\frac{1}{100}$ or $\frac{2}{100}$ in position; and much the same in more distant stars.

The fainter companions are of course more difficult, and the error may amount to $\frac{1}{10}$, but seldom to $\frac{2}{10}$ of a second. This extraordinary precision is due to the excellence of the telescope, and the perfection of the clock motion, which keeps the star as it were fixed. By applying a power of 1000, the $\frac{1}{100}$ of a second can be appreciated; and for the small errors that arise, otherwise unaccountable, the atmosphere must be blamed.

The amount of labour undertaken by the professor, will be better understood by a few words as to the numbers of observations necessary, and the time afforded by the average state of the weather. Observing each of the 3000 stars on only three different days, required upwards of 18,000 measurements in position and distance; but many objects among them demanded annual operations,—thus 70 Ophiuchi was measured fifty-four times, ξ Ursæ Majoris thirty-eight, and γ Virginis forty-six times. There are about 120 fine nights in the year, and, including the evening hours, the average of stars observed in each night was twenty-five. An apparently fine night, however, is not always favourable for these duties; so that if a power of 300 cannot be used, it is better not to measure at all; and as, for the more difficult tests, Struve used a power magnifying 1000 times, or thereabouts, the constancy of application may be readily gauged. In the earlier years he accomplished less, having been a good deal occupied with sweeping the heavens, and measuring that grand arc of the meridian; which arc is now being continued from Livonia to the North Cape.

The elder Herschel divided his double stars into classes, according to their apparent distance from each other; and his example has been followed by other astrometers. In the Catalogue before us, Professor Struve has arranged his objects in eight classes, from the fraction of a second in distance to 32″; and each of these contains two subdivisions, one of which consists of those whose satellites are not below the eighth magnitude. "The division of the double stars into orders," he says, "according to their mean distances, does not rest on mere appearances. Stars of the first order, distant from each other from 0 to 1″, are generally those whose actual linear distances from each other are the least; and the same holds good in the case of the other orders. Wherefore, the nearer the stars appear to each other, the more intense is the action of gravity by which they are retained in conjunction, the more swiftly do they move in orbits round the centre of gravity, and the shorter are the periods of their revolutions." If it be allowable to question the arrangement of so noble a work, it must be said that this partition cannot meet with full approbation, especially as regards the binary series: and that classification which neither gives a notion of the sizes of the stars or their orbits cannot be wholly satisfactory. Besides the division's being arbitrary, it has another and an insurmountable defect, in that, according to the time at which it was first classed, the same star would appear to belong sometimes to one order, and sometimes to another. Of this a notable instance in point, is afforded by the well known γ Virginis, which remarkable star, only so lately as the time of Sir William Herschel's marshalling, was placed in his third class; but by the augmented velocity with which the satellite approached its *periastre*, or shortest distance from the primary, it quickly changed into the second, and from thence into the closest of the first class; in the beginning of 1836 it became optically single, and is now, (July 1844,) again qualifying for the second class.

Besides arranging his several classes with all the precision which the case admits of, M. Struve has paid particular attention to the relative *sizes*, or rather brightness of his sidereal host, and has therein produced some curious deductions. He considers the stars of the sixth magnitude, to be in proportion to the number of those of the first magnitude, as 8 to 1. Making due allowances for the loss of light in passing through the lenses, the Fraunhofer-telescope is so much larger in its object-glass than the eye, that it receives 1700 times more light. Upon this basis, it is inferred that a star forty times further off will appear through a telescope of the same size as another seen with the naked eye, so that we may conclude that those of the twelfth magnitude are forty times more distant than those of the sixth, the latter being the smallést which we can generally discern with the naked eye, and the former the smallest discernible with the Dorpat tube: consequently, the stars of the twelfth magnitude are probably 320 times more distant than those of the first magnitude;

and those of the eighth are about thirty times further off than Aldebaran. This able Professor has also undertaken the task of separating the physical from the optical double stars. Among 653 selected from all his eight classes, there are only 48 that are probably optically double: the very close ones are all physical; and the same rule is applicable to the triple and multiple stars. Out of 27 of these objects, of from 32″ to 7′ apart, Argelander's labours show 13 to be physical, 9 optical, and 5 doubtful. Of the wider ones, none have so changed in position as to enable their orbit to be approximated, whence it is concluded, that even where they have a physical connection, the period of revolution cannot well be less than 20,000 years. The most remarkable among those detected to be optically double*, are:

α Lyræ - -	1 and 11 magnitudes	-	43″ apart.
α Tauri - -	1 and 12 ,,	-	108″ ,,
α Aquilæ - -	$1\frac{1}{2}$ and 10 ,,	-	152″ ,,
β Geminorum -	2 and 12 ,,	-	208″ ,,

M. Struve, on instituting a rigid comparison of his own with Sir William Herschel's observations, came to the conclusion that there are fifty-eight double stars undoubtedly revolving, thirty-nine probably so, and sixty-six suspected of being so; but each of these numbers has been considerably enlarged since 1837. The trajectories hitherto examined are far more elongated than those of our planets; but the masses of the latter are small fractions of that of the sun, whereas in the binary stars the satellite and its primary may be equal bodies, or at least of the same order of magnitude. Among Struve's fifty-eight we find forty-eight that are unquestionably connected, and the closest being under the strongest attraction, revolve the fastest: so that our planet Uranus is even slower than some of those distant suns, whence either they are closer to their primary, or their mass is greater than that of our sun. The broad result of these labours, will best appear in the following table; where the last column is made up, not by taking the sum of the three preceding ones, but by adding that proportion of the fourth and fifth in which change may safely be assumed:

* The distances are here slightly altered, in accordance with my own measurements.

Order.	Number of Double Stars in each Order.	Number of Stars in which Change is certain.	Change is probable.	Change is suspected.	Sum of Changes.
I.	91	13	4	3	15
II.	314	10	6	5	15
III.	535	12	5	12	19
IV.	582	7	9	14	17
V. VI.	583	7	9	14	17
VII. VIII.	535	9	6	18	18
Sums - -	2640	58	39	66	101

Savary, Encke, Herschel II., and Mädler, have severally computed the orbits of binary stars on the modified basis of the Keplerian laws, referred to the agency of some power like that of gravity; and I have also investigated the paths and elliptical elements of several, as will elsewhere appear. In the present instance it will suffice to add a list of the most remarkable of those to which an *annus magnus* can be assigned, either satisfactorily or approximately:

ζ Herculis - -	35 years
γ Coronæ - - -	40
η Coronæ - -	44
ζ Cancri A.B. - -	60
ξ Ursæ Majoris -	65
η Ophiuchi - - -	80
ω Leonis - -	82
τ Ophiuchi - - -	83
λ Ophiuchi - -	86
51 Libræ - - -	100
ξ Boötis - -	120
γ Virginis - - -	150
α Geminorum - -	240
127 P. XIII. Virginis -	240
36 Andromedæ -	250
4 Aquarii - - -	300
ε Arietis - -	400
pr. μ^2 Boötis -	460 years
37 Pegasi - - -	500
61 Cygni - -	514
ζ Cancri A.C. - -	550
σ Coronæ - -	560
ι Leonis - - -	580
μ Draconis - -	600
49 Serpentis - -	610
12 Lyncis - -	680
η Cassiopeæ - -	700
ζ Aquarii - -	750
ε Boötis - - -	980
γ Leonis - -	1000
5 Lyræ - - -	1000
ε Lyræ - - -	2000
δ Herculis - - -	2046
65 Piscium - -	3077

For the sake of the tyro it may be proper to premise, that the two stars composing the double one are for the most part of very dissimilar intensity, and often of very dissimilar colours; and no one who has ever directed a telescope to the heavens, can have failed to be struck with the brilliant hues they present, especially such lovely objects as γ Andromedæ, α Herculis, and ϵ Boötis. The phenomenon of the tints displayed by the smaller stars is considered by M. Arago as owing to an excess of refrangible rays, acted upon by an absorbing force in the atmosphere of the larger star; but this cannot be the universal law. Sometimes the strongest of the two is of a yellow, red, or orange tinge; still more frequently the secondary is blue, purple, or greenish, and those colours so palpable as to be visible in objects of the smallest magnitude. Now, as many of these border on the extremes of the prismatic spectrum, the larger star being allied to the red, and the smaller to the violet, the exhibition may, in such cases, be the effect of contrasted complementary tints—corresponding to the male and female lights of Milton. We all know that a white light appears greenish when near a strong red one; and becomes bluish when the neighbouring colour is yellow. In combinations of this nature, some of the secondaries lose their colour on hiding the primary; but as many of the examples defy this test, their colours are too decidedly indicated to be merely imaginary. As α Leonis is of a brilliant white tint, the deep purple of its *comes* cannot be an illusion; and in δ Serpentis both the bodies are blue.

It will thus be seen that this department of sidereal inquiry offers an interesting field for continuous investigation; and, accordingly, we find that M. Struve has paid a strict attention to it. By his observations it is shewn that, besides the white, there exist stars of every shade of the prism; and that when the principal body is not white, it approaches the red side of the spectrum, while the satellite offers the bluish of the opposite extreme. Yet this apparent law is not without exceptions in the Catalogue before us; on the contrary, the most general case is, that the two stars are of the same colour, as will be seen in the following summary, wherein he finds among 596 brilliant double stars:

375 pairs of the same colour and intensity.
101 pairs of the same colour, but different intensity.
120 pairs of totally different colours.

Among those of the same colour, the white are the most numerous, and of 476 specimens of that species, he found:

295 pairs, both white.
118 pairs of yellowish, or reddish.
63 pairs, both bluish.

The number of red, or reddish, stars is double that of the bluish tinge; and that of the white stars is twice and a half greater than the red ones. The combination of a blue companion with a coloured primary, happens:

53 times, with a white principal star.
52 times, with a light yellow.
52 times, with a yellow or red.
16 times, with a green.

Professor Struve's chromatic designations are, obscurissima, obscura, pallida, livida, alba, sub-flava, flava, sub-cærulea, cærulea, rubicunda, and rubra; he supposes the 9th magnitude to be the outside boundary in which he recognises colour, but I have been much struck with the beautiful blue tint of the smallest stars visible in my telescope. This, however, may be attributed to some optical peculiarity. The Professor found, what I have also experienced, that Sir William Herschel saw most objects with a redder tinge than they have since proved to bear. This may be owing to the effect of his metallic mirror, or to some peculiarity of vision, or perhaps both. We know there are many examples of very sharp eyes, being unable to distinguish colours correctly, among whom may be instanced the late George, duke of Marlborough, who was an amateur astronomer, and possessed a good sight in other respects. There are others who have this singular physical defect with regard to particular colours only; as our estimable countryman Dalton, who, though so conversant with the laws of the spectrum, could not discriminate between scarlet and brown. So also those two celebrated men, Troughton and Dugald Stewart, were affected, but their peculiarity of vision consisted in confusing scarlet with green, and pink with blue: to the former the ripe cherry and its leaf were of one hue, only to be distinguished by their form; yet his eyesight was sharp enough for the examination of the minutest subdivisions upon graduated instruments. Among other instances of this peculiarity of the sense of colours, I was greatly surprised on finding that an intimate friend of my own could not perceive the strong colours of γ Andromedæ and other remarkable stars with my telescope, as I was well aware of his exquisite taste and execution in missal-blazonry; but he assured me that he cannot easily discriminate between brown and green; albeit I have specimens of his art in which those colours are treated as well as they could be by any eyes in the Royal Academy. Sir John Herschel examined the eyes of an individual thus circumstanced, and satisfied himself that all the prismatic rays had the power of affecting them with the sensation of light, and producing distinct vision; so that, he considers, this defect as arising from no insensibility of the retina to rays of any peculiar refrangibility, but rather as residing in the sensorium, by which it is rendered incapable of appreciating exactly those differences between the rays on which these colours depend.

The tints of stars require still closer observation before any correct deductions can be drawn. The ancients recognised no blue stars; they only spoke of white or red ones, classing among the latter Arcturus, Aldebaran, Pollux, Antares, and Betelgeuze, which also appear red to us; but they added Sirius, the *rubra canicula* of the poets, which, though expressly declared to be red both by Ptolemy and Seneca, is now decidedly white, and brilliantly white too. This instance affords a strong presumption that these colours undergo changes; and there are two remarkable examples of a recent date in γ Leonis and γ Delphini, which, at Sir William Herschel's time of observing them, must have been perfectly white, though the first pair is now of a golden yellow and reddish green; and the second of a bright yellow and bluish green. Blue stars are of modern introduction, since they are first mentioned by Mariotte in 1686, who supposes that they owe this colour to their being fainter, and free from exhalations. Mr. Dunlop, in the Catalogue made at Paramatta, in Sir Thomas Brisbane's observatory, mentions a large group of stars, all the individuals of which are blue,—also a bluish nebulosity; but we have no such object in the northern hemisphere. Nor is it less remarkable that amidst this infinite variety of tints, although single red stars are frequently met with, there is not an instance of a solitary green, purple, blue, or violet-coloured one being found: and among other singularities, the absence of the principal prismatic shades during the phases of the variable stars, is a striking phenomenon, whence may be deduced important conclusions respecting the velocity of different coloured rays. Zahn, in his *Syntagma*, remarks that the stars shine "more like torches burning with eternal flame before the altar of the Most High, than the lamps of the ætherial vault, or the funeral lights of the setting sun;" and he descants on their colours, asserting that from the various hues of the fixed stars, their nature may be inferred, and the planets they imitate at once known. Hence some are designated *Saturnine*, some *Jovial*, and others *Martial*. The Saturnine are those of a leaden or livid colour, and dullish; the Jovial are bright and white; and the rusty-coloured ones are assigned to Mars. The Solar ones, partly yellow and partly red, shine very splendidly: those of Venus are of a box-coloured glow,—*Venereæ sunt buxeæ, seu buxeo splendore clarescunt;* and the Lunar are pale and dim. Such was the knowledge of stellar colours in 1694: a century and a half has altered all this.

§ 3. Clusters of Stars, and the Galaxy.

In clear weather, when the stars are very distinct, certain whitish spots shedding a faint light, will be perceived in several parts of the sky. On examining them with a sufficient instrument, we discover in them a multitude of little stars set very close together; being mostly below the sixth magnitude, and therefore undistinguishable by the naked eye. Their intermingled and united light occasions the patches alluded to, most of which require optical aid; but the Præsepe, the Pleiades, the Hyades, the Locks of Berenice, and a few others, are well known to the merest gazer. From their cloudy appearance these spots were termed Nebulæ, by the ancient and middle-age astronomers, and indeed down to very recent times; that word, however, as we shall presently see, is now used in a more restricted sense. Lambert and Michell had some sagacious views as to the constitution and mechanical structure of these groups; (see pp. 281, 289, and 290;) and, but for the accidental failure of his publisher, the celebrated Kant would have anticipated them. The hypothesis which he suggested, that all the bodies in the universe are collected into nebulæ, and that such insulated and scattered stars as we behold, are mere outliers of the nebula to which we belong, was justified thirty years afterwards by the practical investigations of the elder Herschel. Wright, of Durham, also advocated a systematic disposition of the stars in his *Clavis Cœlestis*, (1742,) the curious plates to which are, at least, original enough.

In the present state of our knowledge, it is somewhat difficult to define where the clusters or resolvible agglomerations of stars end, and the nebulæ, or irresolvible masses of luminous matter, begin; the gradations of resolvibility becoming more manifold as optic powers advance. Nor is this the only debatible point respecting these concentrated masses of suns. Though often used synonymously, there is a distinction between groups and clusters. The first designation is given to an assemblage of stars without any particular condensation to indicate the existence of a central force; but sufficiently separated from neighbouring stars to show that they form a peculiar system of their own. Clusters are remarkable for their more symmetrical arrangement, being generally of a spherical form, and so compressed towards the centre as to assume at that point the appearance of a nucleus. These may be considered as so many firmaments distributed through space, each insulated in position, definite in character, and subject to its own dynamical laws. Sir John Herschel, whose practical acquaintance with these objects is so great, thus describes them:

It would be a vain task to attempt to count the stars in one of these globular clusters. They are not to be reckoned by hundreds; and on a rough calculation, grounded on the apparent intervals between them at the borders (where they are seen projected on each other) and the angular diameter of the whole group, it would appear that many clusters of this description must contain at least ten or twenty thousand stars, compacted and wedged together in a round space, whose angular diameter does not exceed eight or ten minutes; that is to say, in an area not more than a tenth part of that covered by the moon. * * * Their round figure clearly indicates the existence of some general bond of union in the nature of an attractive force; and, in many of them, there is an evident acceleration in the rate of condensation as we approach the center, which is not referable to a merely uniform distribution of equidistant stars through a globular space, but marks an intrinsic *density* in their state of aggregation, greater at the centre than at the surface of the mass. It is difficult to form any conception of the dynamical state of such a system. On the one hand, without a rotatory motion and a centrifugal force, it is hardly possible not to regard them as in a state of progressive collapse. On the other, granting such a motion and such a force, we find it no less difficult to reconcile the apparent sphericity of their form with a rotation of their whole system round any single axis, without which internal collisions would appear to be inevitable. * * * If we suppose a globular space filled with equal stars, uniformly dispersed through it, and very numerous, each of them attracting every other with a force inversely as the square of the distance, the resultant force by which any one of them (those at the surface alone excepted) will be urged, in virtue of their joint attractions, will be directed towards the common center of the sphere, and will be directly as the distance therefrom. This follows from what Newton has proved of the *internal* attraction of a homogeneous sphere. Now, under such a law of force, each particular star would describe a perfect ellipse about the common center of gravity as its center, and *that*, in whatever plane and whatever direction it might revolve. The condition, therefore, of the rotation of the cluster, as a mass, about a single axis would be unnecessary. Each ellipse, whatever might be the proportion of its axes, or the inclination of its plane to the others, would be invariable *in every particular*, and would be described in one common period, so that at the end of every such period, or *annus magnus* of the system, every star of the cluster (except the superficial ones) would be exactly re-established in its original position, thence to set out afresh, and run the same unvarying round for an indefinite succession of ages. Supposing their motions, therefore, to be so adjusted at any one moment as that the orbits should not intersect each other, and so that the magnitude of each star, and the sphere of its more intense attraction, should bear but a small proportion to the distance separating the individuals, such a system, it is obvious, might subsist, and realize, in great measure, that abstract and ideal harmony, which Newton, in the 89th Proposition of the First Book of the *Principia*, has shown to characterize a law of force directly as the distance.

Besides the globular clusters, there are numerous others of an irregular figure, which are usually more scattered, and with less indication of an outline or of a centre than those just described. Sir William Herschel considers these as in a state of condensation, by some unknown law of mutual attraction. Some of these, especially in his eighth class, must merely be regarded as congeries of stars placed in a part of the heavens, which appears richer than the surrounding regions, from the ex-centricity of our own station in the universe; but many of them are probably aggregations under the views given by Michell, though we can have no direct proof of the fact for many ages to come. The circumstance of their gradations, however, affords a strong presumptive analogy. In some straggling clusters the components are nearly of the same magnitude, but in others they are extremely different, the brighter individuals being apparently on a ground, as it were, of star dust, really "powdered with stars;" and there is sometimes found a very red star, much brighter than its companions, conspicuously placed in the cluster. These solitary stars beyond the outliers of such groups, are named *inter-systematical* by Sir William Herschel.

These remarks naturally bring us to that cluster of clusters, the Milky Way; so gazed at as the *Γαλαξίας* or *κύκλος γαλακτικός* of the Greeks, and the *Circulus lacteus* or *Orbis lacteus* of the Romans. It was the *Jacob's ladder*, the *Way to St. James*, and the *Watling-street* of our early star-gazers; Hood, however, is at a loss to account for the last designation,—the *Vatlant-strete* of our old *marynalis*,—"except it be in regard of the narrowness that it seemeth to have, or else in respect of that great highway that lieth between Dover and St. Alban's." The zone seems ever to have been "astonishing beyond astonishment," although the Greek story of its being the result of Juno's pushing the infant Hercules away from her breast, is sufficiently homely. The various reveries of the ancients, however crude, showed their attention to the subject. Metrodorus considered it as an old path of the sun, which he abandoned after the banquet of Thyestes; while others saw in it the marks of Phaëton's accident; a third class thought it was owing to the quantity of ears of corn which Isis dropped in her flight from Typhon; Theophrastus declared it to be no other than the soldering together of the two hemispheres; and Diodorus conceived it to be a dense celestial fire, showing itself through the clefts of the starting and dividing semi-globes. Aristotle considers it as a sublunary meteor, consisting of exhalations of the earth drawn up by solar heat, and set on fire in the middle regions. But for further particulars of this tenour, inquire of Dr. Fulke, in the *Garden of Contemplation* (1640).

More reasonable speculations were at hand. Although Pythagoras is sometimes mentioned as the leader of the opinion, it is generally supposed that Democritus was the first who taught that the Milky Way is a congeries of stars, too small to be seen separately. Ovid represents it as the high road—"whose ground-work is of stars"—to the court of Jupiter: an idea which is closely copied in the broad and ample starry pavement of Milton. Manilius also suggests the effect of the compound effulgence of such a myriad of minute stars; for after alluding to the long-disused track of Phœbus, the milk of Juno, and the like, he demands:

> Anne magis densâ stellarum turba coronâ
> Contexit flammas et crasso lumine candet
> Et fulgore nitet collato clarior orbis?

This, of course, became the settled belief, and only awaited the confirmation of the "optic tube." In the *Hamāsah*, a collection of old Arabian poems, Ta 'abbata Sharran calls this luminous zone the "mother of clustered stars;" and Pagnini described it as a road strewed with little stars, "una strada seminata di minutissime stelle." At length, shortly after the invention of the telescope, Galileo brought the matter out of the region of conjecture by resolving the Galaxy,—though certainly with his inefficient instrument*, not to the complete amount which he announced, in the *Nuncius Sidereus*. From that time, every optical improvement has increased our knowledge of this world of worlds, as Kant significantly designated it; the thick-sown glories of which it might stagger "a seraph's computation" to number. "This remarkable belt has maintained," says Sir John Herschel, "from the earliest ages, the same relative situation among the stars; and, when examined through powerful telescopes, is found (wonderful to relate!) to consist *entirely of stars scattered by millions*, like glittering dust, on the black ground of the general heavens." So many of my own examinations of various spots of this astral treasury, will be found in the second volume, that a general notice of it may here suffice.

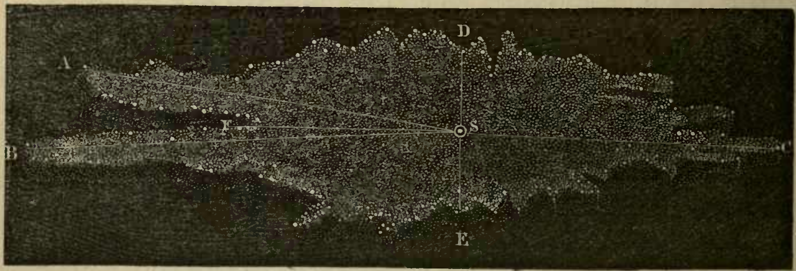
The Via Lactea to the gazer is not a uniform zone, but a succession of clusters; it may be considered as a kind of constellation, extending three or four degrees on each side of a great

* The object-glass of Galileo's telescope is still preserved at Florence, where I had the pleasure of seeing it, in 1817, through the kindness of that estimable scientific veteran, Padre Inghirami, of the Scuole Pie.

circle,—the only real and sensible circle in the heavens,—inclined at about 60° to the ecliptic, which it cuts near the two solstitial points, in the northern hemisphere between the horns of Taurus and the feet of Gemini, and in the southern hemisphere between Sagittarius and Scorpio. It traverses the asterisms from Cassiopea and Perseus, which it nearly covers, passing by Auriga, between Taurus and Gemini, over Orion's club, and the preceding parts of Monoceros, through Argo to the Southern Cross, keeping opposite to the Magellanic clouds, or *Sacks of Coals*, of our early navigators. It then returns towards the north, and passing over Ara, divides itself into two rich streams, with a sharp bifurcation. The eastern branch flows over the tail of Scorpio, the bow of Sagittarius, through Aquila, and the east wing of Cygnus, to the great field at Cassiopea; the western arm passes over the tail of Scorpio, the right side of Ophiuchus, through Cygnus, where the streams re-unite, and form perhaps the strongest and the brightest portion of our skies. From thence the Milky Way reaches Cassiopea again, the place of its beginning. In investigating this mighty region, the elder Herschel thought he was able to number eighteen millions of stars, and as most of these had a whitish glimmer in the back ground in his most powerful telescope, he inferred a yet imperfect resolvibility; but in the intermediate spaces, where the Galaxy divides, the stars appear large and far apart; and in the blank spots, called *chasmata*, not the trace of a star could be found.

As the ancients had speculated upon the Milky Way's being a congeries of minute stars before the telescope had proved the fact; so also Wright of Durham, Kant of Königsberg, and Lambert of Alsatia, came to the conclusion that our sidereal system is not spherical, but that the stars are systematically disposed in a plane stratum, before the labours of Sir William Herschel produced a demonstration to this effect, which is confirmed by almost every perception. That great man, undismayed by the apparent difficulties of the task, invented a simple method of *gauging the heavens*, supposing the stars to be of equal size and equally scattered. In order to determine the comparative mean richness in stars of any two regions of the firmament, he made use of a telescope the field of which embraced a circle of 15′

diameter; a space which is less than the one-fourth part of the apparent size of the moon. Towards the middle of the first of these regions, he counted successively the number of stars included in ten contiguous fields of view. He added these numbers, and divided the sum by 10; the quotient was the mean richness of the region explored. The same operation of gauging, or sounding, and the same numerical calculation, gave him an analogous result for the second region. When this last result was double, triple, decuple the first, he legitimately deduced the consequence from it, that in an equal extent, one of these regions contained twice, three times, or ten times more stars than the other. (See p. 279.) From the results of *thousands* of observations, he inferred that millions of stars, nearly at equal distances from each other, form a thin layer or stratum comprised between two plane surfaces, parallel to and near each other, but prolonged to immense distances in every direction; and that our sun is one of the stars composing this stratum, occupying very nearly the centre of it, both relatively to its thickness, and to all its other dimensions. This may be explained by a diagram:



Here the Galaxy is represented according to the Herschelian theory, long, flat, and bifurcated at one of its extremities. It is plain that a visual ray cast from S to A, to B, or to C, will there encounter very condensed masses of stars, with a general diffusion of lucid whiteness, while in the transverse direction of SD or SE, the number of visible stars will be comparatively smaller, and the heavens will appear darker; as also will be the case, in a less degree, along the line SF. It was Sir William's idea, that towards the shallower parts of the Galaxy there might be a line of forty successive stars, at equal distances from each other, between our sun and its extremities; while in the longer direction of the mass, there are in some places upwards of nine hundred of them. These sagacious suppositions may be admitted, even though the assumed postulates, equable magnitude and equable distribution, should happen to be inaccurate. Every inference derived from strict investigation shows, that all the stars we can see with our eye are deeply immersed in the Milky Way, and form a component part of it. The great investigator's son, writing to me from the Cape of Good Hope in 1836, dwelt with singular delight on the splendour of the southern regions of the Galaxy; from the constellation Orion to that of Antinous it exhibited a belt of superior brilliance, strangely interrupted, however, with vacant and almost starless patches, especially in Scorpio, giving him a full impression that the whole is not a stratum, but an annulus, with the sun ex-centrically situated within it, and nearer to its southern than to its northern portion.

By reasoning and experiments which cannot but be received as pretty conclusive, Sir William Herschel *sounded* the profundity of space to nearly 500 times the distance of Sirius; in other words, he examined stars at the inconceivable remoteness of 10,000 billions of miles. Hence it seems if the "world-island" in which our system is placed were viewed from the cluster in the hand of Perseus, it would probably appear as an assemblage of telescopic stars ranged behind each other in boundless perspective; from that of Andromeda, it would diminish to a milky or pure nebulosity. Lambert, speaking of the immense distance* of these objects, says, "It would not be at all astonishing, if milky-ways, situated still further from us in the depths of the heavens, should make no impression on the eye whatever." These, he suggests, have a common revolution around the centre of centres, the Throne of Nature and the Footstool of the Divinity. "What painter, what poet, what imagination," he demands, "is sufficiently exalted to

* So lately as 1806, the *philosopher* Laurent Potier des Laurières, assured the legislative body of France, that the rays of the sun, broken and divided by the contact of the earth, go to form the Milky Way; and this he *proves* to be only 180 leagues distant.

describe the beauty, the magnificence, the grandeur of this source of all that is admirable, and from which order and harmony flow in eternal streams through the whole bounds of the universe!" Truly amid so much glory we are lost in wonder, and cannot but be penetrated with the awful conviction that all these aggregations seem to obey, like the various bodies of our solar system, an attractive force. There does not seem to be a bearing of gravitation, not an element, not a law, not a phenomenon, which does not find a practical illustration in all those inquiries into the structure of the universe, where facts confirm the results of reasoning. Sir William Herschel closely investigated this important subject, and boldly came to the conclusion that the stars of the Milky Way will be gradually compressed through successive stages of accumulation into globular clusters, to the breaking up of that glorious zone; and he points out several divisions in which such an effect has already taken place. "We may draw," he says, "an important conclusion from the gradual dissolution of the Milky Way; for the state into which the incessant action of the clustering power has brought it, is a kind of *chronometer*, that may be used to measure the time of its past and present existence; and although we do not know the rate and going of this mysterious chronometer, it is nevertheless certain, that since a breaking up of the parts of the Milky Way affords a proof that it cannot last for ever, it equally bears witness that its past duration cannot be admitted to be infinite." Such stellar wonders set man "adoring and aghast:" for it seems reasonable to think that, in the almost infinite series of ages, such a clustering power may inevitably bring on the rupture and dislocation of the vast Via Lactea, as Herschel conjectured.

§ 4. The Nebulæ.

The observation of nebulæ, properly so called, is of modern date; for the term *nebulous* was applied by the ancients, only to clusters of small stars. Numerous observations of these objects, as well as reflections, which while gazing at them intrude, will be given in the Cycle; but after all they are not objects for the generality of amateurs, armed with small, or at most, middling telescopes. My own instrument, used with a low magnifying power so as to keep as much light as possible, showed about a couple of hundreds tolerably well, but only a small portion of them with satisfactory distinctness. They offer, however, a most noble field to the observer who has sufficient means to explore it, for nature has yet to be caught in the fact of condensing the phosphorescent or self-luminous matter, diffused throughout certain regions of space, into future systems, according to the plausible speculations of Sir William Herschel. Indeed, his bold conceptions open a larger view of the universe than could have been formerly entertained; and though some slight traces of nebulous influence in the creation may have been brought into notice, nothing, or next to nothing, about it was known, till the astronomer of Slough published the unexpected results of his judicious observations.

Nebulæ carry the mind into the highest region of astronomy; not merely showing the existence of suns, but of systems of suns in sublime perspective, vastly separated in space, and unlimited in number, the whole of which are probably revolving around some incomprehensible centre. There are many so remote as to confound inquiry, and even the nearer ones are inconceivably beyond our fixed stars. They appear to depend on two entirely different causes, the one on distant agglomerations of stars, the other on masses of diffused luminous matter; the first being resolvible by the application of optical aid, the second remaining cloudy under the best telescopes yet constructed. This last class necessarily suggests the recognition of a modified matter wholly distinct from stars, throughout the universe. The numbers of the nebulæ seem to be bounded only by the incapacity of our means for exploring the heavens; for every telescopic improvement shows more of them. Thus in the vastness of space, no awful void or vacancy occurs, but the dynamical conditions adapted to secure the indefinite preservation of such celestial myriads is not within the compass of human imagination. These objects have been frequently discussed in considerations upon celestial architecture, since the gauging and sounding given to them by Sir William

Herschel. It is true that Tycho Brahé may have had an orthodox notion upon the subject, and that Kepler thought the new star of 1604 was composed of the conglomerated matter of ether; but neither of those astronomers anticipated the regular Herschelian Nebular Hypothesis which was furthered by the adoption of Laplace, and continues to unfold an inexhaustible mine of speculation. Indeed, it surpasses not only every preceding view of the kind, but will ensure the admiration of future ages, however much it may yet have to be modified. The reader who wishes to be fully acquainted with what we yet know in this most interesting department, must study the labours and opinions of Herschel in the *Philosophical Transactions.* Suffice it here to say, that he signally realized Thomson's sublime philosopher:

> Not to this evanescent speck of earth
> Poorly confined—the radiant tracks on high
> Are his exalted range; intent to gaze
> Creation through, and from that full complex
> Of never-ending wonders, to conceive
> Of the Sole Being right.

The nebulæ appear under diversified forms and sizes, from the circular or elliptical figure to shapes of utter irregularity, and from several degrees to a few seconds in diameter. Two or three may be perceived by good though unaided eyes, but the telescope shows vast numbers relieving the dark vault of the heavens with their luminosity. At first Sir William maintained that these faintly illuminated patches were all masses of stars; but after further and more delicate exploration, he became convinced that some of them were not of a starry nature, and chaunted his palinody in an able paper read to the Royal Society in February, 1791. Their characteristic appearances are, as just alluded to, very multifarious; in consequence of which the subdivisions in classing them are numerous. They vary in extent, aspect, brightness, and resolvibility, under contours rectilinear, curvilinear, and mixtilinear; yet are mostly round in different positions of perspective; and a degree of sphericity is indicated by their generally being brightest towards the middle. Though not uniformly distributed, they congregate to a zone crossing the Galaxy at right angles; as indicated by the following statement of the 2306 nebulæ recorded in Sir John Herschel's Catalogue of 1833, which contains the major part of his father's objects, and therefore offers a good average proportion:

I. Hour.	89 Neb.	IX. Hour.	72 Neb.	XVII. Hour.	32 Neb.
II. ..	109	X. ..	110	XVIII. ..	18
III. ..	89	XI. ..	153	XIX. ..	34
IV. ..	24	XII. ..	271	XX. ..	37
V. ..	36	XIII. ..	441	XXI. ..	36
VI. ..	32	XIV. ..	214	XXII. ..	45
VII. ..	56	XV. ..	153	XXIII. ..	60
VIII. ..	55	XVI. ..	42	XXIV. ..	98

Among the principal classes are: I. *Clusters*, where all the stars are readily distinguishable; which are already described. II. *Resolvible Nebulæ*, or such as excite a suspicion that they consist of stars, and which any increase of optical power in the telescope may be expected to resolve; they are intrinsically too faint to affect us by their individual light, and their relative irresolvibility may be ascribed to vastness of distance. III. *Nebulæ*, properly so called, in which there is no appearance whatever of stars. These exist in great variety. Sir John Herschel describes a singular mass in the Magellanic Clouds, consisting of a number of loops called the "True Lover's Knot." IV. *Planetary Nebulæ*. These are extraordinary objects and of enormous magnitude, as will be seen in the course of the Cycle. With circular or slightly oval discs, their light is so equable over the surface, without central condensation, as strongly to resemble that of planets. They are usually of a bluish-white tint, and are quite irresolvible. Herschel regarded their physical constitution as very problematical. Were they composed of stars their light ought to increase in intensity towards the centre; and if they are supposed to be single celestial bodies, they defy all analogy, for some of them have actual diameters thirteen thousand times greater than the diameter of the sun: after much hesitation he decided on considering them as agglomerations, in a state of transition, of the diffused matter already very much condensed. V. *Stellar Nebulæ*, or those which approach to the appearance of stars, with atmospheres or blurs. And VI. *Nebulous Stars*, or nebulæ connected with very small stars which might be classed together. Many stellar bodies exist which seem to have a nebulous atmosphere about them, while to some a small fan-shaped patch seems to adhere by one end. Our sun is supposed to have an appearance of this kind from a proper distance, for the phenomenon of the zodiacal light is supposed to be a condensation of the etherial medium. The diffused nebulæ of a rounded form are not of great dimensions compared with the others. Sometimes there exists between these very distinct and circumscribed objects, a very slender thread of nebulosity attaching them together by their circumferences, as shown in the elegant plates accompanying Sir John Herschel's Catalogue of 1833. This countenances the nebular hypothesis of condensation, since it indicates a common origin for those objects. The same indefatigable astronomer thus beautifully sums up the Nebular Theory:

The nebulæ furnish, in every point of view, an inexhaustible field of speculation and conjecture. That by far the larger share of them consist of stars there can be little doubt; and, in the interminable range of system upon system, and firmament upon firmament, which we thus catch a glimpse of, the imagination is bewildered and lost. On the other hand, if it be true, as to say the least, it seems extremely probable, that a phosphorescent or self-luminous matter also exists, disseminated through extensive regions of space, in the manner of a cloud or fog, now assuming capricious shapes like actual clouds drifted by the wind, and now concentrating itself like a cometic appearance around particular stars; what, we naturally ask, is the nature and destination of this nebulous matter? Is it absorbed by the stars in whose neighbourhood it is found, to furnish, by its condensation, their supply of light and heat? or is it progressively concentrating itself by the effect of its own gravity into masses, and so laying the foundations of new sidereal systems or of insulated stars? It is easier to propound such questions, than to offer any probable reply to them. Meanwhile, appeal to fact, by the method of constant and diligent observation, is open to us, and, as the double stars have yielded to this style of questioning, and disclosed a series of relations of the most intelligible and interesting description, we may reasonably hope that the assiduous study of Nebulæ will, ere long, lead to some clearer understanding of their intimate nature.

Such are the nebulæ: myriads of globes and systems throughout the *expansum infinitum* obeying that silent course of change to which the whole universe is subject,—chaotic rudiments under active arrangement advancing towards organization and beauty! The scrutiny of future astronomers may tend to evolve the conditions of those most mysterious bodies; but if in all those parts of the creation which we can understand, we discover nothing but the most consummate wisdom, it is proper to conclude, that in those the ends of which we cannot comprehend, there exists the same wise plan of government. There are those, however, who would curb the inquiries of philosophy and contemplation, and compel reason to regard our speck as the paramount object of the ALMIGHTY COSMOGONIST; but assuredly they labour under a similar hallucination with the Greek madman, who fondly thought all the ships that sailed into the Piræus were his own. Such sages adhere to their oft-repeated axiom,

> Where ignorance is bliss, 'tis folly to be wise,

as well as to its converse in another of the *nugæ:*

> When science from creation's face
> Enchantment's veil withdraws,
> What lovely visions yield their place
> To cold material laws.

But who dare talk of magic, and dreams, and coldness, while viewing the august magnificence and unspeakable immensity which the GREAT CREATOR has vouchsafed to spread before us! Here we contemplate infinity and eternity in their fullest sense; wherein the inquirer must give up measuring by time and space, even though armed with so wondrous a gauge as light. But though man may thus perceive a limit to his power, he cannot but continue his labour, however much it may appear to be in vain, at squaring so beautiful a circle of thought. The prediction which Seneca uttered 1800 years ago, "veniat tempus quo posteri nostri nos tam aperta nescisse mirentur," may truly be repeated now; and it will probably be as sterling in the good year A.D. 3600, as at present.

§ 5. Concluding Remarks.

The reader who has accompanied me thus far, will now have witnessed the progress of astronomy, from its infancy to its maturity in 1844; and in tracing this wonderful march, he will not fail to have perceived that his countrymen are among the foremost of its most successful cultivators. And here a word or two is requisite, because during certain late Dorcas-and-Gregory squabbles, it was rumoured among the smaller classes that England had done little for science; that we in England are incapable of looking aloft; and that as far as Uranian skill is concerned, we are lagging astern of all Europe. Let us look at this; and I trust to being excused for regarding it with the eye of an official Visitor of the Royal Observatory.

It will be seen by what I have advanced, that astronomy is indebted to the English for the law of gravitation, for aberration, nutation, proper motions, several of the secular inequalities, the periodicity of comets, solar parallax by transits of Venus, and the establishment of standard stars. It will also be seen that the greatest inventions and improvements were produced by us in quadrants, circles, pendulum-clocks, telescopes, chronometers, sextants, and other instruments; and I have the *ipse dixit* of Laplace for saying, that a greater number of good observations have been furnished by England than by any other country. We moreover armed geometers with the *Principia*, Fluxions, and Logarithms. Yet it seems, because certain *academic* men adhered to Newton's synthetical modes of investigation, and thereby allowed the continental geometers to forereach upon us for half a century in transcendental inquiry, that therefore the English had done nothing. Logical conclusion! To the actual lover of knowledge, such discussions are frequently insipid, often annoying, and always wearisome. Even during the time impugned, although with the exception of Herschel's unparalleled exertions we perhaps were not dazzling the public eye, and the *faire des x* might be napping, the application of talent to all the useful arts was far and widely diffused; the effects of which are to be traced in our costly voyages of discovery, our improved navigation, our numerous public and private observatories, the degrees of the meridian measured and under measurement in England, Ireland, India, and the Cape of Good Hope, and our extensive naval and military surveys. But such results of intellect are not for a particular spot; they belong to the world at large, and are only here cited to meet the antagonist clamour. When Sir John Herschel presented the medal of the Astronomical Society to Mr. Baily in 1827, he felicitously said: "It has frequently been our good fortune to acknowledge and applaud the claims of foreign merit, and to prove by our awards, that no mean jealousies, or narrow and mistaken views of national honour, are capable of blinding our judgment or biassing our decision; but that he who, whatever be the spot of earth he inhabits, most promotes the cause of astronomical science, is most our brother and our countryman."

We are upbraided with the imperfection of our scientific institutions, and the few honours bestowed by our government on men of science. Now suppose this were true, however the charge may bear upon those in high places, it cannot but be considered as complimentary to English intellect, in that, however unaided by power, it has commanded the full respect of the world, in pursuing knowledge for the sake of knowledge. The march of intellect (*da veniam verbo*) in Britain and in foreign nations, was differently modified by the character of the people and their governments. In other countries, academies have been founded by monarchs, and they constitute part of the state machinery; but D'Alembert, in the preliminary discourse to the *Encyclopédie*, acknowledges that the English have contributed more to the advancement of science, unpensioned, than the natives of any other country aided by royal munificence. "Témoin l'Angleterre, à qui les sciences doivent tant, sans que le gouvernement fasse rien pour elles. Il est vrai que la nation les considère, qu'elle les respecte même; et cette espèce de récompense, superieure à toutes les autres, est sans doute le moyen le plus sûr de faire fleurir les sciences et les arts." Our Royal Society is the oldest existing scientific corporation in the world; and our Board of Longitude preceded all similar institutions by eighty years. "L'Angleterre ayant devancée la France par la création d'un Bureau des Longitudes," said the late M. Grégoire, bishop of Blois, in a letter which he wrote to me on the 17th of April, 1830, "nous fûmes seulement les imitateurs d'une nation qui a rendue des services si eminens aux sciences astronomiques et nautiques;" and Grégoire, it will be remembered, was the founder of the French Board of Longitude here alluded to.

A *coup de tonnerre*, or rather *brutum fulmen*, has indeed been levelled at Greenwich, the astronomical capital of England; an establishment which has accomplished more for the improvement and practical uses of astronomy, than all the observatories in Europe taken together. If a shade of temporary *vis inertiæ* appeared, it was only perceptible by the very light which that institution has yielded, and therefore required a far different treatment from that which it received. Nowhere has there ever been in succession so able a set of directors; who have produced a treasury of observations of such labour, skill, and accuracy, as to excel all other collections in utility and application. This is no vain boast, since it is a fact which the most illustrious foreigners have admitted and recorded. Thus Lalande declared that Greenwich had reared an eternal monument to the glory of Great Britain; Piazzi always professed his deep obligations to that temple of Urania; and Carlini, Caturegli, Brioschi, and Inghirami, have individually passed the highest encomiums upon its utility and value. Laplace, when I had the high honour of conversing with him upon the subject in 1820, remarked that "science must now wait for further Greenwich-observations." Baron de Zach affirmed that if any one should assert, that our astronomical tables would be equally perfect if the other 130 European observatories had never existed, he would be very well able to support his assertion, however extravagant it might appear at first view: "Près de soixante et dix ans de suite, sans interruption," said he in 1819, "cet observatoire a fourni à la science les meilleures observations, faites avec les instruments les plus parfaits, par des astronomes les plus habiles, et sur lesquelles réposent toutes nos théories, tous nos catalogues d'étoiles, nos meilleurs tables du soleil, de la lune, et des planètes; en sorte que si quelqu'un voulait avancer que toutes nos tables astronomiques seraient également parfaites, si tous les autres *cent-trente* observatoires n'avaient jamais existé, il pourrait fort-bien soutenir sa thèse, tout extraordinaire, je dirai même, toute extravagante qu'elle paraisse au premier coup-d'œil." But the able and estimable Bessel was most indignant at the aspersions on the Greenwich operations; and in a letter to M. Schumacher, he says, "I saw the censure with surprise, because I had always considered the collection of observations at Greenwich as singularly valuable, and as a rich source of astronomical truths. Whoever is dissatisfied with the actual riches of the Greenwich observations, would do well to make the attempt to excel them*; he would convince himself by such an experiment, that the labour and patience required for doing so much, are fully sufficient to exhaust the powers of any man." And this, be it borne in mind, is by him who reared that noble Greenwich monument, the *Fundamenta Astronomiæ*, in 1818.

But perhaps the most remarkable tribute, was that paid by Delambre in his eloquent éloge on Maskelyne, delivered before the Institute of France, on the 4th of January, 1813, a time not at all remarkable for Anglomania. With equal liberality and judgment he said:

Since the establishment of a Board of Longitude in France, the Observatories of Paris and Greenwich have been conducted on nearly the same plan, and furnished with similar instruments†; collections of observations are annually published, which serve to verify each other; and when the clouds which overshadowed one of the observatories have not equally extended to the other, the deficiency is supplied. The communication is uninterrupted and the obligations reciprocal: if our tables are in a great measure founded on the English observations, the English observations are partly founded on our tables.

* * * * *

Maskelyne made a catalogue of the stars, not very numerous, but corrected in the most careful manner; which has served during thirty years as the basis of all astronomical inquiries. In short, it may be said of the four volumes of observations which he has published, that if by any great revolution the works of all other astronomers were lost, and this collection preserved, it would contain sufficient materials to raise again, nearly entire, the edifice of modern astronomy. This cannot be said of any other collection; because to a degree of correctness seldom equalled, and never surpassed, it unites the advantage of a much larger series of observations.

It may here be noticed, that Dr. Maskelyne observed his thirty-six stars, and sometimes more, from 1765 to 1810, and formed the standard which has proved not only of such moment to physical astronomy, but—as the "nautical stars" have been so eminently useful—also to navigation. From the time of his

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* This is not unlike the sage Mansie Wauch, in his commendation of poor Mungo's poem: "Some may judge otherwise out o' bad taste or ill nature; but I would just thank them to write a better at their leisure."

† He might have added, by the same artists; for when M. Arago obligingly conducted me over the Paris Observatory in 1820, they had a transit instrument which was made by Ramsden; a mural quadrant by Bird, and another by Sisson; a zenith-sector by Graham, and several telescopes by Ramsden, Herschel, and Dollond.

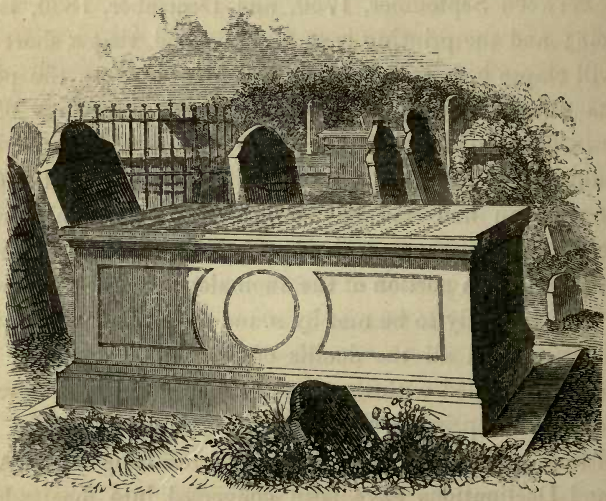
death they have been unceasingly attended to by both his successors, as the following random selection of the number of times some of them have been observed, since the 10-foot transit instrument was put up in 1816, will show:

Star.	Right Ascension.		North Polar Distance.	
	POND. 1816 to 1835	AIRY. 1836 to 1843	POND. 1816 to 1835	AIRY. 1836 to 1843
Polaris - -	2130	723	2365	733
Aldebaran -	656	124	714	122
Capella -	808	104	755	242
Rigel -	693	135	163	66
Betelgeuze -	478	149	526	86
Sirius -	499	177	487	258
Procyon -	1069	191	809	92
Regulus -	561	149	628	142
Arcturus -	878	254	935	317
Etamin -	304	105	1796	137
Wega - -	1160	226	1943	571
Altair -	1339	238	1469	128
Deneb - -	892	94	1263	242
Alpherat -	489	144	576	88

As the Royal Observatory was expressly established, and placed under the charge of the Admiralty, for the specified purpose of finding the longitude, and improving navigation, it may be as well to remind the nautical reader, that it is to this institution that he is indebted for the *Nautical Almanac*, the Lunar Observations, and various aids which have enabled him to raise the finding of a ship's place from an art into a science. "The Commissioners of Longitude," said Dr. Maskelyne, in his preface to the first Ephemeris, "in pursuance of powers vested in them by a late Act of Parliament, present the publick with the *Nautical Almanac* and *Astronomical Ephemeris* for the year 1767, to be continued annually; a work which must greatly contribute to the improvement of astronomy, geography, and navigation." Well has this noble Greenwich-production realized the prediction: and that establishment is still working with the same object in view, even more methodically than ever. We shall shortly be made acquainted with the moon's actual place, under determinations from which that careering satellite can no longer escape, or wander fifteen or twenty seconds of space from its appointment. Although the existing theories and tables of the moon are founded entirely on the continued and accurate observations which have been strictly carried on at Greenwich Observatory ever since its establishment, the present Astronomer Royal will now be enabled to render that series still more complete, by the express employment of an efficient altitude and azimuth instrument for that purpose; and besides the usual astronomical labours, there are branches for the examination and rating of chronometers, for meteorology, and for magnetism.

There is still another point, which has been watched with deep interest by all who value the scientific character of our country. The erection of a new transit instrument at the Royal Observatory in 1750, was an important event in the history of modern astronomy. From that date commences a most valuable and extensive series of the lunar and planetary observations, which had mostly remained in *gurgite vasto*, till the present Astronomer Royal gratuitously undertook to superintend their reduction. This weighty and operose labour, embracing the period between September, 1750, and December, 1830, is now complete; and the printing is so far advanced, that a short time only will elapse before the results are placed before the public. Persons unacquainted with the nature of calculations of this kind, can form no adequate idea of the amount of thought, skill, and industry, which are necessary for the arrangement and success of such an undertaking. Errors of observation, derangement of the instruments, omissions and inaccuracies in printed records, form but a portion of the anomalous perplexities encountered; and are only to be met by sound judgment, and intimate acquaintance with all the details of practical astronomy. Nor has the labour ended with the mere reduction of the observations recorded in the printed volumes. Not only have these been cleared from every kind of error, but the resulting Right Ascensions and Declinations have been converted into longitude and latitude throughout; the place of each planet—the Asteroids excepted—has been computed for the time of observation, from the best tables extant; the tabular and observed places compared; and expressions found for the discordance in terms of the heliocentric errors of the earth and the planets. The lunar reductions have been conducted on a similar plan. About 8000 places of the moon have been determined from observation, and the corresponding tabular places computed from Damoiseau's *Tables de la Lune*, modified by the introduction of Plana's coefficients and new terms. The comparison of the results deduced from observation with those obtained from the Tables, has already established the fact, that the diameter of the moon, as given by Burckhardt, is erroneous to the amount of nearly six seconds in arc.

This, then, is Greenwich: and his capacity is not to be envied who still denies that it is the brightest gem in the national diadem. The statement I have made certainly does not accord with certain positive allegations recently uttered before a select circle of officers of the United Services; but it is, nevertheless, quite true, therefore incontrovertible, and ought to be universally known.



The Tomb of Halley, at Lee. See p. 55.

Chapter IV.

DETAILS OF THE OBSERVATORY.

Here truths sublime and sacred science charm,
Creative arts new faculties supply;
Mechanic powers give more than giant's arm;
And piercing optics more than eagle's eye.

It is in the observatory that theory is reduced to practice, and science illustrated by art; and it is in the observatory that the close relations of time and space become evident. There will be therefore little apology required for forthwith proceeding to describe one. Moreover the astronomer will expect an account of the means by which I was enabled to present him with a *Cycle of Celestial Objects;* in which their mean apparent places, positions, distances, and other minutiæ, are determined by myself. To meet this reasonable desire, a copy of the statement which I made to the Royal Astronomical Society, in 1830, and published in the IVth volume of that Society's *Memoirs*, is here extracted under the sanction of its Council. To render this description more useful to the amateur inquirer, I have made a few necessary additions, and illustrated it with various wood-cut engravings; insomuch that the details will be at once comprehended, even by those who may not have had much personal acquaintance with astronomical instruments: for I am well aware that many of Urania's most ardent admirers have never had the good fortune to gain access to one of her temples. Nor could I well omit to mention the powerful auxiliary to my telescope presented by the Rev. R. Sheepshanks, in his excellent equatorial clock.

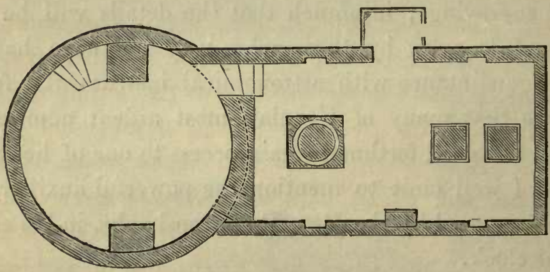
I may further remark with respect to the Bedford Observatory, that it proved fully equal to the object at which I aimed when contriving it; and was on the whole so efficient and of such reasonable expense, that it has been the parent of four others, of nearly the same plan and dimensions.

§ 1. The Bedford Observatory.

Account of a Private Observatory, recently erected at Bedford. By Capt. W. H. Smyth, R.N., Foreign Sec. to the Society.

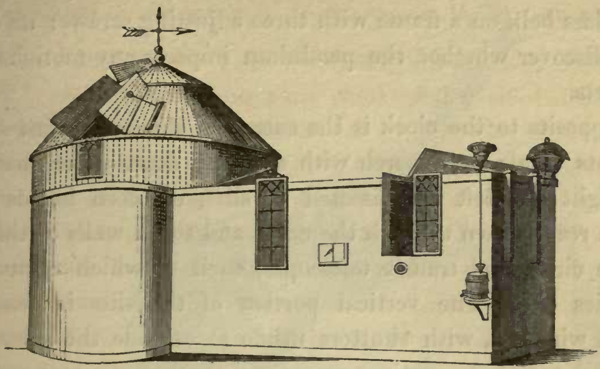
Being now in the possession of a transit instrument and clock, which have been some time preparing for me, I beg to return those belonging to the Astronomical Society; and I have to present my sincere thanks for the liberal manner in which the loan was conferred, as being both grateful to my feelings, and highly illustrative of the earnest and honourable zeal with which the Society ever encourages the efforts of individuals, in the cause of science. In rendering this acknowledgment, I embrace the opportunity of submitting a few details respecting the means now in my power for forwarding the views of our association; because it may be satisfactory to many of its members to be acquainted with the nature and degree of confidence assignable to such observations as I may, from time to time, transmit to them.*

Having duly weighed my object in erecting an observatory, I drew a plan on as small and economical a scale as was consistent with the required efficiency. Aware of the advantages of site and insulation, in guarding against local effects and corpuscular attractions, I caused a deep foundation to be placed on a hard bed of gravel, in the middle of my garden, and raised



Ground Plan.

thereon a nine-inch brick wall, which was lathed and plastered over stout oak battens. The edifice stands at a convenient distance from high roads, and commands the passage of Fomalhaut to the south, and the lower transit of Capella to the north, well clear of trees, houses, or other obstructions. The outer, or meridian room, is seventeen feet in length, twelve in breadth, and ten in height, having a flat roof, covered with sheet-lead.



Elevation.

On a stone pedestal, in the centre of the south wall, stands the clock, enclosed in a strong mahogany case, and bracketted to substantial oak supports. The escapement is Graham's dead-beat; and in order that no irregularity should be given to the maintaining force by friction, the wheelwork is constructed with singular care. It has a screw adjustment for setting it in beat, and cross levels for watching the state of the same; the weight is adjustable by layers of brass, in order that the beat may be exactly regulated to the quantity of drop made by the tooth of the wheel escaping from one pallet to the rest of the other. The pendulum is mercurial; it consists of a round steel verge or rod suspended by a spring, which passes through the quicksilver into a screw socket near the bottom of the inside of the cylinder; thus giving the means of the usual adjustment for length. The cistern is of brass, coated inside with cement and gum-lac, and closed with a graduated circle with fixing screws; this circle is divided into 120 parts on the broad edge of the cap; and as the screw has 30 threads in the inch, it is evident that the cylinder may be raised or lowered $\frac{1}{3600}$th of an inch. The steel rod is covered with a brass tube; so that it is not more exposed to any accidental changes of heat or cold, than the mercury itself, with which it is in constant contact, and therefore in mutual communication of temperature. The cylinder is terminated by a steel point, which indicates the arc of vibration by a neat fixed scale*. Upon the clock stands a small and sensitive inverted pendulum, called "Hardy's Noddy," enclosed in a glass bell, on a frame with three adjusting screws; its object is to discover whether the pendulum imparts any motion to its supports.

Opposite to the clock is the entrance, sheltered from sudden currents of air by a porch with a spring door. The spaces on the right and left are bisected by slits, eighteen inches wide, which reach down through the north and south walls to the level of the circle and transit telescopes, each of which respectively occupies one. The vertical portion of the slits is closed by glazed windows, with shutters inside to exclude the solar rays; and the continuous portions across and through the roof are fitted with wooden flaps, covered with copper, and counterpoised by weights hanging in cells outside the east and west walls. The floor is supported on oak joists, forming square frames around the circle, transit, and clock bases, so that the planks are firm, yet entirely detached from the piers, and therefore communicate no tremors to them; whilst a free circulation of air is secured beneath, by means of small iron gratings. The whole of the piers are raised on solid masonry, from a compact bed of gravel, and their immobility has been well proved.

The transit instrument is an excellent specimen of the skill of Mr. Thomas Jones, of Charing Cross, and was constructed expressly to meet my wishes. It consists of a telescope of $3\frac{1}{2}$ feet focal length, furnished with a very superior object-glass, whose aperture is 3·25 inches: this is supported by broad cones, forming an axis of 28 inches in length, the pivots of

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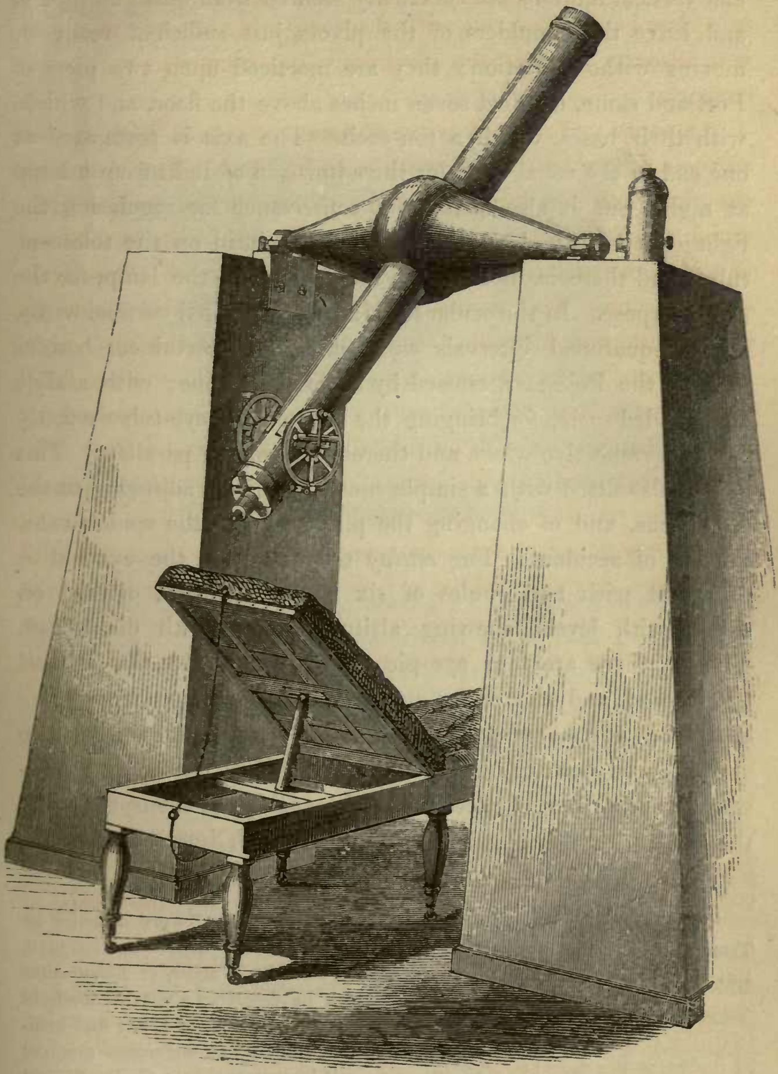
* This may require a word more. The index-arc is marked with four divisions, and each of these in ten parts. The whole four divisions measure 252 parts of the 80-to-an-inch scale; viz. each division = 3·15 inches. Now, from the point of suspension to the index-end on the arc, is exactly 3 feet $9\frac{3}{4}$ inches, as the radius to a circle; and consequently its whole circumference is $= 6{\cdot}2812 \times 45\frac{3}{4} = 287{\cdot}46$ inches $= 360°$: hence $\frac{3{\cdot}15}{287{\cdot}46} \times 360° =$ each division. This is very nearly 4°: so that each division may be considered to = 1°, and the subdivisions each = 6′ of a great circle. This therefore is the valuation of the index readings for the pendulum vibrations.

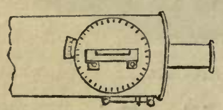
which I have submitted to a rigorous trial as to their cylindrical accuracy, by levelling the axis in every position, with the illuminated end alternately east and west, and I cannot detect any



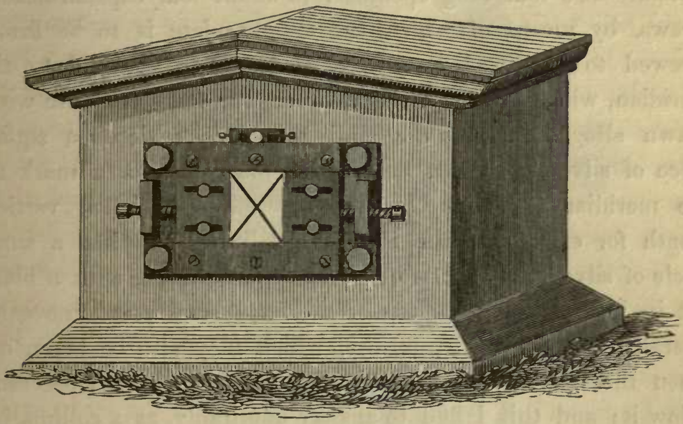
The Transit Instrument, and Observing Chair.

appreciable disparity. They rest on covered Y's, offering a surface of polished Brazilian pebble, an inch in bearing, and which (owing to their bases being hemispherical, and working in corresponding sockets) hold their proportionate weight, as well as insure the axis of the pivots being always strictly in the same right line. The Y's are placed on improved cheeks, whose azimuth and vertical motions are effectually secured from dust and injury, and leave the shoulders of the pivots just sufficient room for moving without friction; they are morticed upon two piers of Portland stone, five feet seven inches above the floor, and which, with their bases, weigh a ton each. The axis is perforated at one end in the usual way, for the admission of light from a lamp at night, but it also contains a contrivance for regulating the light on the lines, by means of a milled head on the telescope tube; and there is, moreover, a rack-screen to the lamp, for the same purpose. In the ocular focus are five principal vertical wires, whose equatoreal intervals were carefully ascertained, besides two for the Pole-star, crossed by a horizontal one; with a slide and divided scale, for bringing the axes of the eye-tubes exactly over the respective wires, and thereby destroying parallax. This part is also fitted with a simple means of nicely adjusting to the solar focus, and of changing the piece bearing the spider-webs, in case of accident. For *setting* the telescope, the eye-end is furnished with two circles of six inches diameter, divided on silver, with levels, shewing altitudes and zenith distances*. Finally, there are four eye-pieces, magnifying 33, 60, 80, and 120 times; and the object-end has a cap pierced with three apertures, adjustable to solar transits, constantly attached to and balanced with the instrument. The level for securing horizontality is a *rider*, of excellent workmanship: it is suspended by the centre, in its long brass frame and cell, instead of by the

* It is generally supposed, that these "setting circles" were invented by Troughton, and first applied to the Greenwich transit instrument in 1816. But Mr. Jones lent me a note-book of the late Mr. Walker, of *Eidouranion* memory, in which he describes a visit he made to the celebrated Jesse Ramsden in 1780; and mentions that he was shown "an ingenious mode of elevating a transit instrument, by a circle of about three inches diameter, and a level at the eye-end. The vernier fixed, and the circle with its attached level moveable." To this statement is the sketch of a telescope so fitted, the accompanying portion of which I traced.

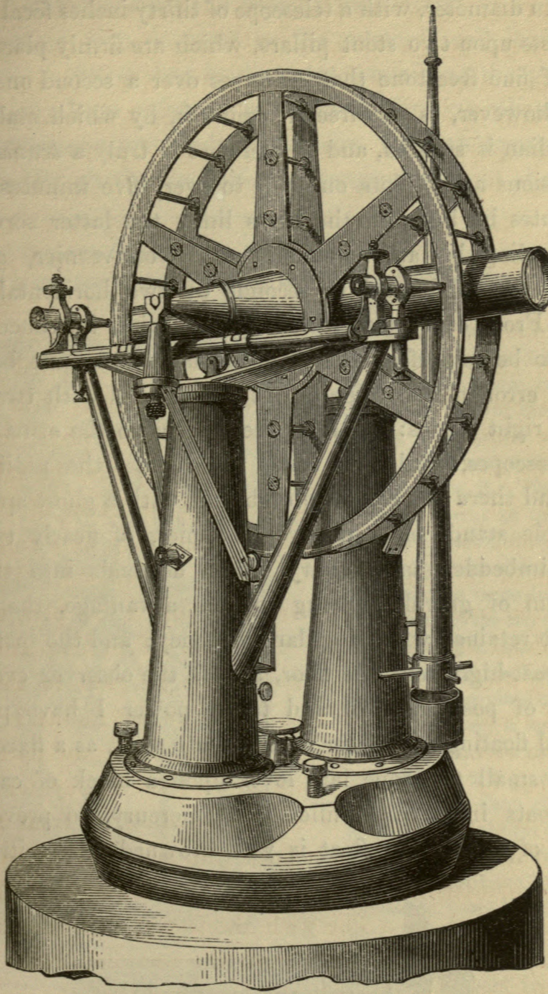


ends, as usual, owing to which it is free from contact, and safe from alterations in the ground curve; it shows seconds, and is accompanied by a small bubble, at right angles, with a screw-counterpoise and pillars, whereby the level may be reversed, end for end, with great facility, with regard to similar positions, and it stands the utmost scrutiny.



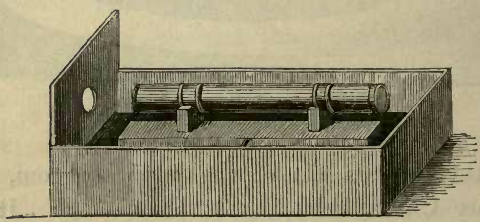
Meridian Mark.

Corresponding to this instrument I have placed so useful and convenient a check, in a near meridian mark, that I cannot but strongly recommend its general adoption, as affording the means, by illumination at night, of verifying the transit's position at the times of observation, besides its being free, in daylight, from the tremulous action arising from the solar rays. Such a mark was formerly objected to, because it was thought necessary that the focal length of the telescope should be adjustable to it; a condition inconsistent with that permanency of position in the axis of vision to the axis of motion, so essential in a meridional instrument, because any lateral motion between the Y's would put the mark apparently out of the meridian. Such was Maskelyne's modification of the principle adopted by Dr. Rittenhouse, viz., a cap with a lens of long focus, slipping over the object-end of his telescope. To obviate the defect objected to, I applied to Mr. Robinson, of Devonshire Street, to construct one for me, on a plan of my own, of which this is the description. A plate of brass, about $\frac{4}{10}$ of an inch in thickness, 5 inches long and 3 wide, is fastened, by four screws passing through its corners, to a stone, into which four brass sockets had been previously fixed, by melted lead, to receive them. On this plate there slides another of the same thickness, $3\frac{1}{2}$ inches long by $1\frac{1}{2}$ broad, attached to the former by dove-tailed side pieces, and adjustable by two long screws pressing against its ends. In the sliding-plate are also four long openings, to admit four capstan-headed screws, by means of which the sliding plate is to be firmly screwed to the fixed one, after the mark is adjusted to the meridian, when, to prevent disturbance, the end screws are withdrawn altogether. On the sliding-plate is soldered a square piece of silver, bearing a well-defined black cross as a mark for the meridian. But as this scarcely affords sufficient vertical length for examining the focal spider-lines, I applied a small circle of silver, one-eighth of an inch in diameter, with a black dot in its centre, to the top of the fixed brass plate, moveable laterally by two slender screws, which may also be taken out when the dot is once vertical with the bisection of the cross below it; and this I find to answer admirably, as a collimating mark, one of the principal uses which I proposed. The stone to which the mark is fixed is morticed into a low pier, to guard against lateral action, and the whole has a firm foundation sunk into the gravel: earnest attention must be paid to this, as a motion of about $\frac{3}{1000}$ of an inch, with fifty feet radius, is equivalent to one second. The remaining and important part of this arrangement is a four-inch lens, ground by Tulley for a focal length of $49\frac{1}{2}$ feet, which is exactly its distance from the diaphragm: this is encircled by a brass rim, and attached by screws to a plate of cast-iron, which is let into the south wall, close under the window, in a line with the transit instrument. It is evident that the rays of light from the meridian mark become parallel after passing through the lens, and that the diaphragm can therefore be viewed through a telescope adjusted to solar focus. Another consequence of the rays being rendered thus parallel is, that no parallel motion of the transit axis would cause a change in the place of the image seen; so that the meridian is a line drawn from the diaphragm through the axis of the lens; and provided these two points remain rigidly permanent, they offer every advantage of a distant meridian mark. After all, the latter one can still be used, when obtainable, as a check to the near one.



The Lee Circle.

Under the western slit of the meridian-room, stands the beautiful Lee Circle, belonging to the Society. It was made by that distinguished artist, our venerable Troughton, in 1793, and is by far the most perfect specimen of simplicity in design, united to comprehensiveness of object, that I have yet met with amongst graduated instruments of similar dimensions: I therefore regret to add, that it not only evinces marks of premature age, but also of former neglect, and even ill-treatment. It is two feet in diameter, with a telescope of thirty inches focal length; and it rests upon two stout pillars, which are firmly placed upon a slab of fine freestone that traverses over a second one. The motion, however, is not free in azimuth, by which stability in the meridian is secured, and it therefore is truly a *transit circle.* The divisions are by dots on gold, to every five minutes, and to ten minutes by lines on the brass limb, the latter serving for rough reading by an ingeniously-contrived vernier, and the former being subdivided to seconds by two horizontal microscopes. From every test which I can devise, its concentricity appears to be so perfect, that the graduated arc must be nearly free from error in that respect. It is furnished with two spirit-levels at right angles: the long one is fixed to the arms bearing the microscopes, while the other rides across the radii of the circle; and there is a capital plumb-line, with a ghost apparatus. The whole stands on a massy stone pier, of nearly two tons weight, imbedded in masonry which descends into the firm substratum of gravel. Owing to this advantage, the adjustments are retained with singular constancy; and the instrument being breast-high from the floor, affords the observer every convenience of position. To add to its power I have placed a horizontal floating collimator in the south wall, as a fixed point; this is a small telescope laid level upon a block of cast iron, which floats in a vessel filled with mercury, to prevent the adhesion of which, the float is well browned with nitric acid.



Immediately above the circle, two horizontal beams, stretching across the observatory, bear a large vertical collimator, which will be presently described; it slides by four friction rollers on an iron pathway, when required to be moved out of the zenith. These additions were made for me by Mr. Robinson, under Captain Kater's personal and friendly inspection*.

Four steps to a doorway in the western wall lead into a circular room, fifteen feet in diameter, containing the polar axis to which my large refractor is attached, forming what I term rather a telescope mounted equatoreally, than an equatorial instrument, though the mechanical arrangement is so simple and

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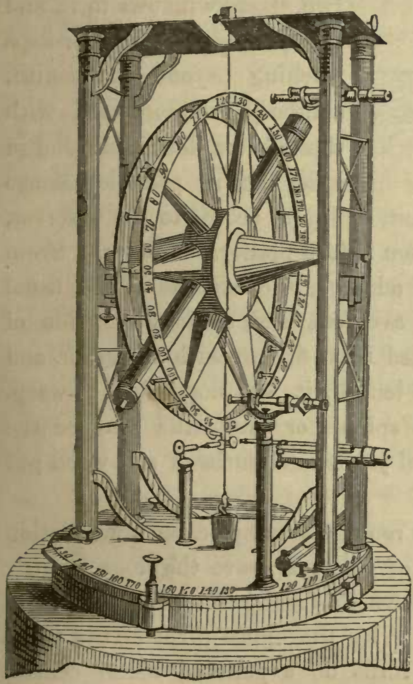
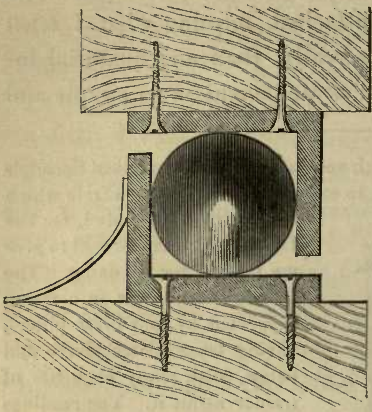
* In the Council's Report, in the IVth volume of the Astronomical Society's *Memoirs*, it is mentioned that I desired to exchange the Beaufoy Circle which I had already mounted, for the Lee one. It may be well to give my reasons for so doing. The Beaufoy Circle was in a frame supported by four brass pillars, having brass plates above and below, with many elements of tremor about it. The readings were by means of microscopes vertically placed, so that in holding a taper to the upper one, the heat was immediately communicated to the top plate; and when taking a star in the zenith, the warm head was directly over the brass plate of support. It is, however, a specimen of such excellent workmanship as to merit the 200 guineas which the late Mr. Cary charged for it; and under skilful care, is capable of good work. As Troughton made the Lee Circle for his friend Mr. Lowe, he only charged him 120*l.* for it, being the cost of the materials and labour. In 1807 it was sold to the Hon. Charles Grenville; and in 1810 it became the property of the Rev. Lewis Evans, at whose death it was offered to me by his son; but being unaware of its excellence, and having the Beaufoy Circle in actual use, I declined it. When, however, my friend Dr. Lee purchased it on my suggestion, I had an opportunity of minutely examining it, and was immediately struck with its simplicity, power, and superiority. To the practised eye, a comparison of the annexed representation with that on p. 333, will be sufficient to justify my preference.



effective, as to reflect much credit on Mr. G. Dollond. Aware of the *swagging* which all rotatory roofs must be liable to when placed, as usual, in the centre of a square room, I determined on adopting a circular one, because it was evident that the wall would offer points of support on all its bearings, and enable me



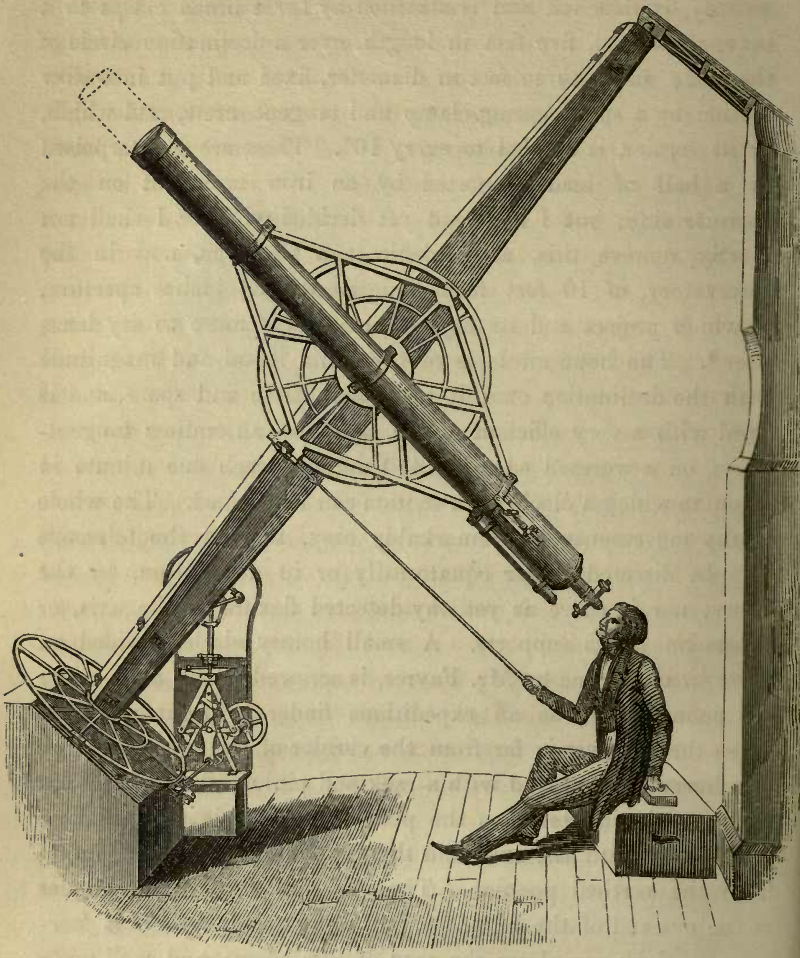
to have a dome of more than ordinary dimensions. The wall-plate is capped with an iron channel, containing three balls of the same metal, four inches in diameter, on which a conical roof revolves, having two glazed windows in it, and an opening with shutter-flaps reaching beyond the zenith, similarly counterpoised with those before described; and in order that no possible damage may be done to the instrument, or injury accrue to the observer, the dome is turned round from a *fixed* platform of steps. From the form of dome which I adopted, the expense of the usual hemispherical framing was avoided; and as it was made of straight pieces of well-seasoned Riga fir, cut with the grain, and resisting in the direction of length, it was not liable to warp. It was jointed together with splines, or thin laths, tongued the whole length with white lead joints, and curbs of soft wood put together so as to break joint.

On the north side of this room, a stone pier, on a foundation of brick, rises to the height of ten feet above the floor, bearing a cast-iron frame, the apex of which, furnished with the requisite adjustments, constitutes the Y for the upper pivot of the polar axis; while the lower one turns on a polished metal centre, imbedded in a stone pier on the south side. The body of the axis resembles, in shape, a large anchor stock: it is made of four mitred slabs of well-seasoned mahogany, on Sisson's plan, strongly braced together by screws that pass through them to interior brass squares, and terminating in large bell-metal pivots, through the shoulders of which fine holes are drilled for the admission of air; its length is thirteen feet by ten inches square in the middle, and eight at the ends. The telescope is carried by a stout axle through a hollow centre of bell-metal firmly secured by flanches, and is attached by three broad clasps to a brass trapezium, five feet in length, over a declination circle of the same metal, three feet in diameter, fixed and put into slow motion by a spiral spring-clamp and tangent-screw, and which, by its vernier, is divided to every 10″. These are counterpoised by a ball of lead supported by an iron crow-foot on the opposite side; but I have not yet decided whether I shall not shortly remove this, and substitute a telescope, now in the observatory, of 10 feet focal length, and $3\frac{3}{4}$ inches aperture, of which project and its object I may have more to say hereafter*. The hour circle is of the same metal and magnitude with the declination one; it reads both time and space, and is fitted with a very efficient clamp, and also an endless tangent-screw, on a wormed edge of 1440 notches, each one minute in value, to which a clock-work motion can be applied. The whole of the movements are remarkably easy, so that the telescope may be directed either equatoreally or in declination, by the finger; nor is there as yet any detected flexure in the axis, or expansion in its supports. A small horary circle, divided on silver, made for me by Mr. Fayrer, is screwed to the axis, under the counterpoise, as an expeditious finder in right ascension when the observer is far from the vernier of the hour circle, or in a hurry: it is moved with a rack and pinion, and is furnished with a swinging level, as the plane of the circle must make a right angle with the axis, and therefore assumes an inclination from the vertical position. There is also a declination-finder at the eye-end of the telescope. A clear-toned, dead-beat *journeyman* clock completes the *gear* of this room; and well-made marks of enamel, silver, and mother-of-pearl, fixed in a distant house, afford means for adjusting the eye-pieces and their foci.

It now remains to describe the telescope itself. It is an achromatic refractor of $8\frac{1}{2}$ feet focal length, with a double object-

* This plan, on a recommendation of Dr. Pearson, was attempted, but the disproportion between the telescopes caused its discontinuance. The 10-foot telescope is the one mentioned at p. 97.

glass of $5\frac{9}{10}$ inches clear aperture, and an area of 27·8 inches, which may perhaps be deemed the finest specimen of the late Mr. Tulley's skill: the flint-glass portion was made from a pure



The Telescope, Dew Cap, Polar Axis, and Clock.

homogeneal disc purchased at Paris, in 1828, by Sir James South, who obligingly disposed of it to me, on his acquiring the gigantic one which he is now mounting. When it came into my possession, I engaged Mr. Dollond to make a concerted range of eye-pieces, which were afterwards carefully proved, by direct experiment, to have powers from 22 to 1200;

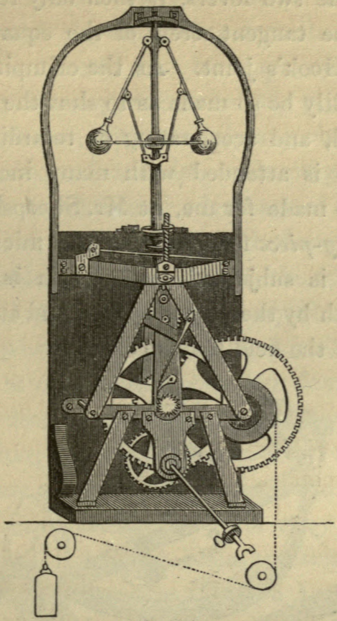
of this range, six of the highest are single convex lenses ingeniously fitted in a polycratic wheel; and nine are eye-tubes of two lenses each, with adapting tubes to each, so that they are speedily shifted without screw-motion or shaking. There is an apparatus to regulate the light agreeably to the intensity required; and the great tube is furnished with judiciously-placed stops, or diaphragms, to the exclusion of the false light called fog. On repeated trials, I find the instrument bears its highest magnifiers with remarkable distinctness, as is especially evinced by the roundness of small discs, the dark increase of vacancy between close double stars, and from particular portions of the moon when dichotomized; I have therefore reason to presume that the curves of the lenses are in exact chromatic and spherical aberration throughout; and the focal distance accurately proportioned to the densities of the flint and crown glasses. Besides the diaphragms for moderating the stray light, every caution was observed for excluding fog and unequal refractions, in order to preserve the full space-penetrating power; a property resulting from a certain breadth in the visual pencil of rays, in proportion to the amplifying power made use of, and therefore different both from distinctness and magnifying power. Under this care, nothing can exceed the definition and sharpness with which the telescope comes to focus, even under low powers and different-sized apertures. A fine double-line position micrometer, whose screws have been rigidly examined under every revolution, and a spherical rock-crystal micrometer by Dollond, for measuring minute angles where illumination cannot be used, accompany the eye-pieces, with a scale of powers from 62 to 850*. The whole battery can be rendered diagonal for objects

* By repeated measurements of the sun at high altitudes, the value of each division of the double-wire micrometer heads was = 0″·19845, and consequently of a revolution = 19″·845. And the threads of the screws were rigorously tried for the same divisions, on an equally divided scale, and proved to be equal. Besides the micrometers here mentioned, Mr. Baily kindly presented me with an excellent annular one by Fraunhofer, which by repeated measures of stars near the ecliptic, and on the meridian, I found to have a radius of 472·5 seconds in arc. Dollond's spherical crystal was, from its limited capacity, rather difficult to fit with a scale; but by comparing a set of dots upon paper, with their ascertained values by the wire micrometer, a result was gained of 0″·27 for each division.

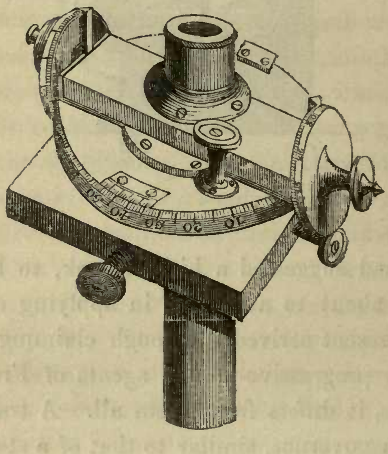
in the zenith, by the instant application of a Wollaston Prism made to fit them: there is also a contrivance, of the utility of which I am as yet doubtful, called "Budd's Centre," for viewing satellites by hiding the body of the planet, and a pearl screen for shading the moon's limb during occultations. The finder, which is a 20-inch telescope of 1·6 inches aperture, is an excellent specimen of optical skill.

In giving this high character of my telescope, it is proper to state that I have tried its light by the cluster in the sword-handle of Perseus, by several of Messier's nebulæ, and by resolving portions of the Via Lactea into stars. Its distinctness is proved by the ready vision of the companions of Polaris, Rigel, α Lyræ, and α^1 Capricorni; and also by the facility with which λ Ophiuchi, τ Aquarii, θ Persei, μ Cephei, δ Serpentis, ζ Herculis, and ϵ Boötis, are seen double; ζ Orionis and ξ Libræ triple; β Capricorni quadruple; and σ Orionis multiple. Lastly, I estimate its general action by the Lunar mountains, cavities, and shadows, under all powers; the lucid polar regions of Mars, the sharpness of the double ring of Saturn, the gibbous aspect of Venus, the shadows of Jupiter's satellites across his body, the splendid contrast of colours in α Herculis, γ Andromedæ, and other superb double stars, and the comparative facility with which such tests as σ Coronæ Borealis, τ Aquarii, θ Virginis, η Boötis, and δ Equulei, admit of measurement. Of these it may not be uninteresting to add, that, in consequence of a letter from Mr. Herschel, I examined the remarkable orbital change of quadrant which has occurred in the first, since 1825; and that I have had a fair comparison with him, in measuring the position and distance of the last, to very considerable accuracy.

Shortly after these experiments were made, this instrument received a valuable addition to its efficiency, in a clock for giving it motion in right ascension. This excellent adjunct is represented in the annexed sketch, the weight for driving it being under the floor of the observatory; it was presented to me by the Rev. Richard Sheepshanks, who invented it. I had long been made sensible of the inconvenience of preserving equable motion in an equatorial, while endeavouring to counteract the apparent motion of the heavens with a long Hook's-joint handle acting upon the hour-circle tangent screw in one hand, and with the other working at micrometer measures.



Mr. Babbage had suggested a kitchen-jack, to be regulated by fans, and was about to assist me in applying one, when Mr. Sheepshanks' present arrived. Though claiming affinity on the whole with the progressive-motion agents of Fraunhofer, Gambey, and others, it differs from them all. A train of wheels is made to carry a governor, similar to that of a steam-engine, and its axis, which revolving swiftly, occasions the regulating balls to separate, and, with the aid of an absorbing wheel, gives a smooth action to the hour circle; yet under such control as to be readily adjustible to sidereal, solar, or even lunar motion, so as to make any celestial object appear to be fixed in an immovable field. This permits such steady gazing, that one of its effects is equivalent to an increase of optical power. The performance is simple and effective. As the *centrifugal* balls of the governor separate, they elevate a collar which is attached to the middle of a lever reaching entirely across the clock. This lever communicates with a shorter one below it, in immediate connection with the train of wheels, and thus the elevation of the balls *governs* the whole. The rate being regulated by the rod connecting the two levers, it then only remains to transfer the motion to the tangent screw of the equatorial hour-circle, by a rod with a Hook's joint. As the clamping of the tangent-screw cannot readily be so made as to shut the star exactly upon the point desired, and accelerating or retarding the clock-rate for such purpose is attended with many inconveniences, Mr. Dollond therefore made for me, at Mr. Sheepshanks' suggestion, a movable *slipping-piece* for receiving the micrometer, of which a representation is subjoined; and which is easily moved in altitude or azimuth by the proper screws, and enables the observer to use any part of the field that he chooses.



While the polar axis was receiving this great accession to its efficiency, the optical power of the telescope received an unexpected augmentation; and one which I found eminently useful in particular cases. This is the mere introduction of an achromatic lens into the ocular focus of the tube, where it adds little to the weight, and but four inches to the length of the instrument; the lens is fixed to an *adapter* 8½ inches in length, of which the part holding the lens is pushed 4½ inches into the eye-end of the tube, where it is interposed between the object glass and its principal focus, and the micrometer is inserted into the opposite end of the adapter. The first intimation which I received of this new *power*, was from the Rev. W. R. Dawes, who when on a visit to me in the summer of 1833, described the success of its addition to his telescope so succinctly, that I forthwith requested Mr. Dollond to furnish me with one also. On receiving it, I directed the telescope upon a watch-plate fixed on a distant chimney, which quickly proved the power of the lens in enlargement, with scarcely any obscuration of light. While the image expanded under each progressive eye-piece, I was surprised at the additional advantage of its simultaneously flattening the whole field of view; and though the magnifying power became double on distant objects, the apparent magnitude of the spider-lines diminished in an equal ratio: a property which, with all powers above three hundred times, is of considerable benefit to operations upon close double stars, and the finer micrometric desiderata. I afterwards raised the discs of the satellites of Jupiter, and examined several double stars, both coarse and delicate, with equal facility and advantage*; the definition being quite distinct, and the stray light rather subdued than increased. After a little practice, I came to the conclusion that the Achromatic Concave Lens will render the instrument to which it shall be applied, equal to two telescopes for particular cases; for if a set of observations be made *with* it, and another set *without* it, the errors of vision will be in some degree neutralized, or even done away with.

Such being the capacity of this beautiful application, I requested Mr. Dollond to furnish me with the particulars of its figure, and other details; as an object of high interest to optical inquiry. To this he kindly returned an answer, dated the 17th of December, 1833, which was so full and so satisfactory, and contained such interesting extracts from Mr. Dawes's journal upon the practice of the lens, that I prevailed on him to

* I had occasion to propose two or three slight alterations to the adapter of this lens; and I also made an improvement in ensuring the zero corrections of my micrometer, by means of small bolts, by which either head could be kept fixed while the other was worked. When Mr. Dollond returned the lens, in August 1834, I immediately applied it to that very delicate star in Aquila, 307 Piazzi XIX., which I had before attacked in vain, and obtained satisfactory results, with comparative ease.

communicate the same to the Royal Society for general information; it is printed in the *Philosophical Transactions* for 1834, together with a mathematical comment thereupon by Professor Barlow, of Woolwich.

To return to the building details. Outside the walls of the observatory, for the space of ten feet, the earth was entirely removed, and the vacancy filled up with broken bricks and gravel; and as all the water from the top is carried off by pipes to a distant cess-pool, the effects of damp are thus guarded against, which is a very necessary precaution where no fire should be lighted. In front of the building there is a solid pedestal for a magnetic transit instrument, of great delicacy of action, and capable of every variety of adjustment.

The secondary arrangement of my plan relates to meteorology, a department of knowledge which has, I think, been hitherto injuriously undervalued in astronomical registers*: for who that has observed much in opposite winds, or seen the increased scintillation and flitting of small stars, or the opening of others previous to rain, would deny that many atmospherical variations still require to be studied to render our theories of refraction less imperfect? There can be but little doubt that many of the minor faults of which instruments and observers have usually borne the *onus*, ought to have been attributed to this uncertain element; and the refrangent force of the atmosphere is so obviously and sensibly affected by humidity, that I generally recorded the state of the hygrometer, with that of the other instruments, in case a third correction for refraction should ever be made; but Delambre and Biot seem to have set that question at rest. In order that my own observations should have all the consistency which equalized temperature can confer,

* Since this was published, a remarkable reform has taken place iu this respect, by the exertions of both public and private individuals. Greenwich now carries on a series of such excellent observations, that they are well calculated to raise meteorology to a science: here are watched and registered the strength and force of the winds, the atmospheric temperature and weight, the amount of horizontal movement of the air, the rain at different heights, the evaporation, the vertical and horizontal magnetic forces, and registers for ascertaining the connexion between electricity and the various meteorological phenomena.

there is a double thermometer of Six's on the wall which divides the meridian and equatorial rooms, hanging parallel to a barometer by Dollond, which some years' experience enables me to rely upon; its cistern is 3½ feet from the floor, and 28 above the river Ouse, or about 117 feet above the sea high-water mark. A self-registering thermometer, by Troughton, is placed on the outside of the north wall, under the transit window, perfectly screened from the sun, and from any reflection of solar rays. Previous to observation, I usually see that all the instruments are in proper state for action, and open the door and north windows, so as to bring the outer and inner thermometers to a near agreement. At the outer angles of the roof, and about fourteen feet from the ground, are placed an evaporator and a rain-gauge. The first is a hollow cylindrical vessel of copper, twelve inches in diameter and five in depth, furnished with a cover elevated on four small pillars three inches above it, but of larger circumference, to prevent the intrusion of birds, and occasion a current of air free from rain and sun. The second is a copper funnel of the same periphery, with a perpendicular rim around its top, to prevent any loss by splashing, during the precipitation of rain, and the water caught in its area is measured off in an adapted glass tube, which is graduated to thousandths of an inch. To these is added a neat hygrometer, made by Robinson, with twisted filaments of the *andropogon contortum*, a grass brought from India by Captain Kater, where it is called *Obeenah hooloo*, which, from its extreme sensibility, admits of an index being graduated to a thousand parts, from immersion in unslacked lime to full moisture. It may be trite; but after Lalande's eulogy of the tinman on the *Quai des Augustins**, I may mention, that an arrow, clear of all obstruc-

* Lalande's anecdote will illustrate what I have asserted, as to the neglect of meteorology at the observatories. In his astronomical *exposé* for 1801, he says: "Well-placed weather-cocks are very rare at Paris. There is none at the observatory, though I requested one on being appointed director; and I have thanked, in the name of all observers, Citizen Bois, tinman, who having built a house on the Quai des Augustins, has erected there a lofty and very movable weather-cock, with letters indicating the four cardinal points, which will be on a line with a meridian I have traced out on the quay. Astronomers,

tions, shows the direction of the wind; it is above the centre of the dome, but, from the interior arrangement of the piers, quite clear of the zenith of the telescope.

Such being the means in my possession for carrying on future observations, I have now to state the *position* of the observatory, in a geographical point of view. And here I must relate an error into which I fell on commencing the building. Desirous of obtaining a temporary latitude for tabulating the Greenwich stars for the transit instrument, I took a micrometrical measurement to the clock on St. Paul's spire, in the town of Bedford, on an azimuth-bearing, which gave 20″ from the perpendicular, and 17″ from the meridian. This I applied to a manuscript note given to me by a friend, with an assurance of its having been written by the late General Mudge; and therefore concluded my latitude to be about 52° 8′ 48″, and longitude 27′ 12″, until, on working several polar distances which I afterwards took, with the Beaufoy Circle, the results came out 52° 8′ 25″·9. As I was then also reducing some observed occultations, and was aware that 23″ of difference must be sensible in the lunar parallax, I determined to prove the point. But that circle having been, by the Council's permission, transferred to the Rev. Michael Ward, I awaited the arrival of the Lee one; and then the erection of the polar-axis room, the delays of workmen, and other causes—of more annoyance to me, than interest to others—prevented my attending to it till the end of August, when the accompanying observations were commenced. It is due, however, to that great national undertaking, the Trigonometrical Survey, to add, that in the mean time I found my friend was unable to substantiate the authenticity of his note; and that I believe the position of St. Paul's steeple, as printed in the *Philosophical Transactions*, to be extremely correct.

Having experienced much loss of time, when on public service, from the necessity of awaiting consecutive periods for completing observations, I resolved to give Captain Kater's

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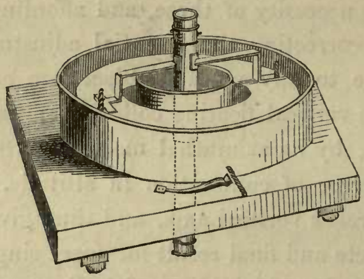
when they go to the Institute, or the Board of Longitude, will have an opportunity of seeing conveniently the direction of the wind; and the same advantage will be enjoyed by the inhabitants of that vast quay, of the Louvre, and the surrounding houses."

Vertical Collimator a strict trial as a zenith point, from its obvious dioptric property of converging parallel rays. In using it with the Beaufoy Circle, I was much pleased with its action; for the convenience of each altitude's being complete in itself, without the necessity of reversing the circle, constitutes an invaluable quality; while the optical axes are so rectified that the centres, or intersecting points in the telescope and collimator, remain coincident during an observation. In the fifteen months which elapsed between the taking down of the one circle, and the working the other, the collimator was covered up on account of the dust occasioned by bricklayers and masons. Yet, soiled as it necessarily became, when it was occasionally uncovered for examination by astronomical friends, it constantly and readily formed as rigid a zero as before the interruption. In the annexed observations, which are amenable to the collimator, without any reference to either level or plumb-line, it will be seen that the inclination of the floating optical axis was purposely varied, by weights, without at all affecting the final deductions. Now, as the accuracy of all celestial labours depends upon the proper compensating adjustments, every improvement in applying them must be cheerfully welcomed by astronomers. The instability of levels, and the difficulty of pronouncing a plumb-line to be either perfectly straight or cylindrical, are universally acknowledged; but the obviating the necessity of these, and affording a ready means of verifying and correcting the essential adjustments of a circle without reference to any external object, are only a portion of the *praxis* of the vertical floating collimator; its principal claim to regard is, that, by its azimuthal motion of 180°, it shows the amount of the error of collimation in altitude, and of any deviation in the circle's vertical axis, and thus gives the means of yielding a complete and final result for every single observation.

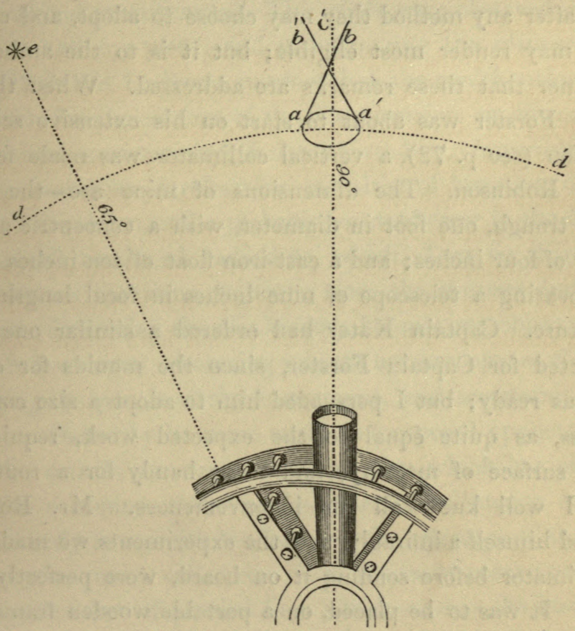
An instrument by which the zenith distance of any celestial object may be immediately obtained, is so important to private observers, that another word may be necessary. The telescopic collimation is an imaginary line extending from the centre of the object-glass to the focus where the middle of the cross-wire is: in most instruments the line of sight is considered to have a certain relation to other parts; and the difference between the existing and required positions, is the error of collimation, which must be exactly ascertained and allowed for, or the observation is vitiated. The best mode of attaining precision in this respect, independently of plumb-line or level, had long been a desideratum in practical astronomy. In 1824 Bessel, following a precept given by Gauss, used that property of a telescope, in virtue of which its cross-wires, adjusted to distinct vision on the wire, may be distinctly seen by another telescope similarly adjusted, at whatever distance the telescope may be placed, provided their axes coincide; in which case the rays diverging from the cross-wires of either telescope, will emerge parallel from its object-glass, and will therefore be refracted by that of the other telescope to its sidereal focus, as if they came from an infinite distance.

About this time, while the German philosophers were thus occupied, Captain Kater was simultaneously employed on the same object in England; and proceeding upon the simplest optical and hydrostatic principles, produced his horizontal floating collimator, which he explained to me in 1824. His paper describing it was read to a meeting of the Royal Society on the 13th of January, 1825. From this he advanced further, I hope partly at my instance, and matured his Vertical Collimator, the instrument in question. The sketch here given shows the



telescope suspended to a circular iron float, enclosed in an annular trough where it swims upon quick silver. It is fixed on a mahogany frame, moving on friction rollers along the beams already spoken of. The telescope is carried clear through all; it must be brought to a vertical position, and the adjustments made, which Captain Kater has so fully detailed in the *Philosophical*

Transactions for 1828. The method of using this adjunct to a fixed instrument is at once easy and pleasing; and he who has been waiting, with a reversed face to his instrument, to complete a set of observations taken the night before, will feel the advantages of it, especially if the sailing of a ship is deferred till such completion is made. On the accompanying diagram, the line from c to c′ may be supposed to represent the visual ray from the observing instrument into space. The little circle *a* and *a′* will represent that described by the diaphragm's centre, in the collimating telescope, as the float is made to revolve 180° in the annular trough; at which point it is checked by a pin and inclined spring, as shown. The optical axis of the floating telescope is here supposed to have an inclination represented,



but purposely exaggerated, by *a b* in its first position, and by *a′ b′* in its second, after being turned in azimuth. The mean of the two, or half the sum of the readings *a* and *a′*, of course constitutes the true zenith direction for c c′, from which the star *e*, measured on the arc *d d*, will be duly corrected.

On the whole, from witnessing that it possesses sufficient stability for its times of action, the conclusion I have arrived at is, that this powerful appendage, whether used above or below, will, in the end, be deemed an integral part of every meridian circle; that its cheapness, portability, and facility of correction, render it highly desirable and available to officers and others employed on scientific missions; and that its results harmonize in a more remarkable degree than by the usual means of level and plumb-line, taken with twice the time and trouble. And when all the obstacles to the extensive use of reflection are considered, the collimator presents advantages too obvious to be overlooked.

Public and other large fixed observatories, are in possession of both time and means for obtaining zenith and horizontal points, after any method they may choose to adopt, and circumstances may render most eligible; but it is to the ambulatory astronomer that these remarks are addressed. When the late Captain Forster was about to start on his extensive scientific expedition (see p. 72), a vertical collimator was made for him by Mr. Robinson. The dimensions of mine are—the round circular trough, one foot in diameter, with a concentric circular opening of four inches; and a cast-iron float of ten inches in diameter, bearing a telescope of nine inches in focal length by 1¼ in aperture. Captain Kater had ordered a similar one to be constructed for Captain Forster, since the moulds for casting were thus ready; but I persuaded him to adopt a size considerably less, as quite equal to the expected work, requiring a smaller surface of mercury, and more handy for a routine of which I well knew all the inconveniences. Mr. Robinson acquitted himself admirably, and the experiments we made with the collimator before sending it on board, were perfectly satisfactory. It was to be placed, on a portable wooden frame, over one of those serviceable machines, the Troughton 13-inch Altitude and Azimuth Instrument. Some time afterwards, Mr. Henry Kater brought me a little floating horizontal collimator, made on his father's model by Professor Amici at Modena: and it struck me as being so adapted for those persons to whom a larger instrument would be inconvenient, that I laid it on the the table of the Royal Astronomical Society for the inspection of the Fellows, at the meeting of the 9th of December, 1836. This instrument is only $1\frac{1}{2}$ inch in length, and, together with the mercury in which it floats, is packed in a small round box, two inches in diameter in the inside and two inches high; so that it may be carried in the pocket. It is the first which was ever made of such small dimensions; but notwithstanding its diminutive size, when applied to the Lee Circle, it yielded a very exact index correction for the horizontal point.

To proceed to the observations already alluded to. The refractions in the subjoined list are reduced by Ivory's Tables, as inserted in Mr. Baily's useful volume of *Astronomical Tables and Formulæ;* and as the *modus operandi* is in some respects new, I have tabulated the various stars, almost to the type of calculation, for the sake of practitioners. The whole were observed with the same eye and eye-piece; and in estimating the ultimate differences, it should be borne in view that the zenith point is not answerable for the amount of the discrepancies; on the contrary, instrumental ex-centricity, faults of reading, imperfections of division, anomalies of refraction, casualties of bisection, derangement of collimation, and a probable constant error in the diagonal lens, are all combined; added to which, I so far disregarded the inventor's directions, as not to close the shutters during the operation of bisecting the diaphragm; because my object was not so much bent upon measuring minute agreements, as the justly estimating the power of the instrument, and ascertaining what might be effected by its more rapid and exposed application. I must also correct an erroneous impression which has obtained, as to the necessity of the vertical floating collimator being returned *exactly* to a zenith bearing over the telescope of the circle. This is by no means called for: it is the ready recurrence of the simple optical law of parallel lines which renders the instrument so eminently useful; for any descending rays, entering whatever part of the field of view, must converge in the centre of the ocular focus, or axis of vision*.

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* Shortly after the reading of this paper, the Royal Astronomical Society awarded their gold medal to Captain Kater, for his invention of the Vertical Floating Collimator.

Observations.										
No.	Date.	Star.	Face.	Micr.	Circle's Readings.	Vertical Collimator. Direct.	Reversed.	Thermometer. Exter.	Inter.	Barom.
	1830.				° ′ ″	z ° ′ ″	z′ ° ′ ″	°	°	In.
1	Aug. 30	α Aurigæ	E	A	83 38 12·6	89 57 46·8	89 57 52·5	45·8	50·0	30·00
				B	38 12·2	57 41·5	57 45·2			
2	..	γ Orionis	..	A	44 1 47·6	89 57 53·3	89 57 48·8	47·8	50·5	30·09
				B	1 45·5	57 50·6	57 45·0			
3	..	α Can. maj.	..	A	21 22 41·5	89 57 54·3	89 57 55·5	51·6	53·0	30·10
				B	22 37·8	57 51·8	57 50·9			
4	..	α Can. min.	..	A	43 29 40·5	89 57 53·3	89 57 56·9	54·0	55·2	30·10
				B	29 38·7	57 50·0	57 53·8			
5	„ 31	α Tauri	W	A	35 56 6·5	89 57 59·6	89 58 4·9	45·0	47·0	30·19
				B	56 4·9	57 58·8	58 3·5			
6	..	γ Aquilæ	..	A	41 52 54·3	89 58 8·8	89 58 9·2	57·0	57·0	30·23
				B	52 48·7	57 59·5	58 0·7			
7	..	β Aquilæ	..	A	46 5 52·3	89 58 9·6	89 58 12·8	56·8	57·0	30·23
				B	5 44·6	58 1·4	58 3·1			
8	..	α^2 Capri.	..	A	65 8 2·5	89 58 13·5	89 58 4·8	56·0	56·0	30·23
				B	7 52·5	58 1·3	57 59·5			
9	..	α Pis. Aus.	..	A	82 30 22·5	89 58 4·5	89 58 8·9	54·0	54·0	30·24
				B	30 18·4	58 0·6	58 4·4			
10	Sept. 1	γ Draconis	..	A	0 35 14·1	89 58 6·6	89 58 5·6	62·0	60·7	30·23
				B	35 9·5	58 1·7	57 59·1			
11	..	β Lyræ	..	A	18 55 31·8	89 58 5·4	89 58 8·9	60·5	59·0	30·23
				B	55 30·2	57 58·9	58 0·8			
12	..	ζ Aquilæ	..	A	38 28 18·0	89 58 8·0	89 58 3·3	59·4	58·3	30·24
				B	28 11·1	58 4·5	57 56·0			
13	..	α^2 Capri.	..	A	65 7 47·5	89 58 1·9	89 57 55·4	57·5	56·4	30·24
				B	7 43·8	57 51·5	57 44·1			
14	..	α Aquarii	..	A	53 13 9·2	89 57 56·2	89 57 59·5	55·0	54·0	30·23
				B	13 6·1	57 50·3	57 53·8			
15	„ 3	α Boötis	E	A	57 54 28·8	89 57 57·5	89 57 53·4	66·4	64·5	29·80
				B	54 30·5	57 58·6	57 54·1			
16	„ 11	α Scorpii	..	A	11 51 14·8	89 58 1·4	89 57 58·7	59·0	57·7	29·75
				B	51 19·9	58 7·9	58 2·8			
17	..	α Ophiuchi	..	A	50 32 6·6	89 57 57·6	89 57 59·9	56·1	55·8	29·75
				B	32 10·5	58 1·4	58 3·2			
18	..	α Lyræ	..	A	76 27 55·7	89 57 54·1	89 57 55·3	53·5	53·8	29·75
				B	28 1·5	57 57·2	57 56·9			
19	..	β Lyræ	..	A	71 0 26·2	89 57 54·4	89 58 1·7	53·0	53·7	29·76
				B	0 30·5	57 57·1	58 3·2			
20	..	δ Aquilæ	..	A	40 38 11·8	89 58 7·6	89 58 15·7	52·5	53·0	29·76
				B	38 1·4	57 56·8	58 3·6			
21	..	γ Aquilæ	..	A	48 3 19·0	89 58 13·5	89 58 10·9	51·9	52·4	29·76
				B	3 12·4	58 3·1	57 58·5			
22	..	β Aquilæ	..	A	43 50 32·3	89 58 10·3	89 58 17·4	51·7	52·0	29·76
				B	50 20·5	57 55·5	58 4·4			
23	..	α^2 Capri.	..	A	24 48 18·2	89 58 14·2	89 58 9·6	51·4	51·1	29·75
				B	48 7·2	58 3·7	57 58·1			
24	..	α Cygni	..	A	82 30 58·4	89 58 10·4	89 58 17·8	50·9	50·5	29·75
				B	30 50·7	57 59·6	58 6·1			

DEDUCTIONS.

No.	Incl. of Collim. $\frac{z-z'}{2}$ ″	Zenith Point. $\frac{z+z'}{2}$ ° ′ ″	Correction. ′ ″	Refraction. ′ ″	Zenith Distance. ° ′ ″	Latitude. ° ′ ″	Remarks.
1	2·350	89 57 46·500	+ 2 13·500	0 6·500	6 19 40·600	52 8 21·500	Wind w.s.w. Fine weather.
2	2·525	89 57 49·425	+ 2 10·575	1 0·587	45 57 3·462	21·482	Indistinct from daylight.
3	0·075	89 57 53·125	+ 2 6·875	2 27·727	68 37 41·202	21·902	Full glare of day.
4	1·850	89 57 53·500	+ 2 6·500	1 1·016	46 29 14·916	23·956	Glare, but well bisected.
5	2·500	89 58 1·700	+ 1 58·300	0 42·885	35 58 46·885	22·525	Fine morning. Wind s.w.
6	1·225	89 58 4·550	+ 1 55·450	0 52·020	41 55 38·970	20·640	Indifferently bisected.
7	0·400	89 58 6·725	+ 1 53·275	1 0·290	46 8 42·015	22·925	Light westerly airs.
8	2·625	89 58 4·775	+ 1 55·225	2 4·925	65 11 57·650	24·020	Indifferent. Evening hazy.
9	2·050	89 58 4·600	+ 1 55·400	7 0·230	82 39 16·080	22·189	Wind w.s.w. & tolerably fine.
10	0·900	89 58 3·250	+ 1 56·750	0 0·614	0 37 10·664	20·664	Fine weather: fair bisection.
11	1·350	89 58 3·500	+ 1 56·500	0 19·800	18 57 47·300	26·820	Indistinct from light haze.
12	3·300	89 58 2·950	+ 1 57·050	0 45·955	38 30 57·555	22·875	B over a faulty dot.
13	3·475	89 57 53·225	+ 2 6·775	2 4·703	65 11 57·128	23·488	Very fairly bisected.
14	1·700	89 57 54·950	+ 2 5·050	1 17·936	53 16 30·636	21·576	B on a bad dot.
15	2·150	89 57 55·900	+ 2 4·100	0 35·141	32 4 1·391	24·871	A fr. n.w. wind on the collim.
16	1·950	89 58 2·700	+ 1 57·300	4 23·620	78 11 8·970	27·430	Hazy. Difficult bisection.
17	1·025	89 58 0·525	+ 1 59·475	0 46·996	39 26 38·871	24·811	Tolerable.
18	0·225	89 57 55·875	+ 2 4·125	0 13·797	13 30 11·066	27·866	Aft. α Lyr. put a wt. on float.
19	3·350	89 57 59·100	+ 2 0·900	0 19·764	18 57 50·514	31·134	Very difficult bisection.
20	3·725	89 58 5·925	+ 1 54·075	1 6·958	49 21 6·283	25·643	Well bisected. Took wt. off.
21	1·800	89 58 6·500	+ 1 53·500	0 51·750	41 55 42·550	25·130	Easy bisection. Put 2 wts. on.
22	4·000	89 58 6·900	+ 1 53·100	0 59·975	46 8 40·475	22·115	Good observ. Took 1 wt. off.
23	2·550	89 58 6·400	+ 1 53·600	2 4·218	65 11 57·918	24·178	Very fair.
24	3·475	89 58 8·475	+ 1 51·525	0 7·566	7 27 21·491	24·491	Tolerable.

Observations.

No.	Date.	Star.	Face.	Micr.	Circle's Readings.	Vertical Collimator. Direct.	Vertical Collimator. Reversed.	Thermometer. Exter.	Thermometer. Inter.	Barom.
	1830.				° ′ ″	z ° ′ ″	z' ° ′ ″	°	°	In.
25	Sept. 12	α Leonis	E	A	50 38 2·8	89 58 14·7	89 58 10·8	58·0	58·9	29·37
				B	37 58·5	58 10·2	58 3·9			
26	..	α Boötis	..	A	57 54 41·3	89 58 9·3	89 58 6·6	57·6	57·6	29·37
				B	54 37·2	58 2·0	57 59·7			
27	..	γ Draconis	..	A	82 20 59·5	89 58 9·3	89 58 13·5	54·0	55·5	29·35
				B	20 56·9	58 0·4	58 3·4			
28	..	α^2 Capri.	..	A	24 48 22·8	89 58 16·9	89 58 14·4	52·0	52·8	29·34
				B	48 10·1	58 9·4	58 6·6			
29	..	β Aquarii	..	A	31 32 54·3	89 58 17·5	89 58 12·7	50·7	50·5	29·34
				B	32 42·1	58 10·5	58 3·6			
30	..	α Aquarii	..	A	36 43 3·9	89 58 16·8	89 58 14·6	49·8	49·9	29·35
				B	42 57·1	58 7·7	58 8·3			
31	„ 13	ζ Aquilæ	W	A	38 28 30·3	89 58 15·7	89 58 17·8	55·2	55·2	29·55
				B	28 18·1	58 1·4	58 3·6			
32	..	α Aquilæ	..	A	43 39 52·8	89 58 19·2	89 58 13·0	53·9	53·7	29·58
				B	39 41·7	58 4·5	57 55·7			
33	..	α^2 Capri.	..	A	65 8 14·5	89 58 16·0	89 58 18·7	53·0	53·0	29·55
				B	7 58·8	58 0·5	58 1·4			
34	..	β Aquarii	..	A	58 23 35·0	89 58 13·3	89 58 8·5	51·4	50·7	29·54
				B	23 25·8	58 2·3	57 55·8			
35	..	α Pis. Aus.	..	A	82 30 36·7	89 58 11·2	89 58 3·9	50·5	49·7	29·53
				B	30 27·3	58 4·9	58 0·5			
36	„ 26	δ Ursæ min.	..	A	55 31 47·1	89 58 21·8	89 58 18·3	54·5	54·7	30·22
				B	31 35·2	58 7·9	58 4·6			
37	..	ξ Draconis	..	A	74 44 40·9	89 58 18·6	89 58 21·5	54·0	53·8	30·22
				B	44 30·9	58 3·5	58 4·4			
38	..	γ Ursæ maj.	..	A	16 48 16·9	89 58 22·2	89 58 19·8	48·5	48·5	30·24
				B	47 58·1	58 9·7	58 6·4			
39	„ 28	α Ursæ maj.	..	A	79 27 2·1	89 58 11·9	89 58 9·4	64·0	59·0	30·19
				B	26 58·3	58 8·5	58 5·3			
40	„ 29	α Ursæ min.	..	A	50 31 38·5	89 58 12·7	89 58 7·1	58·0	58·4	30·02
				B	31 33·7	58 5·9	57 58·4			
41	Oct. 4	α Cephei	E	A	9 42 9·9	89 58 19·5	89 58 14·6	50·0	50·5	30·26
				B	42 0·8	58 2·8	57 53·0			
42	..	β Cephei	..	A	17 38 56·3	89 58 14·3	89 58 20·2	50·0	50·3	30·26
				B	38 45·6	57 51·7	57 58·2			
43	..	α Ursæ maj.	..	A	65 7 58·3	89 58 17·8	89 58 16·5	47·7	48·2	30·28
				B	7 40·9	57 56·2	57 54·3			
44	„ 5	δ Ursæ min.	..	A	34 24 37·4	89 58 3·2	89 58 7·5	54·2	55·4	30·35
				B	24 26·8	57 52·9	58 0·5			
45	„ 9	α Ursæ maj.	W	A	24 49 47·7	89 59 30·2	89 59 29·0	51·0	51·5	30·45
				B	49 42·7	59 28·7	59 28·5			
46	..	γ Ursæ maj.	..	A	16 49 21·1	89 59 27·8	89 59 23·1	49·0	49·6	30·46
				B	49 17·5	59 26·7	59 22·4			
47	..	α Androm.	..	A	23 57 49·8	89 59 20·4	89 59 22·7	49·0	49·1	30·46
				B	57 48·8	59 19·6	59 20·8			
48	..	δ Ursæ maj.	..	A	20 9 4·2	89 59 22·2	89 59 20·3	48·7	48·8	30·46
				B	9 1·8	59 21·4	59 18·3			

Deductions.

No.	Incl. of Collim.	Zenith Point.	Correction.	Refraction.	Zenith Distance.	Latitude.	Remarks.
	$\frac{z-z'}{2}$ ″	$\frac{z+z'}{2}$ ° ′ ″	′ ″	′ ″	° ′ ″	° ′ ″	
25	2·550	89 58 9·900	+ 1 50·100	0 45·991	39 20 55·241	52 8 30·891	Lt. w.s.w. wind. A bad dot.
26	1·250	89 58 4·400	+ 1 55·600	0 35·220	32 4 0·370	23·020	Glare of day; but tolerable.
27	1·800	89 58 6·650	+ 1 53·350	0 0·603	0 37 9·053	19·853	Pretty good, tho' light haze.
28	1·325	89 58 11·825	+ 1 48·175	2 2·221	65 11 57·596	23·846	Tolerable.
29	2·925	89 58 11·075	+ 1 48·925	1 32·582	58 26 55·457	25·017	Indifferent, from haze.
30	0·400	89 58 11·850	+ 1 48·150	1 16·470	53 16 27·820	19·320	Ditto. A mere hazy point.
31	1·075	89 58 9·625	+ 1 50·375	0 45·231	38 30 59·806	25·966	Wind west. Fair observ.
32	3·750	89 58 8·100	+ 1 51·900	0 54·550	43 42 33·700	30·020	Tolerable.
33	0·900	89 58 9·150	+ 1 50·850	2 2·935	65 12 0·434	26·675	Very fair bisection.
34	2·825	89 58 4·975	+ 1 55·025	1 32·938	58 26 58·363	28·823	Rather obscure.
35	2·925	89 58 5·125	+ 1 54·875	6 53·955	82 39 20·830	25·510	Tolerable.
36	1·700	89 58 13·150	+ 1 46·850	0 39·946	34 27 11·946	24·214	Wind w. by s. & clou. Fair obs.
37	0·950	89 58 12·000	+ 1 48·000	0 15·888	15 13 51·988	24·602	Poor bisection.
38	1·425	89 58 14·525	+ 1 45·475	3 12·945	73 13 19·970	25·020	Unfavourably bisected.
39	1·425	89 58 8·775	+ 1 51·225	0 10·637	10 31 19·212	25·668	Aft. this, cleaned out collim.
40	3·275	89 58 6·025	+ 1 53·975	0 47·209	39 27 17·134	26·706	Wind n.w. Fair bisection.
41	3·675	89 58 7·475	+ 1 52·525	0 10·144	9 44 8·019	25·651	n.w. winds. Good obs.
42	3·100	89 58 6·100	+ 1 53·900	0 18·773	17 41 3·623	23·527	B over a faulty dot.
43	0·800	89 58 6·200	+ 1 53·800	2 7·350	65 11 50·750	26·290	Fair bisection. Took off 2 wts.
44	2·975	89 58 1·025	+ 1 58·975	0 40·084	34 27 11·159	25·041	Poor bis. Micros. adjusted.
45	0·350	89 59 29·100	+ 0 30·900	2 5·861	65 11 49·761	28·879	Wind w.n.w. Replaced a wt.
46	2·250	89 59 25·000	+ 0 35·000	3 14·008	73 13 19·708	29·532	Bisected in an Aur. Bor.
47	0·875	89 59 20·875	+ 0 39·125	0 26·437	23 58 54·863	22·462	Cleaned the collim. cases.
48	1·250	89 59 20·550	+ 0 39·450	2 40·646	69 52 56·996	33·885	Indifferently bisected.

Observations.										
No.	Date.	Star.	Face.	Micr.	Circle's Readings.	Vertical Collimator.		Thermometer.		Barom.
						Direct.	Reversed.	Exter.	Inter.	
	1830.				° ′ ″	z ° ′ ″	z′ ° ′ ″	°	°	In.
49	Oct. 9	α Cassiop.	W	A B	86 31 23·1 31 22·3	89 59 31·5 59 30·3	89 59 22·5 59 20·8	48·2	48·0	30·46
50	..	α Ursæ min.	..	A B	53 44 19·4 44 17·5	89 59 21·3 59 19·6	89 59 30·9 59 29·5	47·5	47·5	30·46
51	..	ζ Ursæ maj.	..	A B	17 59 52·5 59 46·5	89 59 31·9 59 33·5	89 59 25·8 59 26·4	47·0	47·2	30·46
52	..	η Ursæ maj.	..	A B	12 22 14·8 22 10·9	89 59 27·4 59 24·3	89 59 33·3 59 28·0	46·8	47·0	30·46
53	„ 26	α Leonis	E	A B	50 47 55·9 47 42·5	0 4 14·9 4 5·6	0 11 43·6 11 39·5	45·5	50·2	29·98
54	..	α Cygni	..	A B	82 40 49·5 40 39·6	0 4 12·5 4 2·5	0 11 45·3 11 42·5	42·0	46·7	30·19
55	..	α Pis. Aus.	..	A B	7 35 58·6 35 41·5	0 4 13·0 4 1·6	0 11 46·9 11 43·6	39·6	41·5	30·26
56	..	α Androm.	..	A B	66 9 26·3 9 37·5	0 4 11·1 4 7·8	0 11 51·1 11 47·5	37·3	39·4	30·27
57	..	α Ursæ min.	..	A B	36 23 19·6 23 13·4	0 4 11·1 4 3·9	0 11 53·9 11 50·4	36·5	39·5	30·28
58	..	δ Ursæ maj.	..	A B	69 58 29·2 58 20·4	0 11 48·7 11 43·5	0 4 13·2 4 0·9	37·1	39·6	30·27
59	„ 29	α Leonis	..	A B	50 49 16·6 49 9·3	0 5 42·6 5 37·5	0 13 6·3 12 59·9	47·0	48·5	29·65
60	..	α Aquarii	..	A B	36 54 15·3 54 6·1	0 13 9·4 13 3·5	0 5 43·6 5 38·5	44·7	49·0	29·72

These observations, as I have already stated, were taken in a ready manner in order to show the property and power of the Vertical Collimator in every-day practice; and the results thus obtained will be worthy of scrutiny, as exhibiting the competence of the data for determining the arc from the observer's zenith to the celestial equator. From the foregoing list there appears,

By 26 stars, S. of zenith, and face E. $52° \, 8' + \frac{639'''{\cdot}742}{26} = 24'''{\cdot}605$

By 16 stars, S. of zenith, and face W. $52° \, 8' + \frac{387'''{\cdot}178}{16} = 24'''{\cdot}198$

$\Big\} = 24'''{\cdot}401$

By 6 stars, N. of zenith, and face E. $52° \, 8' + \frac{155'''{\cdot}673}{6} = 25'''{\cdot}945$

By 12 stars, N. of zenith, and face W. $52° \, 8' + \frac{324'''{\cdot}721}{12} = 27'''{\cdot}060$

$\Big\} = 26'''{\cdot}502$

As the latitude of any place of observation is a point of

Deductions.

	Incl. of Collim.	Zenith Point.	Correction.	Refraction.	Zenith Distance.	Latitude.	Remarks.
	$\frac{z-z'}{2}$ ′ ″	$\frac{z+z'}{2}$ ° ′ ″	′ ″	′ ″	° ′ ″	° ′ ″	
49	0 4·625	89 59 26·275	+ 0 33·725	0 3·605	3 28 7·180	52 8 24·100	Tolerable.
50	0 4·875	89 59 25·325	+ 0 34·675	0 44·110	36 15 50·985	28·915	Very fairly bisected.
51	0 3·300	89 59 29·400	+ 0 30·600	3 1·740	72 2 41·640	26·640	In a bright coruscation of Aurora.
52	0 2·400	89 59 28·250	+ 0 31·750	4 26·080	77 41 41·480	26·560	In the Aurora.
53	3 45·650	0 7 55·900	− 7 55·900	0 48·040	39 20 54·740	25·290	Collim. cleaned, & loaded to a larger circle of the diaphragm's revol.
54	3 48·200	0 7 55·700	− 7 55·700	0 7·779	7 27 18·929	27·299	Tolerable observation.
55	3 48·975	0 7 56·275	− 7 56·275	7 17·468	82 39 25·986	24·626	Lt. haze; but well seen.
56	3 49·925	0 7 59·375	− 7 59·375	0 26·899	23 58 54·374	24·344	Very fairly bisected.
57	3 52·325	0 7 59·825	− 7 59·825	0 44·381	36 16 1·056	25·184	Rather indistinct.
58	3 59·525	0 7 56·575	− 7 56·575	2 39·555	69 53 7·780	30·080	Indifferent. Put another weight on the inner pin, and inserted a new set of wires in the circle's telescope.
59	3 41·525	0 9 21·575	− 9 21·575	0 47·482	39 20 56·107	26·287	
60	3 42·700	0 9 23·750	− 9 23·750	1 17·900	53 16 30·950	22·550	A fair bisection.

interest, I now determined upon giving the circle a close trial, by means of its plumb-line and levels only; and as I did not wish to disturb the newly-introduced spider-lines, I resorted to the upper and lower culminations of Polaris: for albeit I do not consider the slow motion of this star as at all favourable to the nicest bisections, it offers the most perfect theory of latitude attainable, by affording observations entirely independent of tabulated corrections. And though I knew the collimation of the telescope to be wide, I was also aware that it would only partake of the general affections of the circle, as arising from temperature. I therefore adjusted the axes accordingly; and the following results, corrected by Dr. Brinkley's refractions, are very satisfactory, as regards instrumental permanency, however they may fall short of establishing the absolute altitude of the polar point.

Date.	Micr.	Circle's Readings.	Face.	Thermometer. Exter.	Thermometer. Inter.	Barom.	Refraction.	Altitudes. Supra Polum.	Altitudes. Sub Polo.
1830.		° ′ ″		°	°	In.	′ ″	° ′ ″	° ′ ″
Oct. 29	A	39 35 29·3	E	50·1	50·3	29·67	0 47·522	....	50 23 46·078
	B	35 23·5							
..	A	36 24 37·9	E	41·5	46·5	29·79	0 43·036	53 34 44·714	
	B	24 26·5							
„ 30	A	50 43 4·5	W	44·6	45·2	29·99	0 48·582	....	50 42 13·368
	B	42 59·4							
..	A	53 54 3·3	W	51·5	52·0	30·00	0 42·676	53 53 17·324	
	B	53 56·7							
Nov. 1	A	36 24 35·6	E	48·7	50·0	30·8	0 43·007	53 34 46·283	
	B	24 25·8							
„ 2	A	39 35 27·4	E	55·0	52·7	30·9	0 47·820	....	50 23 46·880
	B	35 23·2							
„ 7	A	53 53 58·0	W	42·6	45·5	29·39	0 42·507	53 53 12·693	
	B	53 52·4							
„ 8	A	50 43 2·1	W	44·1	45·0	29·65	0 48·074	....	50 42 10·376
	B	42 54·8							
					Means - -			53 44 0·254	50 32 59·175
					Sum of the means			- - =	104 16 59·429
					½ Sum = Latitude -			-	52 8 29·715
					Latitude by Collimator			- -	52 8 25·451
					General mean -			-	52 8 27·553

Mean. app. pol. dist. by obs. = 1° 35′ 30″·54. By the Tables = 1° 35′ 31″·51, or " + 0″·97

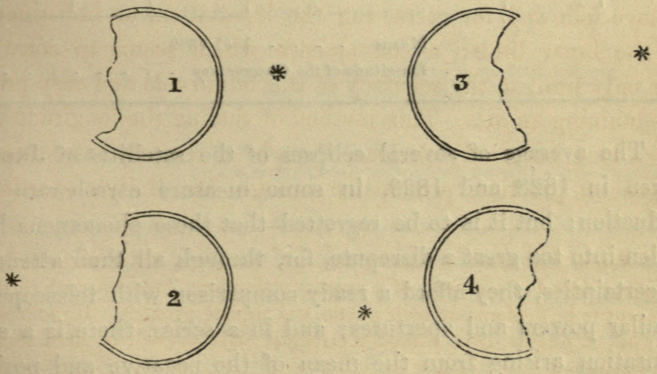
The longitude of the observatory had been pretty fairly established last year as 1^m 51^s·305, by means of many sets of moon-culminating stars, taken in correspondence with Greenwich, Biggleswade, and Cambridge, of which the deductions were forwarded to the society by Mr. Maclear. But although it is therefore unnecessary to repeat the whole, yet an example after Mr. Baily's formula may be given, as expressing the mode I have followed for correcting the irradiation, or indistinctness of the lunar limb: a consequence which seems to constitute the only limit to the accuracy of this admirable and easy process of obtaining an arc. This method of finding the longitude must have long been very obvious, though so recently introduced as a general practice, principally through Mr. Baily's exertions*.

* While this sheet is passing through the press, Mr. Francis Baily, my excellent friend of a quarter of a century's standing, has departed this life; an event to be deplored on both public and private grounds. He expired on the 30th of August, 1844, without a struggle. His loss will be most seriously felt among practical astronomers.

Mr. F. Vernon alludes to it as early as 1669 in a letter to Oldenburg, now in the archives of the Royal Society. A century afterwards it was proposed by Dr. Maskelyne, in the Appendix to the *Nautical Almanac* for 1769; and it was illustrated by Pigott in establishing the difference of meridian between London and York. It is effected by comparing the differences of the observed right ascensions of the selected stars and the moon's bright limb: a method less operose than any other in practice, taking no unobserved data for granted, except the moon's hourly motion in Æ. The more the care taken with the means, the better of course will the observations be: but here no absolute dependence need be placed on the exact position and adjustments of the instrument; and the clock-rate for so short an interval, is next to immaterial.

It should be noted that the moon's place has been calculated carefully, including the third order of differences. It will be seen, according to the following diagrams, that by 1 and 2 the irradiation diminishes the apparent difference of moon and star's right ascension between Greenwich and Bedford; while by 3 and 4 it increases the same. On this point, however, it is extremely desirable to establish a value by transits of the moon's bright and dark limbs, when they can be obtained. Therefore, the transits of the first limb have been algebraically increased, and those of the second diminished, by the assumed irradiation.

Moon's First Limb — * Moon's Second Limb — *



May 1829	Stars.	☽ - * Greenwich.	☽ - * Bedford.	Irrad.	Incr. Æ.	Longitude.	Irrad.	Incr. Æ.	Longitude.
		m s	m s		s	m s		s	m s
13	ν Leonis	13 29·08	13 32·282	+ ·02	3·222		+ ·32		
	213 Virg.	10 36·08	10 32·704	− ·02	3·396		− ·32		
	η Virginis	29 29·04	29 25·752	− ·02	3·308		− ·32		
		☽ 1	Mean - - -		3·309 =	1 42·0818		3·609 =	1 51·324
16	*m* Virginis	34 4·02 ☽ 1	35 7·614	+ ·02	3·614 =	1 42·130	+ 0·32	3·914 =	1 50·579
17	α^2 Libræ	17 25·12	17 29·199	+ ·02	4·099		+ ·32		
	υ^1 Libræ	1 34·90	1 48·457	+ ·02	3·577		+ ·32		
	τ Libræ	6 4·58	6 0·772	− ·02	3·828		− ·32		
	η Libræ	35 36·92	35 33·414	− ·02	3·526		− ·32		
		☽ 1	Mean - - -		3·7575 =	1 41·279		4·057 =	1 49·318
18	η Libræ	21 15·32	21 20·066	− ·02	4·676		− ·32		
	49 Libræ	4 58·86	5 3·400	− ·02	4·520		− ·32		
	ν Scorpii	6 20·98	6 16·180	+ ·02	4·780		+ ·32		
	ϕ Ophiuchi	25 38·44	25 33·775	+ ·02	4·645		+ ·32		
		☽ 2	Mean - - -		4·6553 =	1 59·8716		4·355 =	1 52·139
19	ϕ Ophiuchi	31 25·06	31 29·771	− ·02	4·691		− ·32		
	251 Ophi.	2 59·32	3 04·540	− ·02	5·200		− ·32		
		☽ 2	Mean - - -		4·9455 =	2 02·628		4·6455	1 55·212
20	ξ Serpentis	23 51·76	23 56·832	− ·02	5·052		− ·32		
	281 Serp.	5 10·82	5 15·780	− ·02	4·940		− ·32		
	μ^1 Sagittar.	11 52·64	11 47·436	+ ·02	5·184		+ ·32		
		☽ 2	Mean - - -		5·0587 =	2 02·391		4·7587	1 54·7433
			Means - - - -			1 51·7302			1 52·2192
			Longitude of the Observatory - - - - - - - - -						1 51·9747

The average of several eclipses of the satellites of Jupiter, taken in 1828 and 1829, in some measure corroborate this deduction; but it is to be regretted that these phenomena have fallen into too great a disrepute, for, through all their attendant uncertainties, they afford a ready comparison with telescopes of similar powers and apertures; and in a series, there is a compensation arising from the mean of the negative and positive errors. Even for that fine evening, May 18th of last year (1829), although the planet was in such splendour as to invite attention, I can only find its observation recorded at Cambridge. Nor was I much more fortunate with simultaneous occultations of stars by the moon, till the Society's invitation aroused general notice, and the four following were watched in several places of known difference of meridian. Greenwich, of course, has been selected.

Date.	Stars.		Sidereal Time of observation.	Long. W.	Remarks.
1829.			h m s	m s	
Aug. 21	α Tauri.	Em.	4 59 49·63	1 54·353	Wind S.S.W. and rather hazy.
Oct. 9	67 Aquarii.	Im.	21 48 33·45	1 49·479	Wind N. by W. and cloudy, but fine at intervals.
„ 15	α Tauri.	Im.	22 48 18·96	1 49·271	W.N.W. and misty. * projected $2\frac{1}{4}^s$ on ☽'s disc.
		Em.	23 24 7·89	1 52·841	Wind still W.N.W.; instantaneous.
				$\frac{7\ 25·944}{4}$	= $1^m\ 51^s·486$ for Bedford.

As Mr. Riddle's ingenious formula, recently printed in the Society's *Memoirs*, Vol. IV., p. 315, brings out the observation of the 15th of October to a mean of $1^m\ 50^s·42$, it may be proper to mention, that the method I adopted for the parallaxes was suggested to me by Mr. Maclear, for trial, as a modification of Cagnoli's. The equation is

$$\sin \pi = \frac{\sin p \cos L \sin P}{\cos (D + \pi')}$$

and

$$\sin \pi' = \sin p \sin L \cos D - \sin p \cos L \sin D \cos \left(P - \frac{\pi}{2}\right)$$

viz.

$$\text{sin par. in Æ} = \frac{\text{sin hor. par.} \times \text{cos lat. of place} \times \text{sin star's hor ang.}}{\text{cos (star's declin.} + \text{par. in declin.)}}$$

and

$$\text{sin par. in dec.} = \text{sin hor. par.} \begin{cases} \text{sin lat.} \times \text{cos star's declin.} \\ - \text{cos lat.} \times \text{sin star's declin.} \times \text{cos(star's hor. ang.} - \tfrac{1}{2}\text{par. in Æ.} \end{cases}$$

The peculiarity of this mode consists in the parallax in right ascension being added to the star's right ascension if west, or subtracted if east of the meridian, to find the right ascension of the point of occultation, and then using the geocentric semi-diameter without augmentation. The difference of the squares of the moon's true declination—the declination of this point, and of the moon's horizontal equatorial semidiameter reduced to the equator, at immersion subtracted from, or at emersion added to, the right ascension of the point of occultation, gives the right ascension of the moon's centre; a method by which the errors of the moon's place in right ascension are evaded. I also found Mr. Herschel's equations extremely simple in practice. Here the co-ordinates, instead of being referred to the equator and its perpendicular, are expressed by the method of azimuths and altitudes, with the horizon as a fundamental circle, by which the reduction of parallax to right ascension and declination is avoided. In this form, as well as in every other, there will occur cases of difficulty where the approximations are not convergent enough; and in such cases the calculation must be conducted with greater precaution.

From the tenour of these investigations, being desirous of fixing my longitude to a greater degree of certainty, it was my intention to unite Cambridge, Biggleswade, and Bedford, by flashes of gunpowder at concerted stations. On reconnoitering the country for this object, I was gratified to find that not only Professor Airy and the Rev. R. Sheepshanks promised every aid in their power, but also that Mr. Maclear, with his wonted ardour in all matters of science, on hearing of my intention, voluntarily sent me a tender of his services, and closed by offering to bear a portion of the expense. The appointment of Mr. Maclear to the Cape of Good Hope Observatory, and the employment of Mr. Sheepshanks on important public duties, prevented this measure from being carried into effect.

During the current year the accompanying occultations have been observed with a view to the same object. I have added the reductions for an approximate average, in the absence of proper comparisons; but as they depend entirely upon the Lunar Tables, where an error of $0^{s}\cdot6$ in time on the moon's place produces one of 12^{s} or 13^{s} in longitude, it will be seen that the disparity in the differences must exist until corresponding observations can be met with; for they are not only affected by inflection, irradiation, and the minor discrepancies of the stars, but also by the position, parallax, semidiameter, and hourly motion of the moon*. Indeed, I hold these observations, when only hanging on the Lunar Tables, and especially those wherein the stars are oblique to the paths, to be of little use for accurate points, unless they are watched for a lunar cycle, because the slow motion of the moon's nodes causes her, in short spaces of time, to eclipse nearly the same stars at each sidereal conjunction, and also because the errors in her place are mostly constant for each point of her orbit. And though occultations, particularly when *fully* calculated, have been deservedly ranked amongst the most interesting and useful of the heavenly phenomena, there cannot be a doubt of the existence of some undetected source of fallacy in the computations: some *residual phenomenon*, to use an appropriate phrase of Sir John Herschel's. From corresponding observations, it appears that, if the immersion is positive, the emersion, as regards the assumed longitude, is generally negative, showing that something, as yet unexplained, depends on the direction of the parallax; and that the agreement of the sines, or chords of small arcs, with the arcs themselves, is not sufficiently investigated. Thus, in the obser-

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* "The observations here alluded to have, for the sake of convenience, been arranged, with others, in chronological order, in the paper entitled 'Astronomical Observations,' at the end of the present volume." (*Sec. R. A. S.*) To this note I may append those to which I obtained corresponding observations; being unwilling, for reasons *ut supra*, to vitiate the results with those which were not elsewhere observed.

Date, 1830.	Stars.	Immers. or Emers.	Time. Sidereal.	Time. Apparent.	Resulting Longitude.
			h m s	h m s	m s
Jan. 5	75 Tauri - -	Im.	7 12 18·88	12 06 06·84	1 49·52
..	α Tauri - -	Im.	10 41 53·18	15 35 02·62	1 52·05
Feb. 5	ι Cancri - -	Im.	9 19 58·19	12 03 02·35	1 51·34
March 28	o^2 Tauri - -	Im.	7 42 33·56	7 14 34·52	1 50·93
..	99 Tauri . -	Im.	8 37 15·56	8 09 08·26	1 52·03
July 25	♃'s 2nd Satellite	Em.	17 11 42·29	8 53 19·55	1 52·01
„ 31	♃'s 1st Satellite	Em.	20 26 23·27	11 43 59·62	1 51·38
Oct. 5	θ^2 Tauri - -	Im.	3 12 51·82	14 27 33·05	1 50·47
..	θ^2 Tauri - -	Em.	4 23 41·37	15 38 11·58	1 51·60
..	102 P. IV. Tauri	Im.	4 27 20·31	15 41 39·88	1 50·42

vations of the 5th of last October, it is evident that there exists a constant error in the moon's place; the right ascension is too much, or the declination too little, for either would produce the same effect upon the longitude, because the difference of declination squared, *minus* the square of the semidiameter, is greater in proportion to the diminution of the former. The same appears in that of the 31st, or the star's place is erroneous. In all these reductions the lunar declination has been calculated to the apparent time at Bedford + $1^m\ 51^s$; and the interpolation of the moon's place is by the differential method. The intermixed longitudes by the satellites are only rough estimations from the Ephemeris, but the corrections suggested in the Supplement for 1830 have been applied.

**** Addition by Thomas Henderson, Esq., extracted from a Letter to Captain Smyth.*

"Edinburgh, 72, Broughton St., Dec. 9, 1830.

"I return you many thanks for your kind attention to my request. Your observations are of great service to me. In comparing them, as well as Mr. Maclear's, and those at Greenwich, with the corresponding ones made here, I have deduced the following results.

		BEDFORD FROM GREENWICH.	Diff. of Long. m s
Emersion.	Aldebaran.	August 21, 1829 - - -	1 52·4
Immersion.	Aldebaran.	January 5, 1830 - - -	1 50·6
Imm. and Em.	θ^2 Tauri.	March 28, 1830 - - -	1 52·7
		Mean - - - -	1 51·9

		BIGGLESWADE FROM GREENWICH.	
Emersion.	Aldebaran.	August 21, 1829 - - -	1 4·1
Immersion.	Aldebaran.	January 5, 1830 - - -	1 2·7
Imm. and Em.	θ^2 Tauri.	March 28, 1830 - - -	1 2·4
		Mean - - - -	1 3·1

		BEDFORD FROM BIGGLESWADE.	
Emersion.	Aldebaran.	August 21, 1829 - - -	0 48·3
Immersion.	75 Tauri.	January 5, 1830 - - -	0 48·2
Immersion.	(99) Tauri.	January 5, 1830 - - -	0 47·3
Immersion.	Aldebaran.	January 5, 1830 - - -	0 47·9
Imm. and Em.	θ^2 Tauri.	March 28, 1830 - - -	0 50·3
		Mean - - - -	0 48·4

"Many more such comparisons may be obtained from the observations, but the above are all which I have yet computed, not having entered upon the computation of those for which I had no corresponding observations made at Edinburgh. I had proceeded a considerable way in the investigation of the longitude of Edinburgh from occultations observed here, compared with the corresponding observations made in England and on the Continent; but I have been obliged to leave the work unfinished for the present, by the necessity of attending closely to business of a different description. The same cause has compelled me to stay away from the observatory. So far as I had gone, it appeared that the longitude obtained from the Trigonometrical Survey *recalculated* (12^{m} $43^{s}{\cdot}6$) would be confirmed; and, as the uncertainty in our latitude (which I consider $55° 57' 20''$) must be less, for the present I reckon our geographical position pretty well determined.

"Occultations compared with the Lunar Tables alone, I consider scarcely superior to ordinary lunar distances. They are much better when the Tables have been corrected by meridian observations made at regular observatories; but full advantage is only to be had from them when the errors of the Tables are eliminated by means of corresponding observations, or when, the places being near each other, the tabular errors affect the observations nearly in the same manner."

Having accomplished the object for which this observatory was erected, and being called into South Wales on business but little connected with the heavens, it was dismantled in November, 1839. The transit instrument and clock are now at Cambridge, in the possession of my friend Mr. William Hopkins; the circle has been lent to Lord Wrottesley; and the polar axis and telescope is at Hartwell House, where Dr. Lee has duly installed it in an efficient equatorial room, under the best revolving dome I have yet met with. In this well-constructed temple, everything being almost the same as if the instrument had remained in *statu quo* at Bedford, I have had the advantage of obtaining fresh epochs for several interesting binary systems, since my return from Glamorganshire. The 10-foot telescope mentioned at p. 97, and a capital 3½ foot one, with micrometers and some secondary appendages, remain in my hands; and with an equatorial ladder presently to be described, afford me the means of still watching the celestial phenomena.

§ 2. Hints to Amateur Astronomers.

There are subjects on which many beginners will not listen to advice; and it follows, that just as many subjects must remain uncomprehended by such attempters. Nor is Urania—heavenly maid!—free from such suitors: but still there are many to whom a little assistance will act as a tow-rope, and bring them by their own hauling upon it into the scientific fairway; and it is to this division that my hints are here principally directed. The *furor* of a green astronomer is to possess himself of all sorts of instruments—to make observations upon every thing—and attempt the determination of quantities which have been again and again determined by competent persons, with better means, and more practical acquaintance with the subject. He starts under an enthusiastic admiration of the science, and the anticipation of new discoveries therein; and all the errors consequent upon the momentary impulses of what Bacon terms "affected dispatch" crowd upon him. Under this course—as soon as the more hacknied objects are "seen-up," and he can decide whether some are greenish-blue or bluish-green—the excitement flags, the study palls, and the zeal evaporates in hypercriticism on the instruments and their manufacturers; albeit a moment's reflection would prove that the failure of success, was owing rather to a want of application than of means. Still, however, he may not regard the wondrous works of the Omniscient Architect with the dull unconscious gaze of mere animal sensation: he ought therefore to be restored to a sound view, even though he may not be exactly a devoted Uranian.

The national observatories are now so admirably equipped and worked for the details of meridional operations, that it is only encountering labour almost descending to drudgery, for little purpose, to poach upon their department. But there are many choice branches of astronomy mentioned in the course of this work, which present open fields to the amateur; and being extra-meridional will not be claimed by the scientific regulars. Dollond's immortal invention of the achromatic object-glass, has placed the means of being useful within reach of all who are conscious that "where there's a will there's a way*." Wherever there is a well-wisher to knowledge, armed with a telescope and clock, there will be found an astronomical sentinel, whose watchful aid may efficiently fill up *lacunæ* of interest: and this may be done without encroaching on any professional avocation, by merely steering the middle course between neglect and devoteeism. Those individuals who fear that their instruments are not of sufficient power to render their observations useful, should remember that Galileo's grand discoveries were made with a telescope that magnified only thirty times. It is true that no such "luck" is now to be looked for, and that at present we think less of a magnifying power of three hundred, than they did of thirty in his day, yet it is the mind which stamps a value upon the observations: for attention, habit of precision, good sight and hearing, and earnest perseverance, are qualities in the observer as important as the comparative excellence of his instrument. A man may prove a good astronomer without possessing a spacious observatory: thus Kepler was wont to observe on the bridge at Prague; Schroeter studied the moon, and Harding found a planet, from a *gloriette;* while Olbers discovered two new planets from an attic of his house. A serious error is prevalent, that Sir William Herschel's immortal discoveries resulted from the stupendous power of his telescopes†; but it was

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* The writer upon *Optics*, in the *Library of Useful Knowledge*, tells us that this beautiful discovery was near upon being unfolded by Newton, who spoke upon what might be effected by contrary refractions, the very law which it hangs upon. Yet, perhaps teased with a badly-made refracting telescope, he somewhat hastily pronounced it incorrigible, and its cure hopeless: and it does not anywhere appear that he had the least idea of the different dispersive powers of refracting substances, the very property on which Dollond's discovery is based.

† The advocates of idleness advance the plea, that Herschel attained eminence as an astronomer, though he was no *mathematician.* Can such men ever have seen his papers? M. Arago is indignant at the blatant assertion; and besides pointing out some of his mathematical discussions, mentions that a

to his assiduity and skill that the world were mainly indebted, much as it undoubtedly owes to his mechanical operations; for the principal double-stars, and the planet Uranus, were found with a telescope of but seven-feet focus. Delambre, in his oration to Napoleon, observed of Herschel: "En leur livrant les télescopes qu'il avait construits, il ne leur a communiqué ni son adresse ni son infatigable activité;" and it was well remarked that his instruments "could only be used by the man who made them, and only be made by the man who used them." But Herschel himself declared, that he never observed "with a larger instrument when a smaller would answer the intended purpose," because both time and trouble are thereby saved.

It may, however, distress the observer who labours with inferior means, to pore over accuracies which he cannot hope to reach; but he who diligently applies himself may always accomplish much good and acceptable work. He may not, it is true, be able to enjoy the returning duplicity of such tests as ω Leonis, γ Coronæ, τ Serpentis, 42 Comæ Berenicis, ζ Herculis, and δ Cygni; but he may be assured, that the majority of the binary objects are under the power of a 5-foot refracting telescope, of $3\frac{3}{4}$ inches aperture, with its 11 inches of area*; and that many things deemed invisible to secondary instruments, are plain enough to one who "knows how to see them." He will soon practically comprehend that aphorism of Sir William Herschel's, which states, "It should be remembered that when an object is once discovered by a superior power, an inferior one will suffice to see it afterwards." This has been recently impressed upon me with additional force, since I have been able to see objects with my telescope which were brought to light by the great Poulkova refractor: of this a striking instance will be found under the head of γ Andromedæ†. The eye itself improves, and the

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difficult question was proposed in 1779, on the vibrations of cords loaded with small weights, which Herschel ably solved. This is the prize question which Peter Puzzlem (*J. Landen*) sent to the *Ladies' Diary;* and it also appears in Leybourn, Vol. III., p. 61.

* Where the expense of a 5-foot telescope may be considered too great, many of them may be beautifully seen with a 44-inch of $2\frac{3}{4}$ aperture.

† M. Otho Struve, the distinguished son of the Professor, at his late visit

vision becomes sharper under practice, insomuch that the telescope seems to improve. Now, though we are not all so enthusiastic as to think with Anaxagoras, that "man was born to observe the heavens," it cannot but be satisfactory to see an increase of observers: for the more they abound, the greater is the probability of many of the desiderata being supplied; every present exertion forms rudiments of future knowledge, and continuous labour well directed sometimes conquers where genius fails. Individual observers would be most likely to advance the cause of astronomy substantially, by giving their undivided attention to a particular object.

The details of the Bedford Observatory, just given, may assist a person who desires to apply himself regularly to astronomy; and if he wishes for a deeper insight into the arcana of instruments, he cannot do better than consult Dr. Pearson's truly useful *Introduction to Practical Astronomy*, a work which has been justly designated one of the most important and extensive on that subject, which has ever issued from the press. I propose, however, to offer a few remarks to those who possess telescopes, and wish to make use of them, but without a view to continuous observations: these remarks will, of course, be suited to the power and application of that *appropinquator siderum*, and not to its theory and construction. There are many who commence by attempting to make their own telescope, and affect a disinclination to gaze till they fabricate a perfect one; which is nearly equivalent to refusing a dinner before one can manufacture the knife and fork wherewith to attack it: and such—at as much expenditure of time as would gain a practical knowledge of the heavens, and of as much money as would purchase a fair instrument—turn out a bad telescope. Those who will persist in not observing till they can make their own tools, or procure them absolutely perfect, are in the same category with the boy, whose loving mother would not hear of his going into the water until he had learned to swim.

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to Greenwich on a chronometric mission, presented me with a Catalogue of 770 double and multiple stars thus discovered: it is appropriately dedicated to M. d'Ouvaroff, "au nom des astronomes de l'observatoire central de Poulkova," by my worthy friend, the elder Struve.

The Uranian aspirant will have procured the best telescope he is able to get, and whether refractor or reflector—glass, metal, or fluid—Gregorian, Newtonian, Cassegrainian, Dollond, or Herschelian*,—he will find the aphorism realized of its being a revelation to the sight,

> Which, like the golden bough Æneas bore,
> Transports the mortal to a heav'nly shore.

On the supposition, however, that he is possessed of that very desirable and handy instrument, the 5-foot achromatic refracting telescope, my observations, though they may mostly be generally applied, will be here directed in particular. For astronomical uses, this instrument will of course be furnished with appropriate eye-pieces and micrometer, the power of which is usually so proportioned to aperture and area, that the emergent pencil, though containing the whole of the admitted light, shall not exceed in diameter that portion of the pupil which affords the best vision; and the focus will be accurately suited to the densities of the crown and flint glasses, so as to meet what was once a desideratum in practical optics, the shortening of focal length without diminishing aperture or injuring distinctness. Such telescopes are of reasonable price, and are sufficiently light and compact for handling and moving about, yet strong enough for permanent adjustment of the parts†. Indeed, the "march" is perhaps in no instance more conspicuous than in a comparison between one of these ever-ready tools, and the unmanageable monsters formerly in use. To think of the length of a hundred or a couple of hundred feet for a refractor! Auzout's was three

* In mentioning these various telescopes, I cannot but recollect a curious optical modification invented by Professor Amici, and shown by him to Baron de Zach and myself at Modena, in 1820. It consisted of four small prisms of the same glass so placed, that the refracting edges of one pair were parallel to one another, and those of the other—also parallel to each other—were perpendicular to the edges of the first pair; each pair being in achromatic combination, the one magnifying the breadth of the object, while the other altered its length in the same ratio. It enlarged the image about five or six times.

† It is usual to designate these excellent instruments by the name of *5-foot achromatics*. Dr. Bevis first applied the word *achromatic* to refractors, from the Greek negative *α*, and *χρωμα*, colour. Handiness is their characteristic; but if cut too short in focal length, the curves of the eye-glasses are necessarily deeper, to the increase of spherical aberration.

hundred feet long, and therefore useless; another one was contemplated, and all but completely constructed, of nearly double that length. I was so puzzled to know how they contrived to get the eye and object-glasses of these unwieldy machines *married*, or brought parallel to each other for perfect vision, and so desirous of comparing the performance of one of them, that I was about to ask the Royal Society's permission to erect the aërial 123-foot telescope in their possession, which belonged to Huyghens. The trouble, however, promised to be so much greater than the object appeared to justify, that I laid the project aside,—not wishing to furnish a parallel to the case of the worthy captain, whose veracity having been doubted as to the length of a West Indian cabbage-tree, took the trouble to bring one from Barbadoes to prove his assertion.

The difficulty of directing these aërial refractors, reminds me of a point which may prove a very useful hint to the amateur who possesses a telescope of considerable power, but without the addition of a finder. In this case, much time is lost in *fishing* with highly magnifying eye-pieces, to bring an object into the field of the object-glass, although it is in full view to the naked eye. The remedy is simple enough: it is merely the application of a couple of perforated vanes to the side of the tube, similar to those used on old quadrants, or to gun-sights, and the defect will be overcome where optical power is not demanded, as in planets and the larger stars.

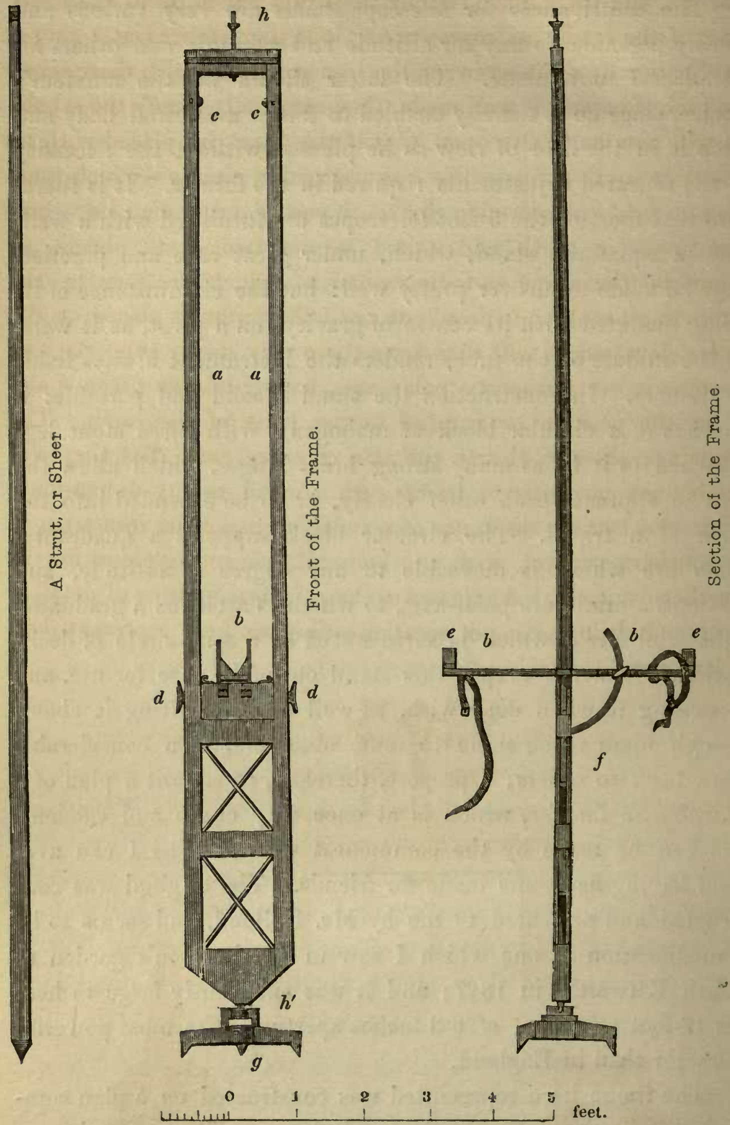
On making the acquisition of a telescope by purchase or otherwise, the first step is so to examine it as to gain a confidence in its performance; and to ascertain that the convenience resulting from its diminished length is unattended by a diminution of its amplifying property. There are several obvious methods of ascertaining whether the object-glass is good; but one of the best proofs of excellence is in the instrument's coming briskly to a focus, for where the eye-pieces can be played in or out without sensibly altering the distinctness of vision, it may be suspected that the spherical aberration of the transmitted rays is not duly corrected. The achromatism, which depends on both material and workmanship, is examined by pushing in or pulling out the eye-piece from the point of distinct vision, when the telescope is placed upon a proper object, till the appearance of the central tints of the prismatic spectrum—in the first case purple and in the latter light green—shows that the extreme colours are corrected. The accuracy of the curvature of the lenses, and the homogeneity of the glass, will be proved by the fidelity of form in the objects looked at, the absence of dispersed light and *wings* to the stars, and the tone of the irradiations which may interrupt the rings surrounding the spurious discs of large stars under high magnifying powers. These experiments can be made by daylight on a printed card, a watch-face, or any strong contrasting marks of a light object on a dark ground; by night the telescope may be directed to the edge of the moon, or to Jupiter, for testing the production of the purple and green fringes just mentioned. The ghost, or secondary spectrum, will more or less haunt most of such instruments, nor can it be exorcised until perfection of figure can be ensured to the lenses; such shadow being imputable to the different refracting media not exerting the same proportional power upon all the coloured rays. In making these trials the whole range of eye-pieces, positive, negative, and single-lens, may be brought into play, in order to judge of the degree of irradiation, and the effect of the interference of the rays which graze the edge of the aperture, under each. But one of the most effective means of testing the goodness of a telescope, is afforded by the double stars, which offer a more precise and sensible test than the planets: and a statement of the magnifying power under which a telescope will separate certain specified objects, is at once a tolerable scale by which to estimate its performance. With a well-made 5-foot telescope*, most of these tests will turn out satisfactorily; for the proportions of focal length to aperture are so well contrived, that the aid of diaphragms to modify redundant light is but little needed. The

* The widow of a deceased friend put one of these admirable instruments into my charge, and I had the pleasure to subject it to a rigid scrutiny for a very interesting purpose: a congregation at Portsmouth, with singularly good taste, having resolved to present their pastor with a telescope as a mark of their approbation of his spiritual labours among them. As this instrument proved itself worthy of Mr. George Dollond, who made it, it was purchased on my recommendation.

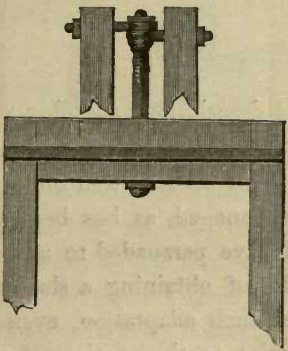
object, therefore, now is, how to use it most conveniently where another 'onomy forbids large means to indulge in astronomy.

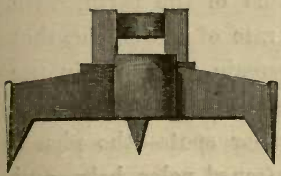
The contrivances for telescope-stands are very various and mostly ingenious, some for altitude and azimuth, and others for parallactic movements. The latter should be the amateur's choice, since he is thereby enabled to follow a celestial body and keep it in the field of view as he pleases, without the necessity of the repeated adjustments required in the former. It is therefore that most of the 5-foot telescopes are furnished with a well-known equatorial stand, which, under great care and practice, may be made to answer pretty well: but the circumstance of its being mounted with its centre of gravity, on a pivot, as it were, in the middle of the tube, renders the instrument always liable to tremors. In construction the stand is solid and portable: it consists of a circular block of mahogany, with three stout legs attached to it by as many strong brass hinges, which allow the legs to approach each other closely, or to be extended into the form of a tripod. The circular block supports a quadrantal brass arc which is moveable to any degree of latitude, and becomes a miniature polar-axis, to which is attached a graduated equatorial circle, which is surmounted by a semi-circle of declination. Now the taking this stand out of its case for use, and repacking it when done with, as well as the shifting it about, though mere moon-shine to some observers, is a considerable draw-back to others; I propose, therefore, to submit a plan of a *Parallactic Ladder*, which is at once very cheap and efficient, and can be made by the commonest workmen, as I can aver from having had some made for friends. The original was constructed and presented to me by Mr. Dollond, and seems to be a modification of one which I saw in Dr. Pearson's garden at South Kilworth, in 1827; and it was sufficiently large to bear his 12-foot telescope, of 6·8 inches aperture—the most powerful refractor then in England.

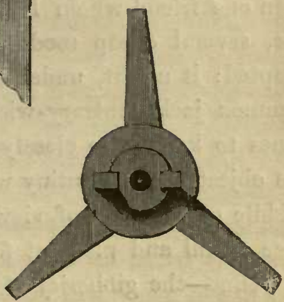
The frame here represented was constructed on a plan combining economy and convenience; it being easily put up in any open place, and if a little care is taken to place it nearly to the meridian and inclination of the pole, it will be found a steady and useful equatorial stand for any sized telescope, the diameter of which can repose on the cradle *b b*. This cradle, moving on hinges, is attached to cords which pass over the pulleys *c c*,



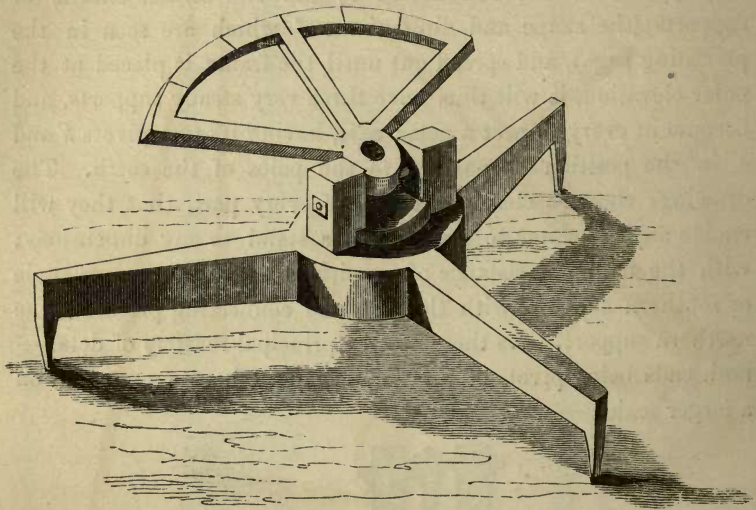
and are made fast by passing them round the cleats *d d*, when the cradle is triced up along grooves in the sides of the frame *a a* to the height which will be the most proper for the declination of the star, and the convenience of the observer, whether standing or sitting. The telescope is laid into the cradle ends *e e*, which form the Ys, and there made fast by the straps nailed on to the lower part of the cradle, as represented; it is then secured at a proper declination by a nut-screw, on the iron arch *f*, of which there is one on each side, and if well made, they materially steady the whole. It will now be readily seen, that if the frame be placed with its lower or south pivot in the iron triangular piece *g*—which must be previously placed upon the south end of a meridian line—and the upper or north end united to the two struts, sheers, or supports (the shape and dimensions of which are seen in the preceding page), and spread out until the frame is placed at the polar elevation, it will thus have three very steady supports, and become in every respect a polar axis, having its two pivots *h* and *h′* in the position or parallel to the poles of the earth. The drawings show so clearly the size of every part, that they will enable any carpenter to frame such a stand to any dimensions; with the trifling assistance of a smith to make the iron triangle or southern support, with the bolt and connecting pieces for the northern support. As these are the principal matters of detail—both ends being pivots of rotation—they are here represented on a larger scale.



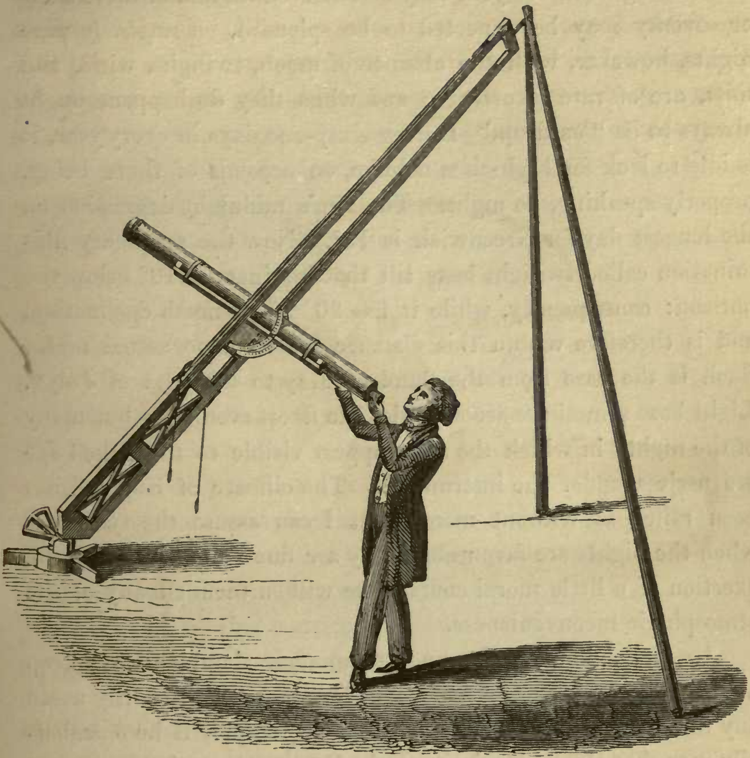




In getting some of these iron triangles cast, an improvement struck me, which has added to the utility of the parallactic ladder. This is the addition of a circular arc to the pivot-socket, roughly marked with lines, showing three hours on each side of the meridian; which are pointed to by a pin at the lower end of the ladder-frame. This, with some equally primitive notches for degrees of declination in the arc *f*, renders it more useful as a finder. A figure of the triangle with the *hour arc* may be acceptable to the workman:



With a stand of this description, the observer, after a little practice, will be able to follow any celestial object with one motion, which in the present construction must be given by the hand; but is very easily managed, as has been proved by more than one friend whom I have persuaded to adopt it. If requisite, several cheap modes of obtaining a slow motion may be adapted; it might, under such adaptation, even be driven by a common jack contrary-wise to the motion of the earth, with vanes to keep it so closely to the same rate of movement, that the object under scrutiny will seem to remain stationary in the middle of the field of view. But in its present state it is at once useful and pleasant for observing solar spots—the phases of Venus—the gibbosity of Mars—the flattened poles, belts, and moons of Jupiter—the rings and details of Saturn—the selenography of our satellite—the aspects of comets—eclipses—occultations of stars or planets—and immersions or emersions of Jupiter's satellites. To the practical observer it speaks for itself.



With a ladder of this description standing at or near his domicile, an amateur will be ready for any phenomenon; for the carrying out and mounting the telescope, is but the affair of two or three minutes. For general gazing, he may watch for proper weather, of which he will find more than he expected, and quite as much as he wants, if he reduces his observations, or follows a formal plan. It is true that Sir William Herschel said, "it appears that a year which will afford ninety or at most one hundred hours, is to be called a very productive one;" but he meant such as are fit for magnifying one thousand times with his 40-foot reflector of four feet aperture, which would only be eligible when the star is half way to the meridian, and the sky perfectly serene and diaphanous. I should say that where a person will look out for opportunities in the mornings as well as evenings, and especially between midnight and daybreak, he will find that nearly half the nights in the year may be observed in, and of these sixty or seventy may be expected to be splendid. *Completely* pure nights, however, with the absence of moon, twilight, wind, and mist, are of rare occurrence; and when they do happen, ought always to be "used up." During sixty-one days in every year, it is idle to look for high-class nebulæ, on account of there being, properly speaking, no night. The sun's midnight depression on the longest day for Greenwich is 15°. Now the secondary illumination called twilight lasts till that luminary is 18° below the horizon: consequently, while it has 20° 28′ of north declination, and is therefore within this distance, we have no actual night. Such is the case from the 22nd of May to the 21st of July*. Light haze sometimes accompanies the finest evenings; but many of the nights in which the stars appear visible to the naked eye are useless under the instrument. The climate of England has been railed at without mercy, but I can assure the tyro that when the nights are favourable, they are fine indeed; and by the exertion of a little moral courage he will surmount many of the atmospheric inconveniences.

As far as he possibly can, the amateur should always keep his instrument clean and fit for use; and he will prudently avoid any unnecessary expenditure of time and temper, if he occasionally sees that the finder is in good adjustment, so that a star on its cross wires will be at or near the centre of the greater object-glass. Without being one of the dabblers before alluded to, he will of course know so much of telescopic construction, and the general laws of the refraction and dispersion of light, as to be able to replace properly the lenses of compound eye-pieces after cleaning them: to prevent mistakes on such an occasion, I would recommend that only one glass be taken out at a time, and that it be replaced before another is removed. There are two kinds

* The co-latitude of Greenwich 38° 31′ 21″, and the obliquity of the ecliptic for 1840, 23° 27′ 37″, give 15° 03′ 44″ for the solar depression.

of lenses, each consisting of a couple of plano-convex lenses; in the Huyghenian, or *negative*, the flat side of each is towards the eye; while in the Ramsden, or *positive*, the curves are turned towards each other, whence there results a flatter but less vivid field. Both of them invert, because it requires a further arrangement of glasses to bring the vision erect, and every additional lens occasions a loss of light at both its surfaces. Light being of greater importance to astronomers than the position of the image, the *upside-down* eye-piece is persevered in; nor is it at all an inconvenience, for the eye quickly accustoms itself to the inversion. Single lenses are used in particular cases; but the aberration arising from the sphericity of their faces, greatly reduces the distinct field of view; and they have but an almost imperceptible superiority of light over the compound ones. In placing eye-pieces into their station, no screwing should distract the attention of the observer; they should each be fitted to adapters, or short sliding pieces of tube, by which they may be readily shifted without delay, or shaking the instrument. It will also conduce to order, and save them from dust, if each eye-piece is provided with a brass cap, also to slip, and be placed thereon when not in use; and the magnifying power of each may be engraved, both on the eye-piece and its cap.

But in advocating a strict attention to keeping clean the eye-pieces, and the outer surfaces of the object-glass, let me warn the observer never to disturb the latter in its cell. The centering of the flint and crown discs is so critical a point in both the spherical and chromatic corrections, that, except in cases of extreme necessity, it should not be disturbed unless by the hand of the artist who made it. Every precaution should be taken to keep damp from penetrating between the two glasses, to prevent the "sweat," or arborescent vegetation which shoots between the surfaces in neglected telescopes. It is even better to let that evil flourish than disturb the lenses, for it will be some years before its growth interferes with the general action of the instrument by a deterioration of its light-transmitting properties. This is a point upon which I warn the class whom Troughton named "the over-handy gentlemen," who in their feverish anxiety for meddling with and making instruments, are continually tormenting them with screw-drivers, files, and what not*. If the tube be left exposed to the weather after the observations are over, the object-glass should be carefully taken out, and deposited in safety: in replacing it, let the air pass through the tube, by drawing the hands down its outer surface two or three times.

On these as well as other grounds, I strongly advise every observer to furnish his telescope with a dew-cap, since fog, mist, vapour, and dew, condense prodigiously on the object-glass, where the deposit may do other mischief besides injuring the distinctness of vision at the moment. To obviate this serious inconvenience, I have applied tubes of paste-board, and of wire covered with muslin, neither of which are very effective for out-door observation, and both are liable to retain damp. Sir John Herschel at last supplied me with a remedy, which upon long practice I can pronounce to be effectual. This is the application of a tube of tinned iron to the object-end of the telescope, densely blackened within, but always to be kept very bright outside. For my largest telescope, this dew-cap was two feet long by nearly 6½ inches in diameter; and for smaller telescopes I had them made somewhat shorter, with apertures of course proportioned to the object-glasses they were to protect. After adopting these simple guards, I had no further *wrinklings*, *twitchings*, *twirlings*, or other stellar annoyances from dew, each incidental contortion then being imputable to the atmosphere only.

While guarding the telescope against damp and dew, it may be well to look to its animated accompaniment. To be of use, the observer must work at his ease; poising the body well in every position, and delicate handling of the instrument, tend very greatly to the efficiency of its action. To feel comfortable he must be attired for the occasion, and the habiliments should be as light as the weather will admit of. I always found very great advantage from the use of large cloth boots, in which I

* Whether by design or not, the mechanicians only know: but it so happens that quadrant and sextant cases are all furnished with that tempting object to the "over handy," the screw-driver. Hence the number of instruments that return from on board incurable.

could freely put my booted feet, and then button them half way up my legs. These, together with a light but warm cloak, and a close cap on the "Welsh wig" principle, completed my personal night equipment.

When about to observe, avoid bright and stimulating objects for a few minutes, so that the pupil of the eye may be dilated, and the sensibility of the visual organ increased: and as little light as possible should be used in readings, &c., in order to prevent the adjustments of the eye from being disturbed. It is best to use, or at all events to begin with, moderate powers, but not so small as to have the emergent pencil larger than the pupil of the eye. With apertures of from 2½ to 3¾ inches, the most advantageous eye-pieces to open the attack with, are, for instance, about 20 for comets, 40 to 65 for the sun, 50 to 80 for Venus and Mars, 60 to 90 for the moon and nebulæ, 80 to 150 for Jupiter and his satellites, 120 to 200 for Saturn, and from 100 to 300 and upwards upon double stars. In each of these cases, after finding the object with the lower eye-pieces, the power may be raised as high as the instrument and existing state of the atmosphere will bear. But it must be kept in mind, that in using high powers, the light is lessened in the inverse ratio of the square of the power; and where the force is augmented out of due proportion, it requires both judgment and perception to get a firm glimpse. The illuminating power being as the square of the diameter of the aperture, affords an index to the capacity of the instrument: and this established, a convenient working eye-piece ought to be applied. Every increase of power diminishes the field, and darkens the object, while tremors* of all kinds are increased, motion being magnified as well as matter, and the limited excitability of the eye is severely taxed. Some of the closer double stars, however, require to be highly magnified to enable a spectator to separate them; and stars of the greater magnitudes with minute companions are difficult, because the brightness of the large one stimulates the eye and contracts its

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* A panacea for instrumental tremors, is to place a couple of unequally long poles so as to bear loosely against the axis on each side, during an observation.

pupil. It requires pretty high powers also to be satisfied as to the colours of a pair of stars, whether they are inherent or complementary; the last being those colours at equal distances from the opposite end of a prismatic spectrum. This, however, is a point on which satisfaction is hardly attainable.

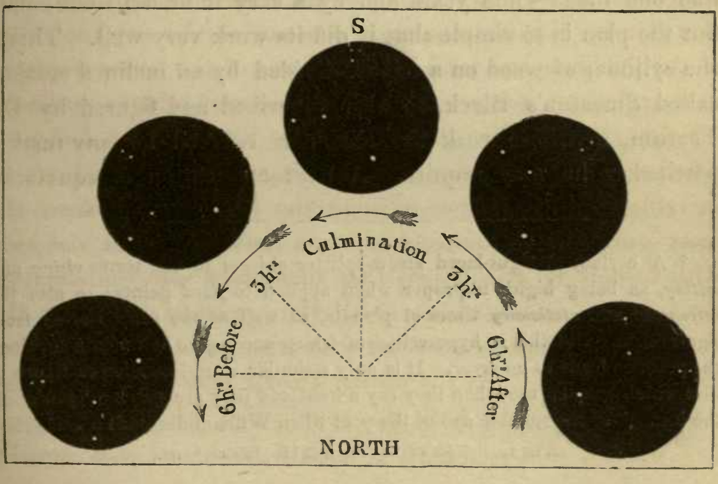
Respecting the magnifying powers of the eye-pieces, especially the higher ones, the mere gazer may trust to the ratio given to him with the instrument: but for accurate work, for the use of prism-micrometers, and for his own satisfaction, he will do well to re-measure them. The focal length of the object-glass divided by that of the eye-glass, gives an approximate magnifying power: but exactness in this respect is requisite in the more delicate observations, and it can hardly be expected that eye-pieces should turn out precisely as intended. Thus, in a series of powers for which I drew up an arrangement, the result was,

65	90	120	150	250	500 ordered.
62	93	118	157	240	416 proved.

To arrive at exact conclusions on this point, various methods of determining the magnifying power of a telescope have been proposed; but Ramsden's double-image dynameter, under various modifications, especially that of Dollond, has been successfully adopted. The construction and application of Dollond's beautiful little measurer are so fully and ably described by Dr. Pearson, that it would be out of place here to say more than, that in using this instrument, it does not require any knowledge of the thickness and focal lengths of any of the lenses employed in the telescope, nor yet of their number and relative positions. "Neither," says Dr. Pearson, "does it make any difference whether the construction be refracting or reflecting, direct or inverting; one operation includes the result arising from the most complicated construction, and sets theory at defiance, with respect to calculations that must take into consideration the previous determination of all the preceding requisites, the obtaining of which is attended with practical difficulties almost insurmountable." As the worthy Doctor lent me the very instrument which drew forth this approbation, while Mr. Dollond was making mine, I gave it a rigid trial, and was equally pleased with its performance; for though it may not be *absolutely* exact, it is yet so relatively excellent that its use ought to be extended, especially among amateurs.

Where the determination is not of great importance, the magnifying power of a telescope may be estimated by looking with one eye directly at an object outside the telescope, and with the other eye through the telescope; by then bringing the image upon the object seen directly, a person may judge of the linear *magnification* with tolerable accuracy, after a little practice. This method is called *false vision;* and when due care is taken in the estimation, the power thus guessed at may assist in obtaining that which belongs to the solar focus.

The equatorial mounting and the optical details being duly attended to, the observer has now only to catch his object, and follow it under smooth and pleasant motion; and if he does not feel a pleasure in the operation which more than repays all his trouble, he should give his instrument to a better man, whom he cannot but very easily find. The true Uranian, however, will advance, and may, perhaps, here pick up a hint which is worth knowing. It will be necessary for a beginner to accustom himself to the varying positions which the constellations undergo between their risings and settings, and this can only be correctly followed by a telescope turning on a polar axis. In fixed instruments, such as circles or transits, which are restricted to



the meridian, the course of a celestial object across the field of vision, under an astronomical eye-piece, will be from the right horizontally to the left. But in extra-meridian or universal instruments, it will vary as regards its line of position with the horizon at each degree of its advance towards culmination, and from thence to its setting. In the preceding diagram, the arrows show the direction in which the bodies pass the telescope, and the dark circles represent the field of vision for every three hours after the group rises, till it goes down*.

Here it is evident that, however the position of the group of stars alters to the eye and the senses, its line of position, as seen from a station at the centre with a polar axis, will be the same at whatever time and point it is looked at. The observer need hardly be reminded, that the foregoing diagram refers to an instrument which is turned towards the south: when it is pointed to the polar districts, each movement becomes reversed in the field, as to the culminations and passages of the circum-polar stars.

In thus recommending the amateur-astronomer to give his telescope equatorial motion, I must add that there are various ways of compassing it. I have shown two of the methods which I employed, viz., the polar axis and the parallactic ladder: but there is also another well calculated for a fixed latitude and a moderate telescope, and it is at once useful and cheap. I had one made some years ago by a very indifferent workman, but the plan is so simple that it did its work very well. This is the cylinder of wood on a tripod, divided by an inclined section, called Smeaton's Block, so ably described and figured by Dr. Pearson, to whose work the reader is referred for any further particulars he may require. A neat application of equatorial

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* A certain straight-laced straw-splitter objects to the terms *rising* and *setting*, as being highly improper when applied to *fixed* points: so also the *retrograde* and *stationary* times of planets, as well as the sun's *moving* from sign to sign. But this is hypercriticism which needs give no uneasiness, since the practice leads to no error. It is only a similar intro-inversion of figure to that which seamen use when they say a headland they are passing "*gets* abaft the beam;" or the notable one of the poet when William descends a back-stay,

The cord *glides* swiftly through his glowing hand.

motion was made by Mr. Babbage, and fitted to a 30-inch travelling telescope, which he kindly lent me to copy: it is really a *multum in parvo*, for it is contrived to carry its tripod-legs, equatorial apparatus, eye-pieces, and secondary appendages, safely stowed within its tube, so that it forms a mere plain cylinder for packing in a trunk or portmanteau on a journey. It is altogether a beautiful instrument, and possesses quite sufficient accommodation for watching many of the phenomena which it is so desirable that travellers should observe.

The use of the wire-micrometer for measuring small angles, is too well known to require especial notice; but its principle being, to move a fine spider-line or wire parallel to itself, in the plane of the image of an object formed in the focus of a telescope, by means of a screw whose *run* is well ascertained, it cannot be resorted to in sidereal practice without the application of artificial light to measure its movements from a fixed wire in the same plane. Now there are many telescopes of very fair power, in which illumination is attended with great inconvenience. In this case, the ingress and egress of a luminous body in a dark field, may be readily managed by means of circular micrometers, as recommended by Bessel, where monotonous computations are disregarded; and the best form appears to be the construction known as Fraunhofer's Suspended Annular Micrometer, in which a steel ring is inserted in a disc of glass, which when applied appears as if *suspended* in the atmosphere. But he who dislikes the trouble of the reductions consequent on the use of this over-extolled tool, may resort to a very neat mode of observing, without the aid of artificial light, by the singular property of the double refraction inherent in rock-crystal. This principle is elaborately treated of by Dr. Pearson, and its effects in prisms, wedges, and spheres, so fully detailed, that the inquirer is referred to the descriptions in his *Introduction to Practical Astronomy*, and the *Memoirs of the Astronomical Society**. But I must call the amateur's attention to a particular point, because it may set him to work at once. In the *Memoirs*, vol. i. p. 91,

* Dr. Pearson kindly lent me his excellent and well-tried double-image micrometer, while Mr. Robinson was employed in making mine.

Dr. Pearson says, "Should the prism used be found to have too great or too small an angle, at any of the distances marked at the scale, it must be changed for another more suitable." The time lost in taking out one, and replacing it by another prism, appearing to Mr. Dollond to be a very great inconvenience, he thought it would much improve this micrometer, if the prisms could be so arranged as to be instantly brought into the proper place. He therefore made a micrometer in every respect like Dr. Pearson's, except in his mode of applying the prisms, instead of which he adopted a wheel containing four pairs of prisms, subtending angles of different values; each being made to stop by a spring catch at the place of the emergent pencil of the eye-glass. By this arrangement the use of this beautiful instrument is much aided, as no time is lost in changing the prism, and the chance of losing an observation by the delay obviated.

Provided the telescope be good, the constant angles of the prisms truly determined, and the eye-piece of the construction termed *positive*, the micrometrical measures taken in this way will be of value; especially those of the angles of position: every attention, therefore, should be paid to those preliminary points; and to make a clean image of the star under prism observation, let care be taken to keep the object in the middle of the field of view.

That useful instrument the Portable Equatorial, which was so much the rage about seventy years ago, compensates by excellent workmanship and accurate divisions, for its diminutive size. Under the proper adjustments, an amateur may readily find the hour of the day, the meridian of the place, and a star or planet by daylight. He will also be able to observe the altitude, right ascension, and declination of a celestial body; and moreover manage to measure angles, and take differential observations. The best stand for such an instrument, is a cask filled with earth or sand; and such I always used for an Altitude and Azimuth Circle, during my surveys in the Mediterranean Sea.

§ 3. Time, and the Transit Instrument.

Though it is no part of the plan of this undertaking to enter into the minutiæ of instruments, still it may assist those who have no immediate oral or written reference at hand, to make a few remarks on that rudder of practical astronomy, the Transit Instrument. But in so doing, there will be no occasion to touch upon those large machines which grace the public observatories; the inquirers who wish for details which treat of the higher refinements of practice, must consult Dr. Pearson's *Practical Astronomy*, and Mr. Sheepshanks's able essay in the *Penny Cyclopædia*. Though I should urge the amateur to procure as large a telescope, with due appendages, as may lie in his power, I would recommend him to sufficient moderation in other respects, and to limit his remaining acquisitions to a portable transit and a tolerable clock; he will then be as well fitted for the purposes of getting the time, and retaining it when obtained, as if he were provided with a 10-foot transit and the most expensive Hardy's-escapement clock. Indeed, recollecting the *vis inertiæ* of large instruments, risk of flexure from their weight on the pivots*, the operose reversions required, and the necessity of an assistant, I might have even said he would be better equipped with a little handy transit than with one of the unwieldy ones. So the best clock for general use is one with a good train of wheel-work, and with a Graham's dead-beat, as being of easy compensation, and understood by every one who pretends to the slightest knowledge in horology. This will seldom vary very sensibly from day to day, though it must be watched when under great or sudden changes of temperature.

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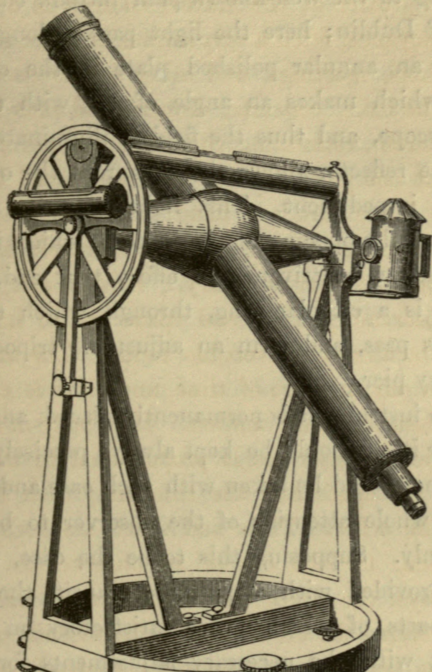
* The flexure on a telescope suspended horizontally may well be suspected, when the experiments of the celebrated Reichenbach are borne in mind; this gentleman, when an officer of artillery, weighed a great gun by the centre, a 24-pounder, and found its flexibility very sensible. And as to the influence of variable temperature on the adjustments of those large transit instruments, a disciple of Hardouin's might have supposed Virgil had it in view when he said, "spirantia molliùs æra," especially as the passage is followed by a hint about the rising and setting of stars.

But though time is so easily ascertained, yet how discreditably is it neglected! This valuable element, the soul of method and business, is strangely kept in provincial towns and cities, where it is not at all uncommon to see public clocks, which have been procured at great cost, ten or twelve minutes out, perhaps as much fast one week, and then altered from some one's watch or dial to as much too slow the next week. Indeed I have known the error still greater at the Mother Church of a county town. This is an annoyance, often a very serious one, not only to assizes, sessions, markets, meetings, and other public occasions, but is also felt in the balls, concerts, dinners, and such-like secondary concerns. Herein, estimating time, temper, and propriety, is a loss of at least one year in every ten, occasioned by breaches of punctuality. Yet a cure is at hand; wherever there is a church and a clock, there also should there be a transit instrument and a registered clock-rate, or no salary. *Verbum sat.*

In the observatory, time and space are so intimately connected, as to be almost convertible terms. The uniform motion of the stars is our measure of time, and time is employed conversely as measuring their motion. If a body move uniformly, the space which it describes is proportional to the time of its motion; and the space and the time may each be taken as a measure of the other. Time and space are both employed in the observation, for the eye of an observer is watching the interval between the wires which the star is travelling, while the ear is receiving the dead-beats of the seconds of time. The clock and the transit as companions, each of which is indispensable to the object in view, ought never to be separated.

Römer, a master-mind in practical astronomy, invented the transit instrument, having constructed one with which he observed out of his window in the year 1690. Within ten years afterwards, Sir Christopher Wren, Mr. Stephen Gray, and Dr. Derham had also contrived machines for the purpose of observing the meridional passages of celestial bodies. But the first who regularly made use of a transit-telescope, with the essential properties now attended to, was Dr. Halley, who erected one at the Greenwich Observatory about the year 1721. This led to the superseding of all other methods of obtaining the right ascension of a star; and Mr. Troughton's genius, by introducing the efficient portable transit, furnished astronomical observers of every description with the means of readily getting the time and regulating their time-keepers. This is the figure of the instrument, as originally constructed by Troughton; but small transits are now made firmer, cheaper, and more ready to be put up.



Here we perceive a frame with vertical standards carrying the Y's, or supports of the axis pivots, and their adjustments; the telescope with its graduated setting-circle; and the riding cross-level. The telescope is led through a bulb, or hollow sphere, to which are symmetrically united at their bases two cones, the apices of which terminate in finely-turned cylindrical pivots resting on the Ys, or angles, which are adjustable by means of differential and antagonist screw-motion. These cones therefore form the horizontal axis at right angles to the telescope's length, so that its movements are entirely confined to revolving vertically on that axis; and the two ends of the axis being placed east and west, it is evident that the telescope must be in the plane of the meridian, north and south. It is furnished with a diagonal eye-piece, by which stars near the zenith may be observed without inconvenience; and also with a lamp for illuminating the wires through the perforated arm of the axis, according to the well-known plan introduced by the Rev. Dr. Usher, of Dublin; here the light passes along the opening till it meets an annular polished plate in the centre of the instrument, which makes an angle of 45° with the axis and with the telescope, and thus the field is illuminated, while the aperture in the reflector allows the rays from the object-glass to pass without impediment. This light may be regulated by slightly turning the opening of the lantern, which is often fitted with a rack-screw contrivance to effect that end. The base of the frame is a circular ring, through which three milled-headed screws pass, and form an adjustable tripod for placing on a temporary pier.

When the instrument is permanently placed, and has a small room to cover it, it should be kept always precisely adjusted, as all observations should be taken with such ease and readiness, as to allow the whole attention of the observer to be directed to that object only. Supposing this to be the case, and that the amateur is provided with a portable transit, the optical and mechanical parts of which prove satisfactory on scrutiny, he must proceed with the necessary adjustments for giving it a true vertical motion in the meridian. For these, the rules and directions are very multifarious, and some of them sufficiently operose; but perhaps the following will meet all the desiderata of the case in question:

I. *Adjustment of the Level.* Having placed the instrument on its Y's, slide the eye-piece in or out till the wires are seen distinctly sharp, for I have always looked at the obtaining of distinct vision as a preliminary measure, although not immediately wanted. Place the level, which may be proved by the indications on its scale in reversed positions, on the axis, taking care to grasp it by the middle, and bring the bubble to the centre by means of the vertical-motion screw. Now reverse the level, and adjust whatever inclination may be indicated, till the telescope's axis is parallel to the horizon. This adjustment being of easy derangement, requires frequent examination; and testing it by the level, with occasional reversions, will immediately detect any alteration. The sure horizontality of the instrument's axis thus gained, is of the gravest import to the observations; and the level should always be carefully examined after touching the azimuth screws.

II. *Place the wires, or spider-lines, truly vertical.* This is a very necessary operation, which may be done by making the middle wire coincide with a distant chalked plumb-line on a dark ground; and is proved by reversing the instrument, which adjustment once made will seldom be found to vary. The *manipulation* is thus managed. Having brought the object viewed to the central vertical wire, by means of the capstan-headed screw which acts horizontally on one of the Y's, observe whether the same part of the object is covered by the wire while the telescope is slowly moved in elevation and depression; if not, correct half the apparent deviation by turning round the cell which contains the system of wires, and give the final touch in the reversed position of the axis. This is a very easy operation, where there is a meridian mark such as I have described at p. 331.

III. *Collimation in Azimuth.* Bisect a distant object with the central vertical wire, then lift the instrument out of the Y's and carefully invert it, holding it by the telescope part without touching the cones. Now, if the wire no longer covers the same part of the selected mark, correct half of the error by the screws which act horizontally upon the wires by moving the circular diaphragm which contains the system, loosening the one and tightening the other; then adjust the remaining half of the difference, by the screw which gives azimuthal motion to one of the Y's. Repeat this operation till the vertical wire covers the same part of the object in both positions of the telescope: the line of collimation will then be perpendicular to the axis, and will not readily be deranged. Baron de Zach recommended to me a method of verifying this adjustment, which he had practised. Note the exact time of the passage of a star near the pole, from the first to the middle wire. This being done, invert the axis end for end, and note the exact time of the star's passing the last wire, which is obviously the very same as that which was called the first in the former position. If the two intervals correspond, the line of collimation may be considered as accurate; but if not, the proper corrections must be made to bring them so.

IV. *Position in the Meridian.* This, the most difficult of all the adjustments, requires frequent examination, since the instrument's being in the true meridian of the place of observation is of the highest importance. The instrument may be approximately placed by a magnetic bearing corrected for the variation, or by suspending a plumb-line to the south at a convenient distance for its shadow to fall along the telescope tube at mean noon. Either of these will place the transit in readiness for taking either the superior or inferior culmination of Polaris, by which it will readily be placed sufficiently close to the meridian, or the great circle which passes through the zenith and the pole, to enable the observer to determine the rate of his clock very accurately. Armed with the time, he may then get the transit absolutely into the meridian by the Pole-star, or the upper and lower passages of any circumpolar star; or by a pair of high and low stars, or two which differ considerably in altitude and but little in Æ, as Capella and Rigel. The polar objects may be the best where the pivots and flexure have not been fully proved, and the method of high and low stars where the clock's rate cannot be implicitly relied upon for twelve hours. In this latter case, Mr. Butt, of the Paragon Buildings, proposed selecting two circumpolar stars of nearly the same declination, but differing twelve hours more or less in Æ, as Polaris and ϵ Ursæ majoris, or α Persei and ι Ursæ minoris; by which method the interval would only be the short time elapsing between the passage of the one star, and the opposite passage of the other; if the differences of the two transits, taken at the reversed situations of the two stars, are the same at both periods, it is a proof that the semidiurnal arcs of the entire circle are alike, and that consequently the instrument is properly placed in the meridian.

When this is ascertained by either method, a meridian-mark should be permanently fixed, and all the work thenceforward is comparatively easy and pleasant.

Such are the adjustments of the transit instrument, and no amateur must think of registering the exact moment when a celestial body passes his place of observation till these conditions are fulfilled, and his means thereby rendered trustworthy. But as there are surveyors and travellers who wish to use this instrument in a rapid manner, and are without a pendulum-clock, a few more words may be necessary.

Supposing that he who travels with a portable transit, is likewise provided with a reflecting instrument, an artificial horizon*, and a chronometer, he will of course have the means of finding that important *co-ordinate*, Time. But even here a hint may be useful. In taking altitudes with a sextant from which it is intended to deduce the time, the best method of obtaining an accurate result seems to be this: take a set of altitudes of the sun's upper limb, and another set of the lower limb, and having worked each set separately, take the means of the times thus obtained, and the error which might arise from any acquired habit of observing, either close or open, will be obviated. Having thus carefully ascertained the error of the chronometer, so that the time may be truly known when the sun's centre will arrive at the meridian, take also the time of passage of the sun's semi-diameter over the meridian at Greenwich from the ephemeris and convert it into seconds: the logarithm of these seconds, added to the difference between the logarithmic co-sine of the latitude and 9·7944, the logarithmic co-sine of the latitude of Greenwich, will be the logarithm of the time in seconds, of the sun's semi-diameter passing the meridian at the place of observation. Subtract this from the time of the sun's centre's passing the meridian, as shown by the chronometer, and also add it to the same; the results will give

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* A Hardouin might deem Lucretius an inventor of the artificial horizon, from his comparison of gazing at the heavens in the street puddles:

Ut videare videre
Corpora mirande sub terras abdita cœlo.

the time shown by the chronometer when the sun's first and second limbs are on the meridian. A little before the time of the first culmination, direct the telescope to the sun, and let an assistant count the seconds aloud, while the observer moves the azimuthal screw so as to keep the sun's preceding limb to the middle wire at the time denoted. The second limb is then to be waited for, and the difference between it and the central wire at the calculated second, will show the proximity to the meridian, and the amount of correction that may be still necessary. This will bring the transit sufficiently close to commence work with; but it will now be necessary for rigid accuracy to refer to the Pole-star, or close circumpolars, in places where they can be seen. In tropical and southern regions, recourse must be had to pairs of high and low stars, which though not so good as circumpolars, on account of the wide arc on the pivots and the liability to flexure of the axis, afford pretty fair approximations.

When the instrument is thus in the meridian, the observer should determine the equatorial value of the intervals of the wires; and the simplest, as well as the most satisfactory mode of effecting this, is watching a star on the equator, or line of no declination, and counting the time in seconds and parts occupied in its meridian passage from wire to wire*. Those slow-moving stars, Polaris and δ Ursæ Minoris, the mean places of which are given for every day in the year in the *Nautical Almanac*, are also well suited to this object; but the motion between the wires not being exactly uniform, it involves the necessity of a correction. The observer, beginner though he be, need hardly be reminded that when the telescope is directed towards the south, the objects are inverted, and the celestial bodies enter the field of view on the west side, and move out on

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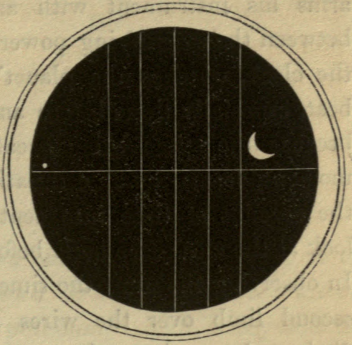
* When several observations are necessarily made on stars of different declinations, which I do not advise, the equatorial values may be thus corrected. To the log. of the interval occupied by the star in passing from any wire to the centre wire, add the log. co-sine of the star's declination (or sine of its polar distance), the sum, rejecting 10 from the index, will be the log. of the equatorial interval, which being determined for each wire, from observations of various stars, the mean will be a correct result.

the east, describing a parallel to the horizontal wire, and passing over the vertical wires in succession; the apparent march of stars from right to left in the telescope indicating a real movement from left to right. To make the apparent movement familiar, I annex a diagram of the spider-lines, or wires, with a star just going off, and the planet Venus—always a fine transit object, whether nearly full, gibbous, or horned—approaching to the first wire. Here five vertical wires are represented, though most tolerable transits have two more near the centre wire for taking Polaris, the movement of which star is too slow to watch over all the wires; and the larger instruments are furnished with seven principal wires.



Here I must remind the amateur of the great advantage of procuring printed skeleton-forms for his observations, since they not only save time, but ensure order and regularity. I had an appropriate set for each instrument, and as they proved to be good working forms, I can recommend them for the adoption of the class addressed. In the present instance I subjoin that for the transit instrument, as it may prove a timely hint. This is the heading of a large page—

TRANSITS observed over the Meridian of BEDFORD.											
Date	Star or Planet.	Telescope Wires.					Mean Passage.	Clock's		Days interval.
		I.	II.	Centre.	IV.	V.		Error.	Daily rate.	

which was ruled across with light blue lines, another conducer to regularity; and the opposite page of each was kept blank, for the insertion of remarks respecting the clock, the level, the meridian mark, the weather, and other incidental matters.

Having brought Venus thus far into the field of view, it will be as well to suppose her transit to take place thus: the observer arms his instrument with an eye-piece ranging somewhere between the magnifying powers of 50 and 100, and listening to the clock, watches the planet's advance, tacitly counting every beat, especially those before and after the transit over each wire, because the space being greater or less on either side at that moment, forms, by an estimation of the eye, the subdivision of the seconds of time into tenths. The observer will carefully look at the clock-face both before and after the object's passage. In observing the sun, the times of passing of both the first and second limb over the wires are observed, and registered as distinct observations, the mean of which gives the culmination of the sun's centre. The taking a good transit speaks well for the eye and ear of the taker, and it requires a little mental and mechanical practice to discriminate to the tenth of a second; but whoever is in earnest will be sure of succeeding, unless nature has treated him harshly. Venus thus observed might be:

	h	m	s
I. Wire - - - -		58	57·2
II. - - - - - -		59	11·1
Middle - - - -	18	59	25·3
IV. - - - - - -		59	39·2
V. - - - - - -		59	53·2

A transit thus taken used to be arithmetically reduced, by adding up the five observations, and taking the mean as the middle-wire passage: but this being tedious where many were taken, Dr. Maskelyne conveniently abridged the numerical process by multiplying by the decimal ·2, which is equivalent to dividing by the integer 5. When such factor is substituted, it is only necessary to add the seconds together without any reference to the minutes, provided one fifth part of a minute, or 12, be as many times added to or subtracted from the product, as will convert it into the same number of seconds that were indicated at the middle wire: for the fractional portion of the second, to be expressed by a decimal, is all that, in a good observation, is wanted to complete the reduction. The above observation of Venus, as an example, will show the facility and dispatch of this abridgment:

Common Method.		Maskelyne's Method.
	m s	s
	58 57·2	57·2
	59 11·1	11·1
	59 25·3	25·3
	59 39·2	39·2
	59 53·2	53·2
	5) 297 06·0	186·0 × ·2 = 37·20
		Subtract 12
Time reduced =	59 25·2	Time reduced = 25·20

In general cases the level and the pivots of the axis of a transit instrument may be assumed to come from the artist perfectly correct; but should the purchaser entertain any doubts upon the subject, he may rigidly investigate their quality. I have already mentioned how the level is to be proved, and if it should be found inexact it may be allowed for by judgment, as the scraping the angles or tormenting the screws may only render a slight error a serious one. As to the pivots, the giving them their true cylindrical shape is always attended to with the utmost skill which mechanical ingenuity can exert: yet it may so happen that the two are not absolutely of the same size, a case in which I would recommend the larger one to be worked in the western Y, so that its corrections, where necessary, may be always additive. There are methods of proceeding when a level is broken; but having no feeling in common with instrument-breakers, I will not load the page with them; for I never saw or heard of an accident of the kind, either ashore or afloat, which was not directly imputable to carelessness, and such carelessness generally assignable to conceit. In a word, a purchaser may be as fastidious as he listeth in ordering his instrument; but when it is obtained, he should ascertain the nature and amount of its discrepancies, and then work away, supplying any accidental defect with the other co-ordinates of a transit, the head and the hand. But he may rest assured, that any mechanician of character will furnish him with a tool fully capable of good work; it not being their practice to suffer bad ones to pass out of their hands. An example of the occasional level-practice may serve as a drill; and here, as in the other cases, I give the every-day working for an amateur, without the nice refinements which are often less useful than perplexing.

The illuminated end of the axis being east, examined the horizontality of the axis. The eye-end of the telescope being elevated to an altitude of about 60° south of the zenith, applied the level:

Readings of the level:	West.	East.
	1′ 6‴·0	1′ 5‴·5
Level inverted	1′ 0‴·0	1′ 10‴·9
Sum -	2′ 6‴·0	2′ 16‴·4

Sum of West readings	-	2′ 6‴·0
„ East „	-	2′ 16‴·4
Difference	-	10‴·4
¼th part	-	2‴·6

by which quantity the west end of the axis is low, the sum of the west readings being less than the sum of the east.

Then lowered the east end of the axis, and applied the level, the telescope remaining in the same position:

Readings of the level:	West.	East.
	1′ 3‴·0	1′ 6‴·8
Level inverted	1′ 7‴·7	1′ 1‴·5
Sum	2′ 10‴·7	2′ 8‴·3

Sum of West readings	-	2′ 10‴·7
„ East „	-	2′ 8‴·3
Difference	-	2‴·4
¼th part	-	0‴·6

by which quantity the west end of the axis appears to be high, the sum of the west readings being the greater.

Then moved the telescope 180°, so that the object end of the telescope became elevated, and again applied the level:

Readings of the level:	West.	East.
	1′ 6‴·7	1′ 2‴·0
Level inverted	1′ 0‴·5	1′ 7‴·9
	2′ 7‴·2	2′ 9‴·9

Sum of West readings	-	2′ 7‴·2
„ East „	-	2′ 9‴·9
Difference	-	0′ 2‴·7
¼th part	- -	0‴·7

by which quantity the west end of the axis appears to be low, the sum of the west readings being less.

The mean of both determinations is W. end 0′ 0″·5 low; hence the axis may be assumed to be perfectly horizontal.

If the right ascension of the body be a quantity sought for, the state of the level enters into the calculation as a factor of importance. Having determined the inclination of the axis as above, the correction to be applied to the time of observation may be computed from the following formula:

$$\textit{Correction} = b \cos. (\pi - \lambda) \text{ co-sec. } \pi.$$

where b is the factor for the inclination of the axis, π the star's polar distance, and λ the co-latitude of the place.

The corrections thus treated of are purely instrumental, and it may be assumed that the transit is now quite equal to the task of at once making celestial observations for the general purposes of a *finder;* but to promote rigid exactness, an example or two of cases in illustration of what has been stated, may refresh the memory and guide the amateur's proceedings. With such an object in view, the Greenwich observations of 1840, the epoch of this work, are selected, because the register extracted from is accessible to every one. He who is well practised in the several canons for unravelling a day's work, will be quite at home in the following plain rules:

I. *The Pole-star.* If the western interval be greater than the eastern one, the telescope points to the east of that end of the true meridian, which lies under the elevated pole (be that north or south); and *vice versa.* The angle of this deviation may be thus investigated:

To the log. of half the difference between the intervals in seconds,
(Or the difference between either interval and XII^h sidereal time), add
The log. tangent of the star's polar distance, and
The log. secant of the latitude of the station.

The sum, abating 20 from the index, will give the logarithm of a number of seconds of sidereal time, which, converted into space, will express the angular deviation of the instrument from the true meridian. Thus:

Green^h. observed 2nd Jan., 1840, Polaris Æ	1^h	1^m	37^s·47	
„ „ „ sub P.	13	1	27 ·38	

Western semicircle less by 10·09 divided by 2 = 5^s·05 log.		0·703291
Secant of the latitude of Greenwich,	51° 28′ 39″	0·205639
Tangent of the star's polar distance	1° 32′	8·427618
Hence the plane of the instrument, or factor of deviation W. of North = 0^s·217 = 3″·255 +		9·336548

The formula upon which this practical rule is founded, is thus expressed:

$$\text{Deviation} = \log. \frac{\Delta}{2} + \log. \sec. L. + \log. \tan. \pi - 20$$

where Δ = the difference of the intervals for the twelve hours reduced to seconds, π = the polar distance of the star, and L = the latitude of the place.

II. *High and Low Stars.* There are no instrumental means of examining the adjustment of the transit instrument in azimuth, as in the case of collimation and level. It must be deduced from the observations themselves when those two errors have been applied. A star in the zenith will transit exactly at its calculated time, be the error in azimuth ever so large; but the time of one transiting on the horizon will differ from the calculated time from the *Nautical Almanac*, by the whole amount of the error in azimuth, multiplied by the co-sine of the star's declination. If the southern one passes too soon for the computed difference, (whether its passage be before or after the northern one is immaterial,) the telescope will point to the east of the true meridian, and *vice versa*. The angle of deviation may be found as follows:

To log. of difference of interval in seconds, add
The log. co-sine of the declination of each star,
The log. co-secant of the difference of declination (sec. of sum), and
The log. secant of the latitude of the station.

The sum, abating 40 from the index, will give the logarithm of the number of seconds of sidereal time, which, converted as above into space, will express the angle made by the instrument and the true meridian; as in the following example, where the components both being of the first magnitudes, are admirably adapted for the portable transit, being easily visible by day.

Greenwich, 3rd March, 1840. Clock − 15·04.

Nautical Almanac, Capella	$5^h\ 4^m\ 54^s{\cdot}15$	and observed at Green.		$5^h\ 4^m\ 38^s{\cdot}36$
" " Rigel	5 6 52 ·12	"	"	5 6 36 ·25
Computed difference	$1^m\ 57^s{\cdot}97$	Observed difference		$1^m\ 57^s{\cdot}89$
Observed difference	1 57 ·89			
Difference of obs. less E.	$^s{\cdot}08$	log. 8·903090		
Co-sine Capella's Dec.	45° 50′	9·843076		
" Rigel's "	8° 23′	9·995334		
Secant of Sum of Decs.	54° 13′	0·090854		
Sec. latitude of Greenwich	51° 28′ 39″	0·205639		
Azimuthal deviation - - -		9·037993 = $0^s{\cdot}109$ = 1″·63		

Though six decimal places are here taken from the Tables, in practice four will be found to be quite sufficient.

The object of these remarks is to give the amateur the means of readily *managing* his time, as well as the finding of stars and identifying them for extra-meridional observations. But it should be mentioned, that by placing a transit east and west, that is, in the prime vertical, terrestrial latitudes and differences of latitude may be readily determined: for this purpose I recommend the inquirer to read an able paper on the subject, by my friend and former shipmate, Lieutenant Henry Raper, in the Xth volume of the *Astronomical Society's Memoirs*, page 337. The portable transit may also be successfully employed, in determining the longitude, by observing the meridional transits of the moon, and the moon-culminating stars; a list of the latter for each lunation, is given in the *Nautical Almanac.* My high opinion of the simplicity and effectiveness of this method, has been already given in page 358.

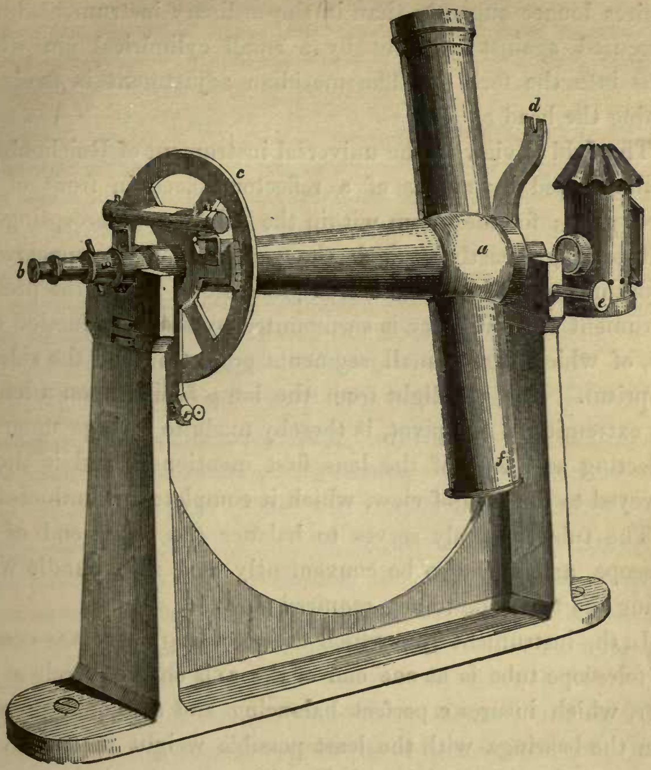
The observer will soon find that sidereal time, having reference to the absolute revolution of the earth round its axis, is the only uniform and equable standard of time. The orbital motion of the earth combined with the diurnal motion gives rise to the solar day, or the interval between two meridian passages of the sun; this is nearly four minutes longer than the sidereal day, or than the actual revolution of the earth. In consequence of this difference, every star in the course of the year comes on the meridian at every period of the natural or solar day. For many ages sidereal astronomy was confined to night observations; but since the application of telescopes, the transits of the larger stars may be taken equally well in full daylight. This important process is asserted to have been first practised by Joseph Gautier at Aix, who saw Arcturus "non seulement en plein soleil, mais pas même encore dans la force du crépuscule." This was on the 23rd of July, 1669; but on searching the Royal Society's archives, I find a letter from Flamsteed—*Derbiensis-Anglus*—to Mr. Oldenburg, of the 18th February, 1670, which makes it clear that Dr. Hook had also made the discovery. As it is one of the earliest communications of the *Derbiensis-Anglus*, who afterwards became our first Astronomer Royal, the reader may like to see a copy of it *verbatim et literatim:*

S^r^.

I had yours of the 4th Instant some while since, but delay'd to give an answer, because I hoped to gain time, to calculate some such Appulses, as M. Hook desires; I find a visible Application of ☽ to ♀ on June 29, in the morning, and to ♃ on the 20 of September before noon too; both which, if I had not been hindred by a distemper, I intended to have given a good account of; however I shall send you the predictions of them time enough before the appearance; if I have health and leisure. I find no appulses of the ☽ to any of the bigger fixed starrs, save spica, this yeare, in all her applications to which I find none, save those in my papers, which you have allready, that will be observeable, but if M. Hook thinks, He can by day observe her Applications to the Pleiades or starrs of the second or third Magnitude, I shall bestow some houres paines to find him matter for the Experiment, which if it succeed, I hope wee may hereafter have more accurate observations for the restoring of the Lunar numbers then as yet wee possesse. S[r]. if M. Hook esteem not his invention a secret, to be concealed, I could beg that he would be pleased to gratify mee with a communication of his method of observing, and he shall allways find mee ready to recompence with the communication of such prœdictions, as may show the diurnall Apulses, or any thing else which may occur in the course of my studyes worth his knowledge; if he can perform well in the day, his way will be of singular use and great encouragement to such Astronomers as love that Science, yet like not the practise, because it requires them to break their rest in making nocturnal observations: but however, exceeding acceptable to my selfe, because my weake body, and frequent distempers permit mee not to wait in the colds of the night for observations; And farther, by day the times and appearances may be more exactly observed with the helpe of any vulgar assistant, when for night observations it is necessary to have an expert & skilfull companion: pray therefore, if M. Hook bee not nice of his method, desire him to impart it to mee, who am S[r]

Your obliged servant
John Flamsteed.

By this time the amateur, if he has been able to keep himself awake, will perceive that the transit instrument, in some shape or other, is an indispensable adjunct to the telescope and clock. It may happen that he has not the convenience for properly mounting the instrument just described, and yet is desirous of regulating his time for gazing. In this case he may use the Englefield *side-transit*, made by Mr. Thomas Jones of Charing Cross, a simple and cheap instrument adapted for confined situations, easy in its verifications and adjustments, and well adapted by its compact form and lightness, for moving from place to place as occasion may require. As the construction, however, exaggerates the disadvantages necessarily induced by a telescope in which the reflection precedes the refraction, I will here introduce an excellent chamber-transit, invented by Mr. William Simms, the worthy representative of Troughton. This may be fixed in any window with a proper aspect, and the object glass will be sufficiently in the open air, to be out of the undulations occasioned by the cold air flowing into the room:



This figure represents a portable transit-instrument, made, so far at least as the telescope is concerned, upon the plan of the universal instrument of Reichenbach; a prism or diagonal plane of polished speculum-metal being so fixed within the sphere *a*, as that the rays from the object-glass are reflected through the axis in which the eye-piece and diaphragm are accordingly fitted.

The observer's place is therefore at *b*, and whatever may be the altitude of the observed object, his position remains unaltered, neither has he to change his place in order to set the telescope to the required altitude, for the graduated circle *c* is before him; and if the clock be seen in the same direction, nothing can exceed the ease and comfort with which transit observations may be made with such an instrument.

The horizontality of the axis is effected by an ordinary striding level, which in this case passes over the circle *c*, and therefore requires longer supports than in the ordinary instrument, but it is secured against accident by a small cylindrical pin which drops into the fork *d*. The meridian adjustment is made by turning the head *e*.

The field of view in the universal instrument of Reichenbach, is illuminated by means of a reflector placed in front of the object glass; for the prism within the sphere *a* intercepting the light passing directly through the perforated pivot, appeared to make this mode of illumination impracticable; but in the present instrument this difficulty is surmounted by the introduction of a lens, of which three small segments project beyond the sides of the prism. Now the light from the lamp falling upon a lens at the extremity of the pivot, is thereby made to diverge upon the projecting segments of the lens first mentioned, and is thence conveyed to the field of view, which it completely illuminates.

The tube *f* merely serves to balance the object-end of the telescope, and may also be conveniently used as a handle when setting the telescope to any required altitude.

In the instrument from which the preceding figure was drawn, the telescope tube is at one end of the axis and the circle at the other, which insures a perfect balancing and an equal pressure upon the bearings, with the least possible weight in the several parts; but the ex-centricity of the telescope makes it less easy to correct the line of collimation in it than in the ordinary transit instrument, and it is therefore intended in future to fix the telescope equally distant from its bearings.

§ 4. On finding the Stars.

Armed with his time and telescope, the amateur astronomer may now take the field, and make observations of interest and utility, if he proceed on a deliberate *festina lentè* principle. He has only to recollect that one good observation is worth more than fifty bad ones, and "hasten slowly" to obtain it.

The principal stars may be easily recognised by allineations; and the objects in the *Bedford Catalogue* are pointed out by the like reference; but an introductory view will facilitate the application of the rules. The beginner should commence with such stars as never set in our climate, and he may then refer the situations of others to their positions with respect to these. A moonlight night, if not too strongly illuminated, will be the best for him to learn some standard points, because the principal stars only show themselves, and determine the figure of the asterism; and he will find that the winter affords the best nights, both from their length, and the absence of twilight. The observer wil have made himself acquainted with the Great and Little Bears, some of the principal points in the Zodiac, Orion, the Pleiades, and the more remarkable groups, as a key to the others. His meridian line, however rude, will show him the *southing*, or passing of every object over that meridian, and from thence he will readily advance upon the vicinity; an operation in which good celestial maps or globes will largely assist. But in resorting to such aid, it must not be forgotten that by virtue of the apparent rotation of the heavens, the stars, though preserving their mutual distances and relations, turn with that motion: the ideal lines which join them therefore receive variable directions, which may appear to differ from those on the maps, being sometimes horizontal, sometimes inclined, and sometimes vertical, after the manner represented by the small group passed round in the diagram on p. 383. This difficulty, however, need only be alluded to, since it is so readily overcome as to offer no real impediment to allineation; and though the tyro must not expect to become familiar with all the component stars of a constellation at once, he will soon unravel the apparent confusion, and know the lucida of each asterism, together with several of its principal components.

The Great Bear is the most conspicuous of those constellations which never set in our latitude; the tail and body consist of seven brilliant stars, four of which are likened to a wain or plough, and the outer three are fancifully called the horses. The hind-wheels, or the two farthest from the horses, are designated the Pointers, because they direct the eye upon the Pole-star, at the tip of the Little Bear's tail; and further on to the constellations Cepheus and Cassiopea, which are situated in the Milky Way, where it is nearest to the pole. Cassiopea consists of several well known stars, which are likened, accordingly as viewed, to the letter M or W in form. The two northernmost wheels of the wain point at the very bright star Capella, in Auriga, which is also circumpolar in our latitude.

Descending diagonally along the Milky Way from Cassiopea towards Capella, we come to Mirfak, in Perseus, and a little further from the pole we find Algol, the variable star in Medusa's head: if we pass across the Milky Way in the opposite direction, we arrive at Deneb, the lucida of Cygnus; and beyond the Swan, a little out of the Milky Way, is Wega, the bright star in the Lyre. The Dragon consists of a very lengthy chain of stars sweeping partly around the Little Bear; and in the space bounded by Cassiopea, Cygnus, and Draco, is the constellation Cepheus.

Near Algenib, and pointing directly towards it, are two conspicuous stars of Andromeda, and a third is a little beyond them. Andromeda will be readily known by the connection of the lucida in her head, with the large trapezium of Pegasus.

An imaginary line projected through the Great Bear and Capella passes to the Pleiades, and then turning at a right angle towards the Milky Way reaches Aldebaran, the Bull's Eye, and the shoulders of Orion, who is known by his brilliant belt, consisting of three stars placed in the middle of a quadrangle. Aldebaran is a star of a reddish tint, and the most prominent of the Hyades, a cluster resembling the letter V, not far from the Pleiades. Aldebaran, the Pleiades, and Algol, make the upper, while Menkab, in the Whale's jaw, with Aries, form the lower points of a W. The head of Aries is denoted by two principal stars, one of them having a smaller attendant.

A fancied line drawn from Polaris, and led midway between the Great Bear and Capella, passes to Castor and Pollux, two well known stars in the heads of the Twins; and to the south of Gemini it meets Procyon, the lucida of the Lesser Dog. From thence, by bending the line across the Milky Way, and carrying it as far again, it reaches Sirius, in the Greater Dog's mouth, and passes on to the conspicuous star which is the *a* of Columba Noachi.

Algol and the Twins point at Regulus, the Lion's heart, which is situated at one end of an arc, with Denebola, the tuft of the Lion's tail, at the other end. South preceding Regulus is Cor Hydræ, and the space between them is occupied by the Sextant of Hevelius. The Pole-star and the middle horse of the wain direct us to Spica, the lucida of Virgo, considerably distant, and at the horizon leads us into Centaurus. The Pole-star and the first horse conduct us nearly upon Arcturus, in Boötes, by which fine star, Spica, and Regulus, a splendid triangle is formed. Following at a distance to the southward is Antares, the Scorpion's heart, constituting with Arcturus and Spica another large triangle, within which are the two bright stars of Libra.

The Northern Crown is nearly in a line between Wega and Arcturus; and the heads of Hercules and Ophiuchus are between Lyra and Scorpio. In the Milky Way, below the part nearest to Lyra, and on a line drawn from Arcturus through the head of Hercules, is Altair, in the Eagle, making with Wega and Deneb a conspicuous triangle. Closely following Aquila is a remarkable group of stars called Delphinus.

The last and brightest of the three principal stars in Andromeda makes, with three of Pegasus, the large square or trapezium already mentioned; of which one of the sides points to Fomalhaut, situated at a considerable distance in the mouth of the Southern Fish, between the tails of Cetus and Capricorn.

The line of the ecliptic may, with considerable accuracy, be traced by the eye, when it becomes familiar with the stars here enumerated. Not far from the Pleiades are the Hyades with Aldebaran, a little sonth of the ecliptic. To the north-west of Aldebaran, at some distance, is the chief star of Aries; while to the north-east of that star are Castor and Pollux. Regulus is on the line of the ecliptic; and Spica is but a little south of it. The ecliptic thus known, the zodiacal constellations are easily distinguished, in their order from west to east. Thus Aries lies immediately between Andromeda on the north and Cetus on the south, the three reaching nearly from the horizon to the zenith; Taurus will be recognised by the Pleiades, Aldebaran, and the Hyades; Gemini by Castor and Pollux; Cancer, the highest of the signs, by the Præsepe looming through its desert wastes; Leo, from the stars Regulus and Denebola; Virgo, by Spica, to the south of Coma Berenicis; Libra in mid-distance between Corona Borealis and the pole; Scorpio, by the reddish star Antares, and its three other very conspicuous stars; Sagittarius, as being the lowest of all the signs; Capricornus, south of the Dolphin; Aquarius, under the neck of Pegasus; and Pisces between Pegasus, Andromeda, and Cetus. As more will presently be said respecting these signs, it may suffice here to present the Latin hexameters, which were constructed to enable beginners to retain their names:

Sunt Aries, Taurus, Gemini, Cancer, Leo, Virgo,
Libraque, Scorpius, Arcitenens, Caper, Amphora, Pisces.

Or in the downright English memory-verses:

The *Ram*, the *Bull*, the heavenly *Twins*,
And, next the *Crab*, the *Lion* shines,
The *Virgin*, and the *Scales;*
The *Scorpion*, *Archer*, and *Sea-goat*,
The *Man* that holds the water-pot,
And *Fish* with glitt'ring tails.

All the stars which are situated in the same horary circle will obviously pass the meridian at the same time, from the horizon through the zenith to the pole. In proportion to their proximity to the equator, the larger will be the circle described by the star, and the smaller as they near the pole; consequently, as the stars move over equal portions of circles in equal times, whatever be the diameters of the circles, the motion of those near the equator is apparently very rapid, and that of the polar ones as slow. Thus the changes of the whole are in simultaneous concert; and the following table exhibits the aspect of the heavens on the first day of every month, at midnight, throughout the year. The *exact* risings and settings of the constellations cannot, of course, be observed, owing to intermediate horizontal obstacles, but the noting them will mark the spot where they may be first looked for. The *Risings* are taken along the horizon, from the north round by east to the south; the *Culminations* from the north horizon, over the pole and zenith, and thence down to the south; and the *Settings* are brought from the north round by west to the south. Polaris, though not always precisely on the meridian, is included in every month, as a standard mark and pointer.

Mo.	Rising.	Culminating.	Setting.
JANUARY.	Hercules, *the legs.*	Draco, *the body.*	Cygnus, *the neck.*
	Corona Borealis.	Polaris.	Pegasus, *the hoofs.*
	Boötes, *the knees.*	Camelopardus, *the head.*	Pegasus, *northern wing.*
	Virgo, *the shoulders.*	Lynx, *the head and neck.*	Pisces, *the ribbon.*
	Crater, *the middle.*	Gemini, *the legs.*	Cetus, *the body.*
	Pixis Nautica.	Monoceros, *neck and chest.*	Eridanus, *middle reach.*
	Argo navis, *the mast.*	Canis major, *the head.*	Columbæ Noachi.
FEBRUARY.	Lyra.	Cygnus, *the tail.*	Pisces, *the northern fish.*
	Hercules, *the shoulders.*	Cepheus, *the knee.*	Aries, *the fore legs.*
	Serpens, *the head.*	Polaris.	Cetus, *the head.*
	Virgo, *the feet.*	Ursa major, *the head and fore legs*	Eridanus, *north reach.*
	Corvus, *the feet.*	Lynx, *the tail.*	Lepus, *the fore legs.*
	Hydra, *the lower fold.*	Cancer, *the claws.*	Canis major, *the hind legs.*
	Antlia Pneumatica.	Hydra, *the head.*	Argo navis, *the compass.*
MARCH.	Cygnus, *the following wing.*	Lacerta, *over the back.*	Andromeda, *the body.*
	Lyra.	Cepheus, *preceding arm.*	Triangulum.
	Hercules, *the head.*	Polaris.	Musca.
	Ophiuchus, *the head.*	Ursa maj., α and β, *the hind legs.*	Taurus, *the neck.*
	Serpens, *the middle.*	Leo, *the flank.*	Orion, *the sword.*
	Libra, *both dishes.*	Crater, *preceding edge.*	Canis major, *the head.*
	Hydra, *the tail.*	Hydra, *the body.*	Pixis Nautica.
APRIL.	Lacerta.	Andromeda, *the body.*	Andromeda, *the feet.*
	Vulpecula et Anser.	Cassiopea, *the waist.*	Perseus, *Medusa's head.*
	Sagitta.	Polaris.	Taurus, *the horns.*
	Aquila, *the tail.*	Ursa major, *the tail.*	Orion, *the head.*
	Ophiuchus, *the knees.*	Canes Venatici, *the fore legs.*	Monoceros, *head and chest.*
	Scorpio, *the head.*	Virgo, *the waist.*	Pixis Nautica.
	Centaurus, *the head.*	Corvus, *the tail.*	Antlia Pneumatica.
MAY.	Andromeda, *the feet.*	Perseus, *the head.*	Auriga, *the legs.*
	Pegasus, *the fore legs.*	Cassiopea, *the feet.*	Gemini, *the legs.*
	Equuleus, *the nose.*	Polaris.	Cancer, *the southern legs.*
	Delphinus, *the body.*	Draco, *the tail.*	Hydra, *the heart.*
	Antinous.	Boötes, *the body.*	Crater, *the base.*
	Scorpio, *the tail.*	Libra, *preceding lanx.*	Corvus, *the body.*
	Lupus, *the head.*	Centaurus, *the hand.*	Centaurus, *the head.*
JUNE.	Perseus, *Medusa's head.*	Auriga, *the kids.*	Gemini, *the heads.*
	Triangulum.	Camelopardus, *the chest.*	Cancer, *the body.*
	Pisces, *the northern fish.*	Polaris.	Leo, *the fore legs.*
	Pegasus, *the wing.*	Draco, *the body.*	Sextans Uraniæ.
	Aquarius, *the shoulders.*	Hercules, *the back.*	Corvus, *the wings.*
	Capricornus, *the head.*	Ophiuchus, *preceding thigh.*	Hydra, *the tail.*
	Sagittarius, *the body.*	Scorpio, *the tail.*	Lupus, *the head.*

Mo.	Rising.	Culminating.	Setting.
JULY.	Auriga, *the waist.*	Lynx, *the head.*	Lynx, *the hind legs.*
	Perseus, *the feet.*	Camelopardus, *head and neck.*	Leo minor, *the legs.*
	Musca.	Polaris.	Leo, *the rump.*
	Aries, *the head.*	Draco, *two folds.*	Virgo, *the shoulders.*
	Pisces, *the tails.*	Lyra, *the lucida.*	Turdus Solitarius.
	Aquarius, *the legs.*	Scutum Sobieski.	Libra, *preceding lanx.*
	Sagittarius, *the hips.*	Sagittarius, *the head.*	Scorpio, *the body.*
AUGUST.	Lynx, *the body.*	Ursa major, *the head.*	Leo minor, *the head.*
	Gemini, *Castor's arm.*	Polaris.	Coma Berenices.
	Auriga, *the knees.*	Cepheus, *the sceptre.*	Boötes, *the feet.*
	Taurus, *the head.*	Cygnus, α, *the body.*	Mons Menalus.
	Cetus, *mouth and body.*	Vulpecula, *the flank.*	Libra, *the following lanx.*
	Piscis Australis, *the head.*	Delphinus, *the body.*	Serpentarius, *the legs.*
	Microscopium.	Capricornus, *the neck.*	Sagittarius, *the waist.*
SEPTEMBER.	Leo minor, *the head.*	Ursa major, *the body.*	Canes Venatici, *Chara's chest.*
	Lynx, *the hind legs.*	Draco, *tip of the tail.*	Boötes, *the knees.*
	Gemini, *the bodies.*	Polaris.	Serpens, *the head.*
	Orion, *the shoulders.*	Cepheus, *head and body.*	Ophiuchus, *the waist.*
	Eridanus, *upper reach.*	Pegasus, *the chest.*	Scutum Sobieski.
	Cetus, *the legs.*	Aquarius, *the stream.*	Sagittarius, *the robe.*
	Apparatus sculptoris.	Piscis Australis, *the head.*	Piscis Australis, *the tail.*
OCTOBER.	Leo minor, *the fore body.*	Ursa major, *the tail.*	Boötes, *the shoulders.*
	Cancer, *the body.*	Draco, *the tail.*	Corona Borealis.
	Canis minor, *the head.*	Polaris.	Hercules, *the shoulders.*
	Monoceros, *the neck.*	Cassiopea, *the head.*	Ophiuchus, *the head.*
	Orion, *the following leg.*	Andromeda, *the breast.*	Taurus Poniatowski.
	Lepus, *the head.*	Pisces, *the ribbon.*	Capricornus, *the head.*
	Fornax Chemica.	Cetus, *the tail.*	Piscis Australis, *the head.*
NOVEMBER.	Canes Venatici, *Chara's chest.*	Draco, *the last quoil.*	Hercules, *the legs.*
	Leo, *the fore body.*	Ursa minor, *the head.*	Cerberus et Ramus.
	Hydra, *the head.*	Polaris.	Sagitta.
	Monoceros, *the flank.*	Perseus, *the head and shoulder.*	Aquila, *head and body.*
	Canis major, *the head.*	Aries, *the body.*	Equuleus.
	Lepus, *the body.*	Cetus, *the mouth.*	Aquarius, *the legs.*
	Eridanus, *middle stream.*	Fornax Chemica.	Apparatus Sculptoris.
DECEMBER.	Boötes, *the head.*	Draco, *the middle.*	Lyra.
	Coma Berenices.	Ursa minor, *the haunch.*	Cygnus, *the head.*
	Leo, *the hind legs.*	Polaris.	Vulpecula, *the hind legs.*
	Sextans Uraniæ.	Camelopardus, *the body.*	Pegasus, *the head.*
	Hydra, *the heart.*	Taurus, *the head.*	Pisces, *the preceding fish.*
	Argo navis, *the mast.*	Eridanus, *northern reach.*	Cetus, *the tail.*
	Canis major, *the hind legs.*	Eridanus, *southern reach.*	Fornax Chemica.

In out-door reconnoitering, do not forget the difference between apparent or true solar time, and mean or equated time. For exactness, the equation must be taken from the *Ephemeris;* but the following table will be sufficient for the gazer to see the mean days of the year on which his watch ought to be an even number of minutes faster or slower than the sun.

Days.	Cor. in min.	Days.	Cor. in min.	Days.	Cor. in min.	Days.	Cor. in min.	Days.	Cor. in min.	Days.	Cor. in min.
Jan. 2	4 F	Mar. 12	10 F	May 1	3 S	Aug. 16	4 F	Sept. 27	9 S	Dec. 5	9 S
„ 4	5 F	„ 15	9 F	„ 15	4 S	„ 20	3 F	„ 30	10 S	„ 8	8 S
„ 6	6 F	„ 19	8 F	„ 28	3 S	„ 24	2 F	Oct. 3	11 S	„ 10	7 S
„ 11	8 F	„ 22	7 F	June 5	2 S	„ 28	1 F	„ 6	12 S	„ 12	6 S
„ 14	9 F	„ 25	6 F	„ 11	1 S	Sept. 1	0	„ 10	13 S	„ 14	5 S
„ 16	10 F	„ 28	5 F	„ 15	0	„ 3	1 S	„ 14	14 S	„ 16	4 S
„ 19	11 F	April 1	4 F	„ 19	1 F	„ 6	2 S	„ 19	15 S	„ 18	3 S
„ 23	12 F	„ 4	3 F	„ 24	2 F	„ 9	3 S	„ 27	16 S	„ 20	2 S
„ 27	13 F	„ 7	2 F	„ 29	3 F	„ 12	4 S	Nov. 16	15 S	„ 22	1 S
Feb. 3	14 F	„ 11	1 F	July 4	4 F	„ 15	5 S	„ 20	14 S	„ 24	0
„ 28	13 F	„ 15	0	„ 10	5 F	„ 18	6 S	„ 24	13 S	„ 26	1 F
Mar. 4	12 F	„ 19	1 S	„ 21	6 F	„ 21	7 S	„ 27	12 S	„ 28	2 F
„ 8	11 F	„ 24	2 S	Aug. 10	5 F	„ 24	8 S	Dec. 3	10 S	„ 30	3 F

Those who are possessed of Astronomical Catalogues, may readily find the mean apparent time of an individual star's passing the meridian on any given day of the year, by adding the number placed against the date, in the following table, to the right ascension of the star taken from the catalogue. This depends, as the reader will perceive, on the star's distance to the east of the sun at the required time; and as the table shows the sun's eastern distance from the first point of Aries, the culmination of every object is of course easily found by the proposed addition. If the sun be more than 24 hours, the latter number must be subtracted from it. From the sum thus obtained—to be roundly exact—subtract 1′, 2′, or 3′, according as it exceeds 6, 12, or 18 hours, or approaches closely upon them: by this ready means the time of culmination is found, counting from the noon of the given day. This table will run very well for a quarter of a century, when, according to a mean calculation, the stars will culminate only 1′ later.

Days.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
1	5 14	3 01	1 12	23 18	21 27	19 24	17 20	15 15	13 19	11 31	9 35	7 31
2	5 09	2 57	1 08	23 15	21 23	19 20	17 16	15 11	13 15	11 27	9 31	7 27
3	5 04	2 53	1 04	23 11	21 19	19 16	17 12	15 07	13 12	11 24	9 27	7 22
4	5 00	2 49	1 01	23 07	21 16	19 12	17 08	15 04	13 08	11 20	9 23	7 18
5	4 56	2 45	0 57	23 04	21 12	19 08	17 04	15 00	13 05	11 17	9 19	7 14
6	4 51	2 41	0 53	23 00	21 08	19 04	16 59	14 56	13 01	11 13	9 15	7 09
7	4 47	2 37	0 49	22 56	21 04	19 00	16 55	14 52	12 57	11 09	9 11	7 05
8	4 42	2 33	0 46	22 53	21 00	18 56	16 51	14 48	12 54	11 06	9 07	7 01
9	4 38	2 29	0 42	22 49	20 56	18 51	16 47	14 44	12 50	11 02	9 03	6 56
10	4 34	2 25	0 38	22 45	20 52	18 47	16 43	14 41	12 47	10 58	8 59	6 52
11	4 29	2 21	0 35	22 42	20 48	18 43	16 39	14 37	12 43	10 55	8 55	6 47
12	4 25	2 17	0 31	22 38	20 44	18 39	16 35	14 33	12 39	10 51	8 51	6 43
13	4 21	2 13	0 27	22 34	20 41	18 35	16 31	14 29	12 36	10 47	8 47	6 39
14	4 16	2 09	0 24	22 31	20 37	18 31	16 27	14 26	12 32	10 43	8 43	6 34
15	4 12	2 05	0 20	22 27	20 33	18 27	16 23	14 22	12 29	10 40	8 39	6 30
16	4 08	2 01	0 16	22 23	20 29	18 22	16 19	14 18	12 25	10 36	8 35	6 25
17	4 04	1 57	0 13	22 20	20 25	18 18	16 15	14 14	12 21	10 32	8 30	6 21
18	3 59	1 54	0 09	22 16	20 21	18 14	16 11	14 11	12 18	10 28	8 26	6 16
19	3 55	1 50	0 06	22 12	20 17	18 10	16 07	14 07	12 14	10 25	8 22	6 12
20	3 51	1 46	0 02	22 08	20 13	18 06	16 03	14 03	12 11	10 21	8 18	6 08
21	3 47	1 42	23 58	22 05	20 09	18 02	15 59	13 59	12 07	10 17	8 14	6 03
22	3 42	1 38	23 55	22 01	20 05	17 57	15 55	13 56	12 03	10 13	8 09	5 59
23	3 38	1 34	23 51	21 57	20 01	17 53	15 51	13 52	12 00	10 10	8 05	5 54
24	3 34	1 31	23 47	21 53	19 57	17 49	15 47	13 48	11 56	10 06	8 01	5 50
25	3 30	1 27	23 44	21 50	19 53	17 45	15 43	13 45	11 53	10 02	7 57	5 45
26	3 26	1 23	23 40	21 46	19 49	17 41	15 39	13 41	11 49	9 58	7 53	5 41
27	3 21	1 19	23 36	21 42	19 45	17 37	15 35	13 37	11 45	9 54	7 48	5 36
28	3 17	1 16	23 33	21 38	19 41	17 32	15 31	13 34	11 42	9 50	7 44	5 32
29	3 13	1 14	23 29	21 35	19 37	17 28	15 27	13 30	11 38	9 47	7 40	5 28
30	3 09	..	23 25	21 31	19 32	17 24	15 23	13 26	11 35	9 43	7 35	5 23
31	3 05	..	23 22	..	19 28	..	15 19	13 23	..	9 39	..	5 19

As it may assist a first attempt to give an example or two, we will show the culmination of Sirius on the 11th of January 1840, of Arcturus on the 11th of March, and of Wega on the 30th of May, for the same year:

I.		II.		III.	
	h m s		h m s		h m s
Sirius, *Cat.* Æ -	6 38 07	Arcturus, *Cat.* Æ	14 08 24	Wega, *Cat.* Æ -	18 31 34
Tabular No. -	4 29	Tabular No. - -	0 35	Tabular No. - -	19 32
	11 07 08		14 43 24		38 03 34
				— 24^h =	14 03 34

In using the right ascensions much confusion is liable to occur under hasty references to sidereal and mean times; and a desired transit has often been lost by him who possesses but one clock. A common watch may be converted into a *journeyman*, by compensating it for a daily acceleration of 4′ on mean solar time, the going of which may be depended upon for a night's gazing. For my own use, I contrived a couple of large concentric discs of pasteboard, the inner one of which was moveable round a brass-pin centre. Both these circles were graduated for twenty-four hours, and subdivided into single minutes; the outer representing mean time, and the inner sidereal time. When the sun's mean right ascension on the inner circle, for the day of observation, is placed at XII. at noon on the outer one, the latter will show the corresponding mean time throughout the day, especially if touched up at intervals for the acceleration. To warn me, while busied in my library, the Greenwich stars were placed against their right ascensions on the inner circle. When Mr. Dollond came to Bedford, he was so pleased with this time-server, that he requested to publish it; which he has since done, and designated it the *Astronomical Remembrancer*.

But to the gazer who may be unprovided with an Astronomical Catalogue, the following table of the approximate apparent times of the meridian passages of the principal fixed stars, with the point in the horizon of their rising and setting, and the duration of their visibility, on the first day of each month, may be acceptable. In this table the stars are so selected as to form a net over the whole of our hemisphere; and where a star is well pointed out by a brighter immediate neighbour, as α Herculis by α Ophiuchi, and α Geminorum by β, the smaller one is omitted in order to render the list as clear as possible.

This table is computed for 1841, and the subtraction of a minute annually during the three subsequent years, will adapt the required time for each star's transit. But on the fourth year after the epoch of the table, that is, 1845, owing to the extra day in leap year, the time again suits within a few seconds, as in 1841. The same progressive alternation recurs from 1845 to 1849, and so on for several similar epochs, until the few differing seconds amount to a minute.

Stars.			Jan.	Feb.	Mar.	April	May	June	July
Constellation.	Names.	Mag.	h m	h m	h m	h m	h m	h m	h m
α Andromedæ	*Sirrah*	1	5 12	3 56	1 12	23 14	21 23	19 21	17 17
γ Pegasi	*Algenib*	2½	5 17	3 5	1 17	23 19	21 28	19 26	17 22
α Cassiopeæ	*Schedir*	3	5 44	3 32	1 43	23 46	21 55	19 53	17 49
β Ceti	*Difda*	2½	5 48	3 36	1 47	23 50	21 59	19 57	17 53
α Ursæ minoris	*Polaris*	2½	6 14	4 2	2 13	0 20	22 25	20 22	18 19
α Arietis	*Hamal*	3	7 10	4 58	3 9	1 16	23 21	21 19	19 15
α Ceti	*Menkab*	2½	8 6	5 54	4 5	2 12	0 21	22 15	20 11
α Persei	*Mirfak*	2½	8 25	6 13	4 24	2 31	0 40	22 33	20 30
α Tauri	*Aldebaran*	1	9 38	7 26	5 38	3 44	1 53	23 47	21 43
α Aurigæ	*Capella*	1	10 16	8 4	6 16	4 22	2 31	0 29	22 21
β Orionis	*Rigel*	1	10 18	8 6	6 18	4 24	2 33	0 31	22 23
β Tauri	*Nath*	2	10 28	8 17	6 27	4 34	2 43	0 40	22 32
α Orionis	*Betelgeuze*	1	10 58	8 46	6 57	5 4	3 13	1 11	23 3
α Canis majoris	*Sirius*	1	11 49	9 38	7 49	5 55	4 4	2 2	23 54
ε Canis majoris	*Adara*	2½	12 4	9 52	8 3	6 10	4 19	2 16	0 8
α Canis minoris	*Procyon*	1½	12 42	10 30	8 41	6 48	4 57	2 55	0 46
β Geminorum	*Pollux*	2	12 47	10 35	8 46	6 53	5 2	2 59	0 51
α Hydræ	*Alphard*	2	14 31	12 19	10 30	8 36	6 46	4 43	2 35
α Leonis	*Regulus*	1	15 11	12 59	11 10	9 17	7 26	5 23	3 15
α Ursæ majoris	*Dubhe*	1½	16 4	13 51	12 3	10 10	8 19	6 17	4 14
β Leonis	*Denebola*	2½	16 51	14 39	12 51	10 57	9 6	7 4	4 56
γ Ursæ majoris	*Phecda*	2	16 56	14 44	12 55	11 2	9 11	7 8	5 0
12 Canum Venat.	*Cor Caroli*	2½	17 59	15 47	13 58	12 5	10 14	8 12	6 5
α Virginis	*Spica*	1	18 27	16 15	14 26	12 33	10 42	8 40	6 34
η Ursæ majoris	*Alkaid*	2½	18 51	16 39	14 51	12 57	11 6	9 4	7 0
α Boötis	*Arcturus*	1	19 18	17 6	15 18	13 24	11 33	9 31	7 27
α Coronæ Borealis	*Alphecca*	2	20 38	18 26	16 37	14 44	12 53	10 51	8 47
α Serpentis	*Unukalhay*	2½	20 46	18 34	16 45	14 52	13 1	10 59	8 55
β^{1} Scorpii	*Acrab*	2	21 6	18 55	17 5	15 12	13 21	11 18	9 16
α Scorpii	*Antares*	1	21 29	19 17	17 28	15 35	13 44	11 42	9 38
β Draconis	*Alwaid*	2	22 36	20 24	18 36	16 42	14 51	12 49	10 45
α Ophiuchi	*Rasalague*	2	22 37	20 25	18 36	16 43	14 52	12 49	10 46
γ Draconis	*Etamin*	2	23 2	20 50	19 2	17 8	15 17	13 15	11 11
α Lyræ	*Wega*	1	23 41	21 29	19 40	17 47	15 56	13 54	11 50
α Aquilæ	*Altair*	1½	0 55	22 40	20 51	18 58	17 7	15 5	13 1
α Cygni	*Deneb*	1	1 49	23 33	21 44	19 51	18 0	15 58	13 54
α Cephei	*Alderamin*	3	2 28	0 12	22 23	20 30	18 38	16 35	14 32
ε Pegasi	*Enif*	2½	2 49	0 33	22 44	20 51	19 0	16 58	14 54
α Piscis Australis	*Fomalhaut*	1	4 1	1 45	0 1	22 3	20 12	18 10	16 6
α Pegasi	*Markab*	2	4 9	1 53	0 9	22 11	20 20	18 18	16 14

Stars.	Aug.	Sept.	Oct.	Nov.	Dec.	Point of Rising.	Hours to mer.	Point of Setting.
Constellation.	h m	h m	h m	h m	h m			
α Andromedæ -	15 13	13 17	11 30	9 33	7 30	N.E. ½ N.	8¾	N.W. ½ N.
γ Pegasi - - -	15 18	13 22	11 34	9 38	7 35	E.N.E.	7¼	W.N.W.
α Cassiopeæ - -	15 44	13 28	12 0	10 5	8 1	*Circumpolar.*		
β Ceti - - - -	15 48	13 52	12 5	10 9	8 5	E.S.E. ¾ S.	4	W.S.W. ¾ S.
α Ursæ minoris -	16 14	14 18	12 30	10 35	8 31	*Circumpolar.*		
α Arietis - - -	17 10	15 15	13 27	11 31	9 28	N.E. by E.	8¼	N.W. by W.
α Ceti - - - -	18 6	16 10	14 23	12 27	10 23	E. ½ N.	6¼	W. ½ N.
α Persei - - -	18 25	16 29	14 41	12 46	10 42	*Circumpolar.*		
α Tauri - - -	19 39	17 43	15 55	13 59	11 56	E.N.E.	7½	W.N.W.
α Aurigæ - - -	20 18	18 21	16 33	14 37	12 34	*Circumpolar.*		
β Orionis - - -	20 20	18 23	16 35	14 40	12 35	E. by S. ½ S.	5¼	W. by S. ½ S.
β Tauri - - -	20 28	18 32	16 44	14 49	12 44	N.E. ¼ N.	8¾	N.W. ¼ N.
α Orionis - - -	20 58	19 2	17 15	15 19	13 15	E. by N.	6½	W. by N.
α Canis majoris -	21 50	19 54	18 6	16 10	14 7	E.S.E. ½ S.	4½	W.S.W. ½ S.
ε Canis majoris -	22 4	20 8	18 20	16 24	14 21	S.E. ¾ S.	3	S.W. ¾ S.
α Canis minoris -	22 42	20 47	18 59	17 3	14 59	E. ¾ N.	6½	W. ¾ N.
β Geminorum -	22 47	20 51	19 3	17 7	15 4	N.E. ½ N.	9	N.W. ½ N.
α Hydræ - - -	0 35	22 35	20 47	18 51	16 48	E. by S. ¼ S.	5½	W. by S. ¼ S.
α Leonis - - -	1 15	23 15	21 27	19 31	17 28	E.N.E.	7¼	W.N.W.
α Ursæ majoris -	2 9	0 13	22 21	20 25	18 21	*Circumpolar.*		
β Leonis - - -	2 56	1 0	23 8	21 12	19 9	E.N.E. ¼ N.	7½	W.N.W. ¼ N.
γ Ursæ majoris -	3 0	1 4	23 12	21 17	19 13	*Circumpolar.*		
12 Canum Venat.	4 8	2 8	0 16	22 20	20 16	*Circumpolar.*		
α Virginis - - -	4 35	2 35	0 44	22 48	20 44	E. by S. ½ S.	5	W. by S. ½ S.
η Ursæ majoris -	4 56	3 0	1 8	23 12	21 8	*Circumpolar.*		
α Boötis - - -	5 23	3 27	1 36	23 39	21 36	N.E. by E.	7¾	N.W. by W.
α Coronæ Borealis	6 42	4 46	2 55	1 3	22 55	N.E. ½ N.	8½	N.W. ½ N.
α Serpentis - -	6 50	4 55	3 4	1 11	23 3	E. by N.	6½	W. by N.
β^1 Scorpii - - -	7 11	5 14	3 24	1 31	23 24	S.E. by E.	4¼	S.W. by W.
α Scorpii - - -	7 34	5 38	3 48	1 54	23 47	S.E.	3½	S.W.
β Draconis - -	8 40	6 45	4 57	3 1	0 58	*Circumpolar.*		
α Ophiuchi - -	8 41	6 45	4 58	3 2	0 58	E.N.E.	7¼	W.N.W.
γ Draconis - -	9 7	7 11	5 23	3 27	1 24	*Circumpolar.*		
α Lyræ - - -	9 45	7 49	6 2	4 6	2 2	*Circumpolar.*		
α Aquilæ - - -	10 56	9 1	7 13	5 17	3 13	E. by N. ¼ N.	6¾	W. by N. ¼ N.
α Cygni - - -	11 50	9 54	8 6	6 10	4 7	*Circumpolar.*		
α Cephei - - -	12 28	10 32	8 44	6 49	4 45	*Circumpolar.*		
ε Pegasi - - -	12 49	10 54	9 6	7 10	5 7	E. by N. ¼ N.	6¾	W. by N. ¼ N.
α Piscis Australis	14 2	12 6	10 18	8 22	6 19	S.E. by S.	2½	S.W. by S.
α Pegasi - - -	14 10	12 14	11 26	8 30	6 27	E.N.E.	7¼	W.N.W.

The foregoing table, as already stated, shows the culminating times of the stars on the first day of each month; and this will be sufficient for the mere general reconnoitre of the heavens, which an amateur may take previous to making a settled gaze with his instrument. To find the time of passage for any intervening day, subtract the portion of time corresponding to the stated day of the month, in the following Table of Corrections.

Days.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
1	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
2	0 4	0 4	0 4	0 4	0 4	0 4	0 4	0 4	0 4	0 4	0 4	0 4
3	0 9	0 8	0 7	0 7	0 8	0 8	0 8	0 8	0 7	0 7	0 8	0 9
4	0 13	0 12	0 11	0 11	0 11	0 12	0 12	0 12	0 11	0 11	0 12	0 13
5	0 18	0 16	0 15	0 15	0 15	0 16	0 16	0 15	0 14	0 15	0 16	0 17
6	0 22	0 20	0 19	0 18	0 19	0 21	0 21	0 19	0 18	0 18	0 20	0 22
7	0 26	0 24	0 22	0 22	0 23	0 25	0 25	0 23	0 22	0 22	0 24	0 26
8	0 30	0 28	0 26	0 26	0 27	0 29	0 29	0 27	0 25	0 25	0 28	0 30
9	0 35	0 32	0 30	0 29	0 30	0 33	0 33	0 31	0 29	0 29	0 32	0 35
10	0 39	0 36	0 33	0 33	0 35	0 37	0 37	0 35	0 32	0 33	0 36	0 39
11	0 43	0 40	0 37	0 36	0 39	0 41	0 41	0 38	0 36	0 37	0 40	0 44
12	0 48	0 44	0 41	0 40	0 42	0 45	0 45	0 42	0 40	0 40	0 44	0 48
13	0 52	0 48	0 44	0 44	0 46	0 49	0 49	0 46	0 43	0 44	0 48	0 52
14	0 56	0 52	0 48	0 48	0 50	0 54	0 53	0 50	0 47	0 48	0 52	0 57
15	1 1	0 56	0 52	0 51	0 54	0 58	0 57	0 53	0 50	0 51	0 56	1 1
16	1 5	1 0	0 55	0 55	0 58	1 2	1 1	0 57	0 54	0 55	1 0	1 6
17	1 9	1 3	0 59	0 59	1 2	1 6	1 5	1 1	0 58	0 59	1 4	1 10
18	1 13	1 7	1 2	1 2	1 6	1 10	1 9	1 5	1 1	1 3	1 9	1 15
19	1 18	1 11	1 6	1 6	1 10	1 14	1 13	1 8	1 5	1 6	1 13	1 19
20	1 22	1 15	1 10	1 10	1 14	1 19	1 17	1 12	1 8	1 10	1 17	1 24
21	1 26	1 19	1 14	1 13	1 18	1 23	1 21	1 16	1 12	1 14	1 21	1 28
22	1 31	1 23	1 17	1 17	1 22	1 27	1 25	1 19	1 16	1 18	1 25	1 32
23	1 35	1 26	1 21	1 21	1 26	1 31	1 29	1 23	1 19	1 21	1 30	1 37
24	1 39	1 30	1 24	1 25	1 30	1 35	1 33	1 27	1 23	1 25	1 34	1 41
25	1 43	1 34	1 28	1 28	1 34	1 39	1 37	1 31	1 26	1 29	1 38	1 46
26	1 47	1 38	1 32	1 32	1 38	1 44	1 41	1 34	1 30	1 33	1 42	1 50
27	1 51	1 42	1 35	1 36	1 42	1 48	1 45	1 38	1 34	1 37	1 47	1 55
28	1 56	1 45	1 39	1 40	1 46	1 52	1 49	1 42	1 37	1 41	1 51	1 59
29	2 0	1 48	1 43	1 44	1 50	1 56	1 53	1 45	1 41	1 44	1 55	2 3
30	2 4	..	1 46	1 47	1 55	2 0	1 57	1 49	1 44	1 48	1 59	2 8
31	2 8	..	1 50	..	1 59	..	2 1	1 52	..	1 52	..	2 12

I now proceed to place before the amateur a successional series of objects for testing the light and defining power, and other properties of his telescope. Each class commences with the widest and easiest of its order, and advances gradually to the most difficult, where considerable diameter of object-glass or metal will be required to divorce the components by reducing the apparent discs. The dividing power of a telescope depends upon the aperture, as is proved where a want of that opening prevents objects from increasing their relative distance from each other, while magnifying them. The Rev. W. R. Dawes drew my attention to this point in the winter of 1831, on the occasion of comparing some occultations of stars, and eclipses of Jupiter's satellites, which we had both taken, he at Ormskirk and myself at Bedford. His views cannot be better expressed than in his own words:

The adoption of something like a uniform or equivalent aperture in our instruments may do something towards the attainment of uniformity of vision; yet after all, we shall, in many instances, have a deceptive appearance of uniformity, rather than the reality. Peculiarities of instruments may be considerable; but those of eyes must, I think, be still greater. Now I fancy that we may obviate all these sources of difficulty, which so grievously interfere with the practical utility of one of the most simple methods of obtaining the difference of longitude. In order to this I should propose, that some suitable celestial object or objects be selected, and made the standard of visibility. The magnifying power might be limited to about 80, a very frequent one; and the aperture employed must be such as will enable the individual observer just to see the test object. By this I mean, not merely to get glimpses of it during "fits of easy transmission," or only to see pretty steadily on some precious night of rare occurrence; but just to see it steadily, when the eye is kept full on the object, and this in the average of clear nights.

With the view of fixing on some suitable objects for this purpose, I have lately examined several, while the moon has been absent; and have come to the conclusion that we could scarcely do better than fix on the minute companion of Polaris. This object offers many advantages possessed by no other. By some, indeed, it may be thought too easy and obvious. But I believe it would require an excellent eye and a superb night, to render it visible at all with much under two inches aperture. I have several times just seen it with one of Dollond's 30-inch achromatics, of two inches aperture, and power 80. But I have met with some persons, who, without any remarkable defect in the eye, required an aperture of 2¾ to see it well. From comparison with other observers, I have reason to think that both my eye and instrument are well adapted to distinguish minute points of light, yet I find it needful to use 2½ inches aperture on my 5-foot achromatic to see this satellite of Polaris steadily.

By constituting this object the standard, we shall, I think, embrace a very considerable number of observers; and I am rather disposed to regret that it does not admit of the 30-inch achromatic being engaged in the work, than to wish that it were less easy. Polaris has the advantage, as one has quaintly said, of being to us "always above the horizon;" it is easily distinguished, and is always very nearly at the same altitude. Unless, therefore, some more desirable object, or more eligible plan, be suggested, I should urge that all eyes and all telescopes be turned towards the pole: and upon an average of five or six clear nights, let each observer satisfy himself with how small an aperture, carrying a power of about 80 times, he can keep its companion steadily in view. We shall then all stand on equal ground, and have no greater source of uncertainty than the state of the atmosphere, which should, of course, be distinctly noticed in the recorded observations.

This useful proposal was not carried into effect, though I had several votes for it. Meantime I made a few trials with my telescope under three different apertures, having had the cap which covers my $5\frac{9}{10}$ inch object-glass pierced with two circular holes of two inches and four inches, both carefully measured and then engraved. With the 2-inch aperture, and easy magnifying powers of from 60 to 100—which showed Polaris and its companion distinctly—I clearly perceived double:

γ Arietis,	γ Leonis,
α Geminorum,	μ Draconis,
α Piscium,	ζ Ursæ majoris,
ρ Herculis,	η Cassiopeæ.

Mr. Dawes made out some of these systems with an aperture of only 1·6 inch; but my perforated cap allowed of nothing smaller than the 2 inches. With the 4-inch aperture, and powers varying from 80 to 120 and upwards, I readily saw:

β Orionis,	σ Cassiopeæ,
α Lyræ,	ε Boötis,
δ Geminorum,	γ Ceti,
ε Hydræ,	ε Draconis,
ξ Ursæ majoris,	ι Leonis.

But it required the full aperture, and powers of from 240 to 300, with favourable circumstances, to scrutinize satisfactorily the following test-objects:

α Arietis,	20 Draconis,
λ Ophiuchi,	ζ Herculis,
ε Equulei,	32 Orionis,
δ Cygni,	κ Geminorum.

There are many cases in which a zealous astronomer may be provided with a telescope of capacity, and yet he may be debarred by local impediments from commanding an unobstructed view of the polar regions. Other tests besides Polaris can therefore be established, so as to suit every site with an object, the correspondents selecting those that can be seen by each under similar circumstances. In such a case, in order that a fair comparison may eventually be made, it would be well to record the observations in a specified form, and in the same denomination of time. In the following lists of the before-mentioned test-objects, the arrangement is suited to what may be termed the successional scale of a telescope's action. We commence with nearly equal stars:—in those objects which are triple or multiple, the close pair only is marked.

Designation.	Place, 1840.					Magnitudes.		Distance.
	Æ.			Dec.				
	h	m	s	°	′			″
γ Delphini - - -	20	39	15	N 15	33·2	A 4	B 5½	12·0
γ Arietis - - -	1	44	45	N 18	30·5	A 4½	B 5	8·8
μ Cygni - - -	21	36	59	N 28	01·4	A 5	B 6	5·5
α Geminorum - -	7	24	23	N 32	14·0	A 3	B 3½	4·9
38 Piscium - - -	0	9	09	N 7	59·2	A 7½	B 8	4·8
44 Boötis - -	14	58	31	N 48	16·8	A 5	B 6	3·7
α Piscium - - -	1	53	46	N 1	59·3	A 5	B 6	3·7
ρ Herculis - -	17	18	10	N 37	17·9	A 4	B 5½	3·6
ζ Aquarii - - -	22	20	35	S 0	50·2	A 4	B 4½	3·5
μ Draconis - -	17	2	02	N 54	41·2	A 4	B 4½	3·3
ε Lyræ - - -	18	39	02	N 39	30·3	A 5	B 6½	3·2
γ Leonis - - -	10	11	08	N 20	39·0	A 2	B 4	2·8
11 Monocerotis - -	6	21	04	S 6	56·1	B 7	C 8	2·7
5 Lyræ - - -	18	39	04	N 39	28·9	A 5	B 5½	2·6
ξ Ursæ majoris - -	11	9	38	N 32	25·8	A 4	B 5½	2·3
γ Virginis (1844) -	12	33	33	S 0	34·3	A 4	B 4	1·9
σ Coronæ Borealis -	16	8	41	N 34	16·1	A 6	B 6½	1·8
π Aquilæ - -	19	41	10	N 11	25·4	A 6	B 7	1·7
ζ Boötis - - -	14	33	31	N 14	25·1	A 3½	B 4½	1·3
ζ Cancri - - -	8	3	02	N 18	07·5	A 6	B 7	1·2
36 Andromedæ - -	0	46	24	N 22	45·7	A 6	B 7	1·0
ε Arietis - - -	2	50	04	N 20	41·8	A 5	B 6½	0·9
μ^2 Boötis - -	15	18	28	N 37	54·7	A 8	B 8½	0·8
20 Draconis - -	16	55	38	N 65	17·0	A 7	B 7½	0·7
ε Equulei - - -	20	51	05	N 3	41·1	A 5½	B 7½	0·5
η Coronæ Borealis -	15	16	36	N 30	52·2	A 6	B 6½	0·5
γ^2 Andromedæ - -	1	54	06	N 41	33·6	B 5½	C 6	0·4

It should here be observed, that Sir John Herschel has published a very elaborate list of test-objects, for the trial of optical instruments in various respects. This list is printed in the eighth volume of the Royal Astronomical Society's *Memoirs*, and is admirably adapted for examining the performance of telescopes of the largest dimensions, even to the Earl of Rosse's *Leviathan.* Amateurs, however, may rest satisfied with their means, if they can distinctly manage the objects which I have selected for them: and here follows my second table, which consists of pairs of unequal stars.

Designation.	Place, 1840.					Magnitudes.		Distance.
	Æ.			Dec.				
	h	m	s	°	′			″
β Cygni - - -	19	24	16	N 27	37·7	A 3	B 7	34·4
ζ Ursæ majoris -	13	17	28	N 55	45·8	A 3	B 5	14·4
35 Piscium - - -	0	6	44	N 7	55·9	A 6	B 8	11·9
γ Andromedæ - -	1	54	06	N 41	33·6	A 3½	B 5½	11·0
ξ Boötis - - -	14	44	00	N 19	46·1	A 3½	B 6½	6·9
ξ Cephei - - -	21	59	10	N 63	51·0	A 5	B 7	5·8
α Herculis - - -	17	7	21	N 14	34·5	A 3½	B 5½	4·5
ε Hydræ - -	8	38	18	N 7	00·2	A 4	B 8½	3·6
ι Trianguli - - -	2	3	06	N 29	33·0	A 5½	B 7	3·5
ε Boötis - - -	14	38	00	N 27	45·1	A 3	B 7	3·3
ε Draconis - - -	19	48	41	N 69	51·6	A 5½	B 9½	3·1
σ Cassiopeæ - -	23	50	55	N 54	51·8	A 6	B 8	3·0
δ Serpentis - - -	15	27	10	N 11	04·7	A 3	B 5	2·8
γ Ceti - - -	2	35	01	N 2	33·5	A 3	B 7	2·6
ζ Orionis - - -	5	32	41	S 2	02·0	A 3	B 6½	2·5
ι Leonis - - -	11	15	35	N 11	24·8	A 4	B 7½	2·5
72 P. II. Cassiopeæ -	2	15	58	N 66	40·7	A 4½	B 7	2·1
ζ Herculis - -	16	35	15	N 31	53·7	A 3	B 6	1·2
λ Ophiuchi -	16	22	51	N 2	20·4	A 4	B 6	1·1
32 Orionis - -	5	22	13	N 5	49·3	A 5	B 7	1·0
4 Aquarii - - -	20	42	57	S 6	13·2	A 6	B 8	0·5
γ Coronæ Borealis -	15	36	01	N 26	48·4	A 5	B 7	0·2

The following table exhibits a choice set of very unequal stars, some of which are difficult from the overpowering brilliance of the principal component. Practice, however, accommodates the eye for meeting such circumstance.

Designation.	Place, 1840.					Magnitudes.		Distance.
	Æ.			Dec.				
	h	m	s	°	′			″
α Lyræ - - -	18	31	30	N 38	38·1	A 1	B 11	43·4
42 Piscium - -	0	14	09	N 12	35·6	A 7	B 13	35·0
δ Equulei - - -	21	6	42	N 9	21·7	A 4½	B 11	28·2
7 Camelopardi -	4	44	28	N 53	29·3	A 5	B 13	27·0
Polaris - - -	1	2	10	N 88	27·4	A 2½	B 9½	18·6
41 Arietis - -	2	40	34	N 26	35·9	A 3	B 13	15·0
θ Persei - - -	2	33	08	N 48	32·9	A 4	B 13	15·0
λ Geminorum -	7	8	54	N 16	49·5	A 4¼	B 12	10·3
η Cassiopeæ - -	0	39	27	N 56	57·9	A 4	B 7¼	9·7
β Orionis - -	5	6	51	S 8	23·5	A 1	B 9	9·5
φ Piscium - - -	1	5	04	N 23	44·1	A 6	B 13	9·0
δ Geminorum - -	7	10	34	N 22	16·3	A 3¼	B 9	7·1
34 Piscium - -	0	1	53	N 10	14·6	A 6	B 13½	7·0
ν Ceti - - -	2	27	29	N 4	53·5	A 4½	B 15	6·0
κ Geminorum - -	7	34	47	N 24	46·5	A 4	B 10	6·0
84 Ceti - - -	2	33	02	S 1	22·7	A 6	B 14	5·0
17 Lyræ - - -	19	1	23	N 35	15·2	A 6	B 11	3·6
11 Cancri - -	7	59	02	N 27	56·4	A 7	B 12	3·2
γ Crateris - - -	11	16	54	S 16	48·3	A 4	B 14	3·0
δ Cygni - - -	19	39	58	N 44	44·6	A 3¼	B 9	1·8

The next table contains nebulæ, and resolvible clusters of stars, in successional order; and they form a capital series of tests for trying the light, optical capacity, and space-penetrating power of the telescope. The easiest way to examine these qualities, is to commence with noticing the effect of the instrument on the Hyades, Pleiades, Præsepe, or any other cluster which requires but slight optical aid. After duly scrutinizing one of these objects, the amateur may then select his test from the following table, taking every precaution to avoid irritating his eye by unnecessary exposure to strong light. With a tolerable instrument, he may expect to *see* the whole of the objects here placed before him; but of course it will depend upon the power employed, to make out the forms and details of some of them, especially of those towards the lower part of the table. In some, cases the minuter circumstances are beyond the reach of any but the most powerful telescopes.

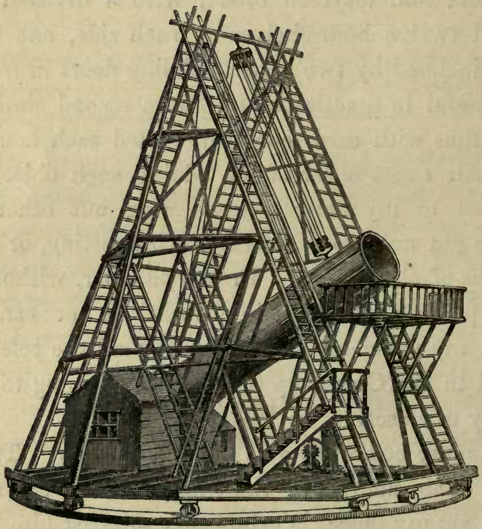
Object.	Place, 1840.					Remarks.
	Æ.			Dec.		
	h	m	s	°	′	
33 H. VI. Persei - -	2	7	58	N 56	24·4	Glorious mass of stars.
31 M. Andromedæ -	0	34	5	N 40	23·6	Large and irresolvible.
13 M. Herculis - -	16	35	58	N 36	45·8	A splendid cluster.
42 M. Orionis - -	5	27	25	S 5	30	Great irresolv. nebula.
5 M. Libræ - -	15	10	26	N 2	41·3	A mass of stars.
51 M. Canum Venat.	13	23	6	N 48	1·7	Irresolv. pair of nebulæ.
3 M. Canum. Venat. -	13	34	45	N 29	10·6	A globular cluster.
27 M. Vulpeculæ -	19	52	39	N 22	17·1	Irresolvible.
15 M. Pegasi - -	21	22	13	N 11	27·4	A globular cluster.
17 M. Clypei Sobieskii	18	11	23	S 16	15·8	Irresolvible.
2 M. Aquarii - -	21	25	10	S 1	32·1	A ball of stars.
28 M. Sagittarii -	18	14	41	S 24	56·9	Compact glob. cluster.
60 M. Virginis - -	12	35	33	N 12	26·1	A double nebula.
53 M. Comæ Berenicis	13	5	3	N 19	1·3	A globular cluster.
10 M. Ophiuchi - -	16	48	45	S 3	51·8	A rich round mass.
103 H. I. Delphini -	20	26	21	N 6	53·2	A mass of minute stars.
70 H. I. Virginis -	14	21	13	S 5	15·1	Resolv. in largest teles.
27 H. IV. Hydræ -	10	17	1	S 17	50·6	Fine planetary nebula.
57 M. Lyræ - -	18	47	37	N 32	50·1	Annular and irresolvible.
64 M. Comæ Berenicis	12	48	52	N 22	33·2	Resolv. but not resolved.
19 H. V. Andromedæ -	2	12	35	N 41	36·1	Irresolvible.

As the grasping of light is so material in viewing nebulæ, it may be mentioned, that for these examinations a reflecting telescope has great advantages over a refractor; but the amateur will, of course, adapt himself to his means. When an object is seen through the tube, the density of light on the retina must be always less than when the object is seen by the naked eye; but the quantity of light in the whole image may be much greater in the former case than in the latter: and it is certain that our power of seeing the object with distinctness, depends on the quantity of light in the whole image. Sir William Herschel uses the terms *absolute* brightness and *intrinsic* brightness, the former to distinguish the whole quantity of light in the image on the retina, and the latter to distinguish its density. He gives an instance, in an admirable paper in the first part of the *Philosophical Transactions* for 1800, where the absolute brightness was increased 1500 times in a reflecting telescope, and the intrinsic brightness was less than to the naked eye in proportion of 3 to 7. The reader who wishes to inquire into the power of penetrating into space by telescopes, should consult this elaborate essay.

The theory of telescopes properly belongs to the science of optics; and it is their effects only which are here alluded to.

Among the minor conveniences for facilitating a night's work in the observatory, I contrived a cubical box made of light thin wood, with a brass handle at the top, to carry it in and out of the dwelling. Having a large stock of skeleton-forms printed for micrometric observations, on stiff paper, I used one each night for every star that I measured; and having catalogued a selection of several dozens in each of the twenty-four hours of Æ, to be observed according as opportunities offered, I found the box above alluded to was the most convenient mode of marshalling my marching detachments of skeletons, leaving the general depôt in my library. An 8vo. page being a good working size for the forms, the box, or rather cabinet, was made 10½ inches from front to back, and fourteen broad, with a division down the middle, and twelve hour-shelves on each side, one inch above each other, inclosed by two vertical sliding doors in front. This proved so useful in practice that I had a second similar cabinet made, and thus with ease repeatedly sorted each hourly pack of forms in their exact order of Æ, adding such objects as were recommended to my notice, or weeding out others that on examination did not prove sufficiently interesting, or well suited to my means of observation. In this manner, without the eye-sore of perplexing erasures, interlineations, or cancellings, I manœuvred my paper squadrons through all the references that are detailed in the Cycle, up to the time of going to press with my fair-copy manuscript.

A word more before we quit the Observatory. Though it is hoped that I am addressing the whole host of the admirers of the science, yet my object is principally to assist him who comes under the denomination of an amateur-astronomer. By this title I mean to imply one who is acquainted with the general principles of the pursuit, and sufficiently familiar with the elementary matter, not to require an explanation of its rudiments. If to this preliminary knowledge—which by the way every gentleman ought to possess—he should superadd a running acquaintance with geometry and decimal arithmetic, he will readily make his approaches. But even without these advantages, much is to be effected by zeal and assiduity. Among my naval readers, I trust there are but very few who have not read the life of Cook; and in so doing they cannot have overlooked the influence on his fame and fortunes, which his self-acquired knowledge of geometry, trigonometry, and decimal arithmetic exercised. The history of Flinders affords another parallel case; for by a zealous application to study, he became a very eminent navigator, as well as a useful promoter of physical science. Lunar observations, the fluctuations of the barometer, and the phenomena of local magnetic-attraction, were all and severally under his persevering investigation.



Quicquid nitet notandum.

Chapter V.

NOTANDA ON THE BEDFORD CATALOGUE.

Les observations des étoiles doubles sont très-délicates, et c'est un vaste et un très-fertile champ à défricher, que nous recommandons aux soins des amateurs qui voudront se rendre utiles, et faire encore autres choses que des observations banales qu'on répète par-tout.—Baron de Zach.

Certain official duties with which I was charged, and other considerations, conspired to make me desirous of examining the heavens with better means, and greater attention, than the nature of the service I had been upon, permitted: and this inclination received its sharpest spur at the close of 1813, when I accidentally assisted Piazzi in reading some of the proof sheets of the Palermo Catalogue. No sooner, therefore, was I released from the survey of the Mediterranean Sea, which had then been under my direction, than a new task opened to my view. My first intention was, to re-examine the mean places of all those stars visible in this hemisphere, from the first to the fourth magnitudes inclusive, by a scheme of comparative operations upon the standard Greenwich points; and my working lists were made accordingly. But the high pressure just then applied to our public observatories diminished the necessity of such a task, and the acquirement of a powerful telescope in 1830, induced me to modify my plan; by observing fewer meridian objects, and entering upon a wider scrutiny of the general sidereal phenomena. The Cycle, therefore, contains the most interesting double and multiple stars, of which the primaries are in Piazzi's Catalogue—a selection of clusters and nebulæ from the works of the two Herschels—and the *élite* of Messier's list of objects, inserted in the *Connaissance des Temps* for 1784. The contents are:

Nebulæ	98	Binary stars	20
Clusters	72	Triple stars	46
Stars and *comites*	161	Quadruple stars	13
Double stars	419	Multiple stars	21

In the following Catalogue, these objects, amounting to 850, are placed in the order of right ascension, and are thus registered:

I. The designation and synonyme; with the mean apparent place, reduced from the time of observation to the common epoch of 1840; with the respective annual precession, worked by Dr. Pearson's Tables.

II. The position and distance of the double or multiple star, and the epoch of the measurements; to these are subjoined, in parentheses, weights of the comparative value of the observations, in numbers from one to ten, the first representing nearly worthlessness, and the latter perfection. These weights are derived from a mean of those which were assigned to the estimated value of the measures before the angles and micrometer heads were read off, and when they ran pretty equal, a mere arithmetical mean was taken; but where they differed greatly, the reduction was made on an algebraic form, similar to the rule for finding the centre of gravity of a number of weights. I am indebted to Sir J. Herschel for this application of the method of least squares, and by it, the mean reduction of several nights was brought to one epoch and value.

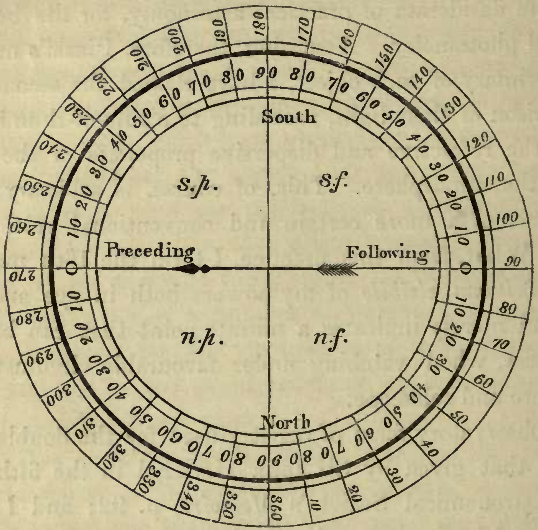
III. This epoch is given in the year and its hundredth parts; and where it is applied to the nebulæ, it signifies the mean date when the observation was made for differentiating their mean places, for many of the principal ones were under constant examination.

IV. This preceding matter, which constitutes the substantial result of my observations, is followed by a general description of the object, with the magnitudes and colours of its components; its place in the asterism to which it belongs, and the most authentic details of its history. In this portion the following siglæ occur:

A.	Argelander.	H. and S.	Herschel and South.
B.	Baily.	M.	Messier.
Br.	Brioschi.	*P.*	Piazzi.
D.	Dawes.	S.	South.
Ḩ.	Herschel I.	Σ.	Struve.
H.	Herschel II.	*T.*	Taylor.

These letters are not to be confounded with those which particularize the component stars. Some astronomers put each group in the order of A, B, C, &c., as they enter the field of view; but I have preferred considering each as a separate and distinct system, calling the brightest A, the next B, and so on. My star A is invariably registered under Piazzi's magnitude, as I know that he took much pains on the subject; and the instrument, climate at Palermo, and skill, were equal to the task. The degree of brightness is however, as already stated, among the desiderata of practical astronomy, for the best eye is but a bad photometer. Assuming, therefore, Piazzi's magnitude for the primary of each object, I have classed the secondaries by a comparison of their light, according to a rule-of-thumb estimation of the refractive and dispersive properties of the existing state of the atmosphere. This, of course, is arbitrary; but in the absence of a more certain and conventional rule, it must suffice. What, from this practice, I term the 16th magnitude, is the *minimum visibile* of my powers both in eye and instrument, and merely indicates a minute point that can be caught by glimpses, when watching under favourable circumstances of atmosphere and telescope.

The observatory form of registry used for the double stars, is precisely that given by Sir John Herschel in the fifth volume of the Astronomical Society's *Memoirs*, p. 92; and I had the advantage of having many hundreds of copies pulled for me by Mr. Moyes, at the same time with Sir John's. In speaking of *above* and *below*, *preceding* or *following*, it is always as seen in an inverting telescope. My double-wire micrometer is one of the very best which the skill and practice of Mr. Dollond was able to produce; and it is really a charming instrument to use. Sir John recommended my trying a full red screen for the lamp, and after a fair trial of this I could never tolerate green again, which so long had seemed the best softener of the illumination. In measuring distances, the alternate + and − reading of the micrometer was practised, to get rid of the zero correction. The position, or angle, made by the line joining the two stars with the direction of diurnal rotation at the meridian, was mostly taken by placing the stars between two thick parallel lines; and was always altered many degrees backwards or forwards to prevent the eye's being biassed. The readings are reckoned from the north, in the direction *n f s p n*, (*north*, *following*, *south*, *preceding*, *north*,) a method which Sir J. Herschel proposed for adoption in 1830, as well for its convenience, as "its avoidance of the continual and most annoying mistakes" of the method introduced by his father, of reading by quadrants. The following diagram shows both forms, as used in the reversed field of a telescope:



The extremely faint objects were estimated either by an annular micrometer, or a vertical bar which I had fitted to an excellent eye-piece, with a small hole in its centre. I also found Mr. Dollond's spherical crystal double-image micrometer excellent for ascertaining the position of objects too faint for illumination. The axis of motion in this sphere lies at right angles with its natural axis of formation, and when the latter is exactly parallel with the direction of the telescope, it exhibits but one image. In proportion, however, as the sphere is turned, by the milled head of the index at the side, the double image separates; and as soon as the *four* images which will be made by a double star are brought to appear as three in a line, the divided arc shows the angular position.

Although my instruments were perhaps hardly competent independently to fix the places of fundamental stars, they were quite equal to the comparative routine I had planned; for the mean apparent places of the Greenwich stars being rigorously determined, those of the objects here selected were rather a task of easy diligence, than a tax upon either the observer or the instrument. The amateur may require a word here in illustration. In national observatories, astronomers have agreed to assume as their first hour-circle, that which passes through the vernal equinoctial point, that is, the portion of the zodiacal sign which forms the *back ground* to the noon-tide sun at the mean equinox in March; therefore, the solar theory necessarily becomes involved in the determination of right ascensions, and a train of complicated corrections is the consequence. But the declination is independent of other observations, and is derived from direct measurement of the meridian distance between the object and the equator, requiring only the errors of refraction and nutation at the time of observation, to be attended to; the effect of aberration being nearly eliminated in the process of the necessary observations. Now as my plan did not require the *finality* and scrupulousness of standard operations, my transit instrument was adjusted to a near meridian-mark, and the circle rendered amenable to its collimators; while all the objects were connected with the dominant Greenwich points. The observations thus made were reduced and brought to a common epoch, after the method pointed out by the able M. Bessel; but as the conditions of my Catalogue did not demand the ultimate degree of precision which an absolute series requires, I found it advantageous to mix a graphic with the numerical process in many of the reductions*. Latterly, however, I received so much assistance from the members of my own family, in this monotonous labour, that I had little to do in the meridian-room, beyond looking to the several adjustments of the instruments.

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* This was by the use of the *squared* paper which Sir John Herschel so much approves of, and which I had long been in the habit of using, before I sent him a supply. The sheets are large, and covered with two sets of equidistant lines, crossing each other at right angles, with every tenth line of each set drawn darker than the rest; forming a set of squares and their subdivisions. These can be numbered or named on the margins, according to the scale required, and the nature of the process.

In the expression of the Catalogue I have preferred the registry of declinations to that of polar distances, on the ground of their being more convenient to amateurs, as the co-ordinate of most of their references; and, at all events, the terms are readily convertible. Polar distances are approved of, on account of their being all of one denomination, so that the letters or signs of N and S are avoided; but still, under the co-efficients now extant, declinations are more convenient for reductions, and also for the computed annual variations; and they are moreover used in most of the rules and formulæ for the discussion of observations. The proper motions of many stars are introduced, from the best sources*, as a most important element in investigating the sidereal laws: it is true, as before alluded to, that many of these may be only apparent, from imperfect registers, and will therefore disappear before the next absolute series of meridional observations; but those which remain, under a *proved* march, will become of paramount importance in future reasonings. To several of the stars I have marked the angle and distance of an eligible companion, for the purpose of watching the motion of the larger component with an expected heliometer: as this was but a preparation, they are only registered on the lowest weight. It is proper to add, that I seldom observed but on the finest nights; and that my objects, with rare exceptions, were limited to 30° of south declination, which, from my observatory, was well clear of vaporous addenda to the refraction. In the equatorial room, all objects south of the ecliptic were taken as near the meridian as circumstances admitted, and they were seldom observed beyond 45^m on either side. From the ecliptic to 20° of north declination, they were allowed about an hour and a half; and between that and the pole the examinations took place as time and opportunity offered.

Such are the corks by which I have attempted to float some of the weighty gold of Urania into the tideway; and as my Cycle is itself buoyed up by the Palermo Catalogue, I ought to

* I must here mention my deep obligation to the late Mr. F. Baily, who supplied me with many proper motions from the MSS. of his great Catalogue of Stars for 1850. This catalogue, it is hoped, will shortly appear.

introduce that admirable work to the general reader. In the year 1803, P. Piazzi published a folio volume, at Palermo, containing the mean apparent places of 6748 stars, as resulting from his own observations from the year 1792 to 1802; and it was esteemed the most complete and accurate, being derived from the greatest number of observations, of all the astronomical catalogues then in being. He had, however, relied upon the positions of the thirty-six Greenwich stars as fixed points of comparison; these were afterwards found to be too small in Æ by about five seconds, and consequently all the objects in Piazzi's lists, were affected by the same error. He also saw good reason to adopt a precession of the equinoxes somewhat different; and, notwithstanding all his care, more errors than he supposed, both of calculation and of the press, had crept in. On these accounts, weighty as was the task, he resolved to ascertain the right ascensions of a hundred and twenty principal stars in his own observatory, by a direct comparison with the sun, after the method first put into practice by Flamsteed, as a basis; to confirm all his former observations by new ones; to re-compute all their places over again, with more correct elements; and, as he says, "Verbo, si per tempus liceret, totum opus emendare, reficere, reformare." The Herculean task, thus opened, was so perseveringly followed up, that it was completed in 1813. The mean places of the stars were referred to Procyon and Altair; and these were compared immediately with the sun. He used refractions deduced by himself, from observations of circumpolar stars in different parts of their diurnal circles; and altogether it may be pronounced the greatest work of its class undertaken by any modern astronomer.

The new Catalogue, which was published in the succeeding year, is, strictly speaking, independent of others; and contains the places of no fewer than 7646 stars, derived from nearly 150,000 observations, made with the celebrated altitude-and-azimuth-circle at Palermo between 1792 and 1813, the reduction of which required 30,000,000 figures. Each star, as may be seen in the appropriate Catalogue column, was observed from five or six to ten or twenty times, or more; while the Greenwich stars were thus examined:

	In Æ.	In Dec.		In Æ.	In Dec.
Algenib - -	130 times.	51 times.	Zavijava - -	100 times.	80 times.
Schedir - -	52	20	Spica Virginis -	170	86
Polaris - - -	36	12	Arcturus - -	190	90
Hamal - -	74	32	Kiffa Australis -	70	30
Menkab - -	68	34	Gemma - -	110	55
Aldebaran - -	120	57	Unukalhay - -	115	66
Capella - -	150	43	Antares - -	185	79
Rigel - -	165	57	Ras Algeti - -	104	62
Nath - - -	125	44	Rasalague - -	124	43
Alnilam - -	94	16	Wega - - -	268	127
Betelgeuze - -	164	51	Tarazed - -	243	33
Sirius - -	240	70	Altair - - -	⊙	51
Castor - - -	229	34	Alshain - -	210	41
Procyon - -	⊙	69	Giedi Secun. - -	184	56
Pollux - - -	250	35	Deneb - -	264	52
Alphard - -	150	52	Sadalmelik - -	186	74
Regulus - -	160	41	Fomalhaut -	184	74
Dubhe - -	124	14	Markab - -	162	55
Denebola - -	150	71	Sirrah - -	137	52

There are numerous instances in my Cycle, where the results of Piazzi's instrument are severely tested by the micrometer, and found to be in admirable correspondence; so much so, as to place the Palermo-volume in the light of an extensive standard catalogue of stars. Nor can I cite this great work, without paying a tribute of respect to its amiable author.

Guiseppe Piazzi was born at Ponte, in the Valteline, on the 16th of July, 1746. Owing to a strong predilection, he became a member of the monastic order of the Theatines, or, as they styled themselves, Regular Clerks, a fraternity much respected. In this society he was soon eminent for intellectual acquirements, and rose to distinction as a professor of mathematics and natural philosophy at Genoa, Malta, and Rome. From too free an expression upon certain theological points, he incurred much ill-will and a prospect of persecution: he therefore, at about the age of forty, resolved to devote himself solely to astronomy; and in consequence, about the year 1785, he obtained permission from Prince Caramanico, the enlightened viceroy of Sicily, to establish an observatory at Palermo. The prince also promoted his views, by enabling him to visit France and England to establish a correspondence, and procure instruments. On this mission he became personally intimate with Bailly, Maskelyne, Herschel, Méchain, Lalande, Legendre, Wollaston, and other great men of London and Paris; and in 1820, the Marquis

Laplace and M. Delambre, to whom he had given me letters of introduction, assured me of their lively recollection of his intelligence and amiability. In England he was remarkable for the attention with which he devoted himself to the objects of his visit; and his first astronomical production was a paper in the *Philosophical Transactions* on the solar eclipse of the 3rd of June, 1788. Piazzi's full conception of his future task was quickly shown, for being resolved to avoid the complicated errors of large quadrants, he engaged Ramsden, the best artist of the day, to construct a reversible altitude and azimuth instrument for him. This noble specimen of mechanical art was commenced in January, 1788, and completed in August, 1789, and is well described by Piazzi, in his work *Della Specola Astronomica, de' Regj Studj di Palermo;* and it is minutely treated by Dr. Pearson in his *Practical Astronomy*, to which the reader is referred. It may therefore suffice here to say, that the vertical circle was five feet in diameter, bearing an achromatic telescope of the first quality, and that it was mounted with every regard to fixity and elegance. Armed with this magnificent machine, he zealously entered upon his great plan, and persevered so spiritedly that he was noted as one of the most active and accurate of modern astronomers. On the new year's day of 1801, he discovered the planet which, in compliment to the island and its sovereign, he named *Ceres Ferdinandea.* King Ferdinand, although more of a sportsman than an astronomer, was much gratified by the incident, and would have commemorated it by a gold medal bearing the astronomer's likeness; but Piazzi suggested that the sum to be so expended might be more usefully applied to the purchase of a large telescope. Besides this discovery of an eighth planet, which opened the way to the finding of three others, he persevered till his grand Catalogue was completed; and I cannot forget his emphatic expression on putting a final correction to the last proof-sheet, in 1814: "Now," said he, "my astronomical day is closed!"

But his Uranian services were not yet concluded; for in 1817, he was appointed Director General of the observatories of the kingdom, and was called to Naples to direct the establishment of a new one, at the Miradois, on Capo di Monte. He was very anxious to have his actual observations printed, but there were no funds for such an object. Most of the manuscripts, however, were carried off or destroyed in the revolution of 1820: in writing to me on the subject, in 1821, he said, "In a short time I shall set out for Palermo; and if, on my arrival there, I shall be able to recover, as I flatter myself I shall, the papers that were stolen from my apartments at the sacking of that city by the Vandals, in July of last year, it may be in my power to send you some additional stars." The hope was never realized. Full of years and honours, Piazzi continued to live at Naples, universally respected and beloved; and excepting a complaint in his eyes, which he attributed to too free a use of bright lamp-illumination for his circle, his health was excellent. But about the middle of June, 1826, his strength began to fail, and he shortly afterwards contracted a severe cold in riding over the Mergellina for air and exercise. He thenceforward was greatly incommoded and oppressed, till Saturday, the 22nd of July, when my friend the present General Visconti called in, and found the venerable philosopher in a sinking state. This was at 2 P.M., and though Piazzi complained that he had never felt so ill before, yet he rallied considerably during the General's stay with him, and among other things desired him, when he wrote to England, to make his especial remembrances to myself and family. Soon after Visconti quitted the room, Piazzi became uneasy, and anxious of being shifted from place to place; and then, feeling that he had not long to live, desired to take the Sacrament. Extreme weakness succeeded, and at 4 P.M. he placidly expired. The funeral ceremonies were alike honourable to the feelings of the Théatins, the Academy of Sciences, the Nobility, and the Gentry of Naples. He bequeathed his library and instruments to the Palermo Observatory, with a liberal annuity in perpetuity, to be appropriated in succession to the education and maintenance of young men who evince a marked partiality for astronomical science.

To return. Sidereal catalogues have hitherto been confined to three forms; in the first and most ancient, the stars are classed according to their respective constellations, as in Ptolemy, Ulugh Beigh, Tycho Brahé, and Hevelius; in the second, they follow each other in one continued series of time or space, as in La Caille, Mayer, De Zach, and Piazzi; in the third, the stars are disposed in classes, according to their zones, or degrees of polar distance, as in those of the Rev. F. Wollaston and M. Bessel. The present Cycle is arranged according to the second of these methods, that is, in order of right ascension; and it will be seen that, besides the mean apparent places of the objects, I have been precise in noting the part of the asterism to which they severally belong*. My inducement to this is, that with all its manifold defects, the system of configurations is still the best method of directing the numerous contemplators of the heavens, who are unprovided with fixed instruments. Though this division of the celestial space be entirely fanciful, yet it is undeniably of great advantage to the out-door observer, in discriminating and describing the position of particular stars, planets, and comets; it also maintains the correspondence and uniformity between the old astronomy and the new; and moreover, the ancients having looked to the rising and setting of certain constellations for their times of ploughing, sowing, sailing, and ailing, a general knowledge of the scheme is necessary for understanding their poets, historians, physicians, and writers *de Re Rustica*. As it appeared impracticable to give a particular name to every visible star, it became necessary to adopt a more general method of distinguishing them†. When observations had been made under mythic influence, and perhaps for astrological ends, this elementary step in astronomy was accomplished by portioning out the skies into imaginary figures of men, monsters, birds, fishes, and other representations of obvious compass; after which the situation of a star could be got at by mentioning its place in the constellation, as the bull's eye, the dog's nose,

* In this department I have named many things for identity, which would, of course, be superfluous, were every one provided with an equatorial instrument: and if the *memorial verses* are found deficient of Attic salt, they may lay claim to being brackish. The respective directions of the stars, will best apply when the group is on or near the meridian.

† Virgil assures us that a seaman first named the stars, of course in the northern hemisphere. So the able mariner Peter Theodore, first formed the southern stars into constellations; and Andrea Corsalis, another sailor, first published them in 1516.

the lion's heart, the lion's tail, the whale's back, &c. This impression struck old Thomas Hood:

Scholar. Why were the stars brought into constellations ?
Master. For instruction sake: things cannot be taught without names.

And the philosophic *tetrandian monogynian* bard:

So erst, ere rose the science to record
In lettered syllables the volant word;
Whence chemic arts, disclosed in pictured lines
Lived to mankind by hieroglyphic signs;
And clust'ring stars, pourtrayed on mimic spheres,
Assumed the form of lions, bulls, and bears.

But notwithstanding the rule pursued in the Cycle, I cannot be indifferent to the manifold defects in the stellar arrangements, which cry aloud for amendment. The taste was bad enough even for those ages when nothing better could reasonably be expected; but of late the rage for innovation has made "confusion worse confounded," and in fabricating new constellations, puerility and meanness aided blind zeal in ransacking the heavens for *amorphotæ*, or unformed stars, wherewith to wheedle accidental rulers of the hour, by exalting them and a heterogeneous assemblage of modern implements, among the heroes and classical symbols of remote ages. "Que pensera, par exemple," asks Baron de Zach, "la postérité de notre siècle et de nos connaissances astronomiques, si dans quelques milliers d'années, elle ne trouvera qu'un de nos planisphères, sur lequel elle verra un centaure décocher sa flèche contre un télescope en donnant des ruades à un microscope? Quel sera son étonnement, de voir une boussole, au coch, et un octant de Hadley prêts à être embarqués sur le navire des Argonautes? Que dira-t-on de ce ballon aréostatique foulé aux pieds du capricorne, moitié chèvre, moitié poisson, et de cette presse d'imprimeur, qui pour se défendre des persécutions qu'elle éprouve, s'est refugiée sous le ventre d'une licorne?" The sense of the day has clapped a stopper on this practice; but the encumbered state of the sidereal catalogues calls for a removal of the confusion. This seems partly practicable by returning to the old forty-eight asterisms, with a couple of those of Hevelius, to make up the half a hundred; and by clipping, if possible, the long contortions of those hairy-headed snakes of a portion of their time and space:

Where with vast convolution Draco holds
Th' ecliptic axis in his scaly folds,
O'er half the skies, his neck enormous rears,
And with immense meanders parts the Bears;
Onward, the kindred Bears with footstep rude
Dance round the pole, pursuing and pursued.

But the recent consecrations of flattery, as *Scutum Sobieskii*, *Honores Frederici*, *Taurus Poniatowski*, *Cor Caroli*, *Robur Caroli*, *Sceptrum Brandenburgicum*, *Harpa Georgii*, and the like, together with every political, national, and worldly-interested allusion, should be at once swept away. So also should be treated the *Sextant*, the *Printing press*, the *Painter's easel*, the *Sculptor's apparatus*, the *Mariner's compass*, the *Log and line*, and other unnatural intrusions into the starry heavens, which, with all the pretensions of the moderns, are just as inapplicable as the grotesque chimeras of the ancients. Indeed, "it is to mythology," says Sir John Herschel, "and to classic antiquity that I should be disposed to retreat, as to a neutral ground, on which to escape from vexatious and interminable discussions on this head." The view is correct: those who would sweep away the constellations altogether as incongruous absurdities, or wicked pagan allusions, seem rather reckless about the consequences of such a measure on astronomical history, chronology, and extra-observatorial practice. Something like a feeler has been put forth; but those globes and maps which contain the stars in boundaries only, will assuredly be less frequently consulted by the million, than those adorned with the usual delineations. Harding's grand Atlas, which contains 12,000 stars on thirty very large sheets, would, but for not having a figure drawn, probably supersede all others.

An attempt was made by the Berlin Academy in 1825, in which it was proposed that twenty-four volunteer observers should each take an hour of Æ, and fill in upon Lalande's *Histoire Céleste*, and Bessel's Zones, all the stars that could be seen by one of Fraunhofer's telescopes of thirty-four lines aperture. Some of these charts I have received, and could not but be struck with Professor De Morgan's description: "The stars have no names, nor any other method of identification, except their place in the map, which looks like a spoiled skeleton of a map plentifully spirted with small drops of ink." They form, however, a strong reserve of points of reference for the route of a comet or a planetary body which may pass by them. The Rev. Francis Wollaston had proposed such a step thirty-six years before, in the seventy-fourth volume of the *Philosophical Transactions*, as a means of detecting any alterations which may happen among the *fixed* stars. In this business, every astronomer was invited to take a part, and to examine a certain number of zones, each one degree in breadth, with a telescope of a large field, mounted on a polar axis, and furnished with a system of wires. On the 13th of February, 1829, I had the honour of receiving, as proxy, the gold medal awarded to M. Bessel, by the Astronomical Society, for those zones, the importance of which was most eloquently detailed by Sir John Herschel. See the Society's *Memoirs*, Vol. IV., p. 217.

To the astronomer who is furnished with his clock and transit, ephemeris, and catalogue, and consequent easy finding of any celestial object, the figures of the constellations are of no import at all; but to the numbers who desire an eye-familiarity with the heavens, they become of consideration as a help to memory, and the simple retainers of much knowledge in an evident and practical shape. It is also most desirable, in looking to the beacons of the ancients, to preserve the history of long periods in their proper form; as in Ptolemy, whose work is a thesaurus of the conclusions which his predecessors had arrived at, where each star is precisely described by its position in the constellation to which it pertains, thus *Polaris* is designated "the star at the extremity of the Little Bear's tail," *Regulus*, "the heart of the Lion," *Castor*, "the head of the preceding Twin," &c. So also in what may comparatively be called our own times, the components of each asterism continued to be described, and the places of planets or the paths of comets estimated. Thus Oughtred writes to Greatorex, in December, 1652, of a *stella crinita non caudata*, that it was to the westward of the star under the foot of Orion: "Upon Saturday, at eleven at night, it was ascended near the shield of Orion, almost as a right line through both the shoulders, so that the comet and they were about an equal distance asunder; then it went upward through the nose of the Bull, till upon Tuesday night it was close, but a very small deale to the westward, to the lowest star of the Pleiades. Upon Wednesday night it was become almost as high as the foote of Perseus, and upon Thursday night was seen above the wing of that foote of Perseus." Nor was this the rule in *gazing* only, for the early catalogues kept up the method transmitted by the ancients. For example, the meridian altitudes observed by Tycho Brahé on the 23rd of November, are registered in this form:

Inferioris in pectore Pegasi - -	55° 30⅓′
Lucida in pectore Pegasi - - -	56 33⅓
Scheat Pegasi in meridian - - -	59 57
Prima alæ Pegasi - - - -	47 5½
Caput Andromedæ - - -	60 55¾
Extrema alæ Pegasi - - - -	46 58½

Even after the lettering of stars by Bayer, the practice of showing their places in the constellations was continued, as an extract from Flamsteed's register will testify:

A. C. 1677.			In constellatione Orionis.		Distantiæ.		
Meuse, Die. *Styl. Vet.*	Temp. App. H.	M.			°	′	″
⊙ Sept. 9	16	53	*Procyon et* Pes lucidus -	β	38	35	30
vel ☽ *mane*		56	———— -	κ	31	37	18
	17	01	Ultima Cinguli -	ζ	30	32	21
		04	Media - -	ε	31	28	45
		07	Præcedens - -	δ	32	19	55
		11	Humerus præcedens	γ	33	26	12
		15	Humerus sequens	α	26	00	42

A sample of Halley's diary brings the practice still later:

1732. ♂ 22 Feb[ry].

	°	′	″	h	m	s		° ′ ″	°	′	″
℞ limb ☾ -	87	19	45	22	58	50	Solis limbus præcedens centro æstimato -	61 8 4 -	57	40	15
T. Eq. -	6	58	21	23	1	00	Limbus sequens.				
Anom. - 8	4	34	11	5	19	41	Cornu Tauri Aust. - - -		30	30	50
⊙ ♓ -	14	30	50	5	25	4	✻ occultata 21ae - - - -		28	25	10
				5	45	51	Geminorum propus.				
				5	47	21	Lunæ limbus, centro æstimato	308 12½.	28	38	20
				5	56	45	Pes Castoris η - - - -		28	55	00
				6	4	46½	Calx Castoris, p. 1 - - -		28	50	45
				7	10	36½	Collum Canis minoris β.				
				7	23	16½	Procyon.				

On the whole, therefore, it may be repeated, that the constellation-system must be continued; but its aid, as an artificial memory, will be greatly increased by judicious simplification. The boundaries of each asterism should be indelibly fixed, so that Aries should no longer have a horn in Pisces, and a leg in Cetus, nor 13 Argus pass through the Unicorn's flank into the Little Dog; 51 Camelopardi might be extracted from the eye of Auriga; the ribs of Aquarius released from 46 Capricorni, and numerous other vagaries of the kind corrected. Then again there is such a jumble of Greek, Roman, and Italian letters, that the profusion is quite confusing. Indeed, as Mr. Baily remarks, La Caille has, in the constellation Argo alone, besides the Greek alphabet, used the whole of our alphabet, both in *small* and *capital* letters, each of them more than three times; in fact, he has used nearly 180 letters in that constellation alone. "Thus," continues Mr. Baily, "we have three stars marked *a*, and seven marked A; six marked *d*, and five marked D; and so on with several others." This intermixture makes it often difficult to distinguish between *a* and alpha, *o* and omicron; and there occur various minglings of Greek, Latin, Arabian, and English words,—the *vox hybrida* of Quintilian,—to add to the general disorder. In the excellent Maps edited by Sir John Lubbock, and published by the Society for the Diffusion of Useful Knowledge, much of this is reformed, and the heavens restored to what Ptolemy described, only the names and boundaries of the most important recent constellations being given. Under κ Cephei, Vol. II., p. 476, is shown one of the many cases in which I regret that these Maps, with Mr. Baily's proposed boundary emendations, have not been received and recognised as the standard authority. Meantime M. Argelander has stepped into the field, with a celestial atlas intituled *Uranometria Nova*, in which the magnitudes of the stars have undergone a strict revision. But for correctness of delineation, his maps are not comparable with those of the Society, as may be seen on examining the legs of Cepheus under Ptolemy's description, the urn instead of a cup for Crater, the head of Cetus, &c. Upon other points of this question, it is well to consider what Flamsteed has said:

From Ptolemy's days up to our time, the names of the asterisms which he uses have always been employed by clever and learned men of all nations: even the Arabs always made use of his forms and names of the constellations. The ancient Latin catalogues of the fixed stars employ the same names; in the catalogue of Copernicus (the first which we have is elegantly written in Latin) and in that of Tycho the same are used, as also in the catalogues compiled in the German, Italian, Spanish, Lusitanian, French, and English languages: and in all the observations, as well of the ancients as of the moderns, the *Ptolemaic figures* of the asterisms and the *Ptolemaic names* of the stars have been employed; and it thence becomes necessary for us to acquiesce in, and adhere to the same, lest by changing the expressions in use, and the forms of the constellations generally received, we should render the observations of the ancients deficient in clearness.

Tycho Brahé died in the year 1601; and two years after his death Bayer published his *Uranometria*, in which he gives maps of all the asterisms; his figures are tolerable, and the stars are pretty well engraved according to their places in Tycho's catalogue; and numerous other small stars not found in that catalogue are added, but only, it appears, from mere inspection, by comparing them, namely, with the fixed stars inserted in his maps from Tycho's catalogue, the nomenclature of which is the same. But since he has drawn all his *human* forms (excepting Boötes, Andromeda, and Virgo,) with their backs turned towards us, those stars which all preceding astronomers placed in the right shoulders, sides, hands, legs, or feet, in his figures fall on the left or opposite side: whoever then by aid of these forms, applies himself to examine the observations of the ancients, or the catalogues of fixed stars printed or published in any language, will find himself brought into straights, if he were not pre-advised of the matter.

The cause of Bayer's error is probably as follows: that since in Ptolemy's catalogues the words *ἐν νωτῳ ἐνμεταφρένῳ* often occurred to him, and consulting the Greek lexicons to find their meaning, he always saw that *νωτος* was translated by *dorsum*, the back, and *μεταφρενον*, tergum, or *interscapilium*, the back of the shoulders, or space between the shoulder-blades, and therefore concluded it meant either the latter, or the part of the back between the loins and shoulder-blades: wherever therefore either of these words occurred to him in the description of any asterism, with the exception of Virgo and Andromeda, he drew it with the back turned towards us. Whence he places on the *left hand* all those stars which Ptolemy and the other ancient astronomers, as well as all up to his own time, placed in the right shoulders, hands, sides, legs, and feet of their figures, and by this means he renders the most ancient observations false or absurd.

To remedy this fault, when he mentions any remarkable fixed star to be seen in the right shoulder, or right shin, he adds, *alias* in the left. And this seems to make some excuse for his error; but as it rarely occurs, it will perplex those who make use of his maps, and render them useless.

But if Bayer had only drawn his map of Sagittarius, or any other of the human figures in such manner that the stars marked in Ptolemy's catalogue as being in the right shoulders, hands, sides, feet, &c., should have stood on the same side in his own figures; then he would have seen that all and several of them ought to turn their face towards us; and thence he would have learned that the word νωτος in Ptolemy's Greek signifies *crates corporis*, the frame of the body or the ribs, and *μεταφρενον*, the space between the shoulders, not only at the back of the body, but also in front, or the space between the fore part of the body and the upper part of the breast; and thus there would have been no discrepancy between his figures and the descriptions of the ancients. For I am persuaded that not only Ptolemy, but even Homer himself, used these words in a more extended sense than is generally admitted into the lexicons*.

Flamsteed thus adds to the reproof which Bayer had received from Schickard, Bartschius, and Hevelius; yet Montucla thinks he may only have erred, from overlooking the inversion which is made by engraving the figures on copper.

But the most able treatment of the matter under discussion, is by my friend Professor De Morgan, in the lucid explanation of the *Gnomonic Projection*, which he wrote to illustrate the Celestial Maps published by the Society for the Diffusion of Useful Knowledge. From this excellent treatise, I am tempted to add the following extract, with the author's consent, as the best key to the question which can be found:

From the actual survey of the heavens, the stars were divided into groups which were fancifully likened to figures of men and animals, before any globes or maps were constructed. Thus the astronomer had certain fixed notions of the positions which the constellations occupied relatively to one another, and to himself, that is, to the centre of the apparent celestial sphere. The stars were distinguished from one another by the positions they occupied upon the body of the constellation to which they belonged; one was in the right arm, another in the left, a third in the leg, and so on. The formation of artificial globes involved a difficulty, as the spectator of the globe was not in the same position relatively to the pictured constellations, as that in which he stood to the apparent celestial sphere, being on the outside and not at the centre. If we conceive an artist, painting the globe in the interior, according to his own notions of the relative positions of the constellations, another person viewing the figures from the exterior, through the glass, would see them all reversed; that is, the hand which the interior observer would call the *right* is the *left* in the opinion of the exterior observer. The same effect is produced by looking through a picture from the back. Most persons must be aware of the manner in which it is necessary to arrange the letters in the printer's composing-stick

* In the *Clavis Homerica* of Patrick, 1771; of Parkins, 1647; and another, 1727; *μεταφρενον* is always said to be the back, or space behind the loins and the shoulder-blades, signifying literally "behind the midriff or heart region." The word *νωτος* is also given as "the back" in all three, for they copy one another word for word. (Flamsteed.)

in order that the impression may be direct, or from left to right. If the types could be arranged as follows:

Maps of the Stars;

the impression taken from them would be the following:

Maps of the Stars;

and vice versâ; so that the types set up in the second way exhibit an impression like the first. The reason why the printer's types cannot be set up in the first position, is that they cannot be completely reversed, since in that case they would only present the unlettered end of the metal to the paper, unless stamped at both ends. The partial reversal that the common types would bear, would simply amount to writing the sentence backwards, and upside down; as follows:

Maps of the Stars;

This is the appearance presented, not to a spectator outside the globe, but to one who stands upside down inside the globe.

If the first arrangement were made on thin paper, the second would appear on looking at it through the paper; and the same alteration takes place when that which has been written or drawn on the inside of a transparent globe, is looked at from the outside. A spectator on the outside sees the figures as he ought to draw them on wood or copper, in order that the impression may represent the appearances presented to a spectator on the inside.

Let us now suppose that the artist in the interior, instead of drawing figures upon the globe, forms thin and flexible statues, in which the front and back, or the two sides of the figure as placed sideways, are perfectly formed, the thickness only being diminished. These he fastens on the interior of the globe, with the fronts towards himself. Hence, where he sees the front of a figure, the spectator on the outside will see the back; where one sees the right hand side, the other will see the left; both will see the same outline, but differently filled up in the two cases, as in the following picture, which exhibits the appearance of a figure from the interior and exterior.

There will now be no confusion between the right hand and the left, since both will fix upon the same hand when asked for either; but those stars which to the spectator in the interior appear in the breast of a figure, will to a spectator at the outside appear in the back.

A word more upon this head. Among other configurations, those forming the *Circulus obliquus* demand a special mention, in addition to what will be found under each sign in the CYCLE. Our elder navigators termed the ecliptic the *Thwart Circle*, the meridian the *Noon-steede circle*, the equinoctial the *Girdle of the Sky*, and the zodiac was the *Bestiary* and *Our Ladye's waye*. This is usually assigned to the Greeks, because Aratus stamps one Astræus as the inventor; but the tale has no more claim to credit, than that the same Titan married Aurora and became the father of Boreas. It will therefore be necessary to go to earlier sources.

The palpable motions of the sun and the moon, must have soon pointed out the divisions of both the solar and lunar zodiacs; the twelve signs being shown by the lunations in the course of the sun in the ecliptic; while the division of twenty-eight parts, used by all the oriental nations, as evidently denotes the space daily described by the moon's proper motion. Laplace was satisfied that the Chinese made astronomical observations 1100 years B.C.; and we find that both they and the Japanese had a zodiac consisting of animals, as *zodiacs* needs must, among which they placed a tiger, a peacock, a cat, an alligator, a duck, an ape, a hog, a rat, and what not. Animals also formed the *Via Solis* of the Kirghis, the Mongols, the Persians, the Mandshus, and the ancient Turks; and the Spanish monks in the army of Cortes, found that the Mexicans had a zodiac, with strange creatures in the departments. Such a striking similitude is assuredly indicative of a common origin, since the coincidences are too exact, in most instances, to be the effect of chance; but where this origin is to be fixed, has been the subject of interminable discussions, and learning, ignorance, sagacity, and prejudice have long been in battle array against each other. Diodorus Siculus considers it to be Babylonian, but Bishop Warburton, somewhat dogmatically, tells us, "Brute worship gave rise to the Egyptian asterisms, prior to the time of Moses."

These points, however, are not sufficiently soaring for the Orientals. Sir W. Jones says, "I engage to support an opinion, which the learned and industrious M. Montucla seems to treat with extreme contempt, that the Indian division of the zodiac was not borrowed from the Greeks or Arabs, but, having been known in this country from time immemorial, and being the same in part with that used by other nations of the old Hindù race, was probably invented by the first progenitors of that race before their dispersion." He continues, "Now I undertake to prove, that the Indian zodiac was not borrowed mediately or directly from the Arabs or Greeks; and, since our solar division of it in India is the same in substance with that used in Greece, we may reasonably conclude, that both Greeks and Hindùs received it from an older nation, who first gave names to the luminaries of heaven, and from whom both Greeks and Hindùs, as their similarity in language and religion fully evinces, had a common descent." The same subject was also inquired into by the late accomplished Mr. Colebrooke, who was, perhaps, more competent to the task than any of his cotemporaries: "I apprehend," says this gentleman, that "it must have been the Arabs who adopted, with slight variations, a division of the zodiac familiar to the Hindùs. This, at least, seems to be more probable than the supposition, that the Indians received their system from the Arabians; we know that the Hindùs have preserved the memory of a former situation of the colures, compared to constellations, which mark divisions of the zodiac in their astronomy; but no similar traces remain of the use of the lunar mansions (*nacshatra*) as divisions of the zodiac, among the Arabs, in so very remote times." In the work ascribed to Zoroaster, the *Zend-Avestà*, it is asserted that the ancient Persians divided the zodiac into the twelve constellations, with names corresponding to those at present used; and they also had a division corresponding to the twenty-eight houses of the moon. But through all the inquiries, the Hindù zodiac claims the highest antiquity, assuming that of Egypt—of which we shall presently speak—to have been borrowed therefrom: and it is curious to find that the days of the week were named, as with us, after the celestial bodies of the solar system. A list of the planets, and the days over which they respectively preside, will illustrate the coincidence; and though the denominations bear an astrological aspect, it would seem that the use of weeks in the East, must be a relic of the tradition of the creation.

Names of the Planets.

Sanskrit.	English.	French.	Italian.
Súrya,	Sun,	Soleil,	Sole.
Sóma,	Moon,	Lune,	Luna.
Mangala,	Mars (*Tuisco*),	Mars,	Marte.
Buddha,	Mercury (*Woden*),	Mercure,	Mercurio.
Vrǐhaspati,	Jupiter (*Thor*),	Jupiter,	Giove.
Sukra,	Venus (*Freya*),	Venus,	Venere.
Sání,	Saturn (*Seater*),	Saturne,	Saturno.

Names of the Week-days.

Aditvár,	Sunday,	Dimanche,	Domenica.
Sómavár,	Monday,	Lundi,	Lunedi.
Mangalavár,	Tuesday,	Mardi,	Martedi.
Buddhavár,	Wednesday,	Mercredi,	Mercoledi.
Vrǐhaspativár,	Thursday,	Jeudi,	Giovedi.
Sukravár,	Friday,	Vendredi,	Venerdi.
Sánívár,	Saturday,	Samedi,	Sabbato.

In the work of Autolycus on the *Risings and Settings* of the stars, as well as in the *Phænomena* of Euclid, the Signs of the Zodiac are mentioned, and the parts into which that zone of the heavens was divided, are called dodecatemories, or twelfths. Macrobius, in his commentary on the *Dream of Scipio*, and Sextus Empiricus in his *Adversus Mathematicos*, have recorded the ingenious method which was used by the Chaldeans in this zodiacal determination. It was by means of a clepsydra, made of two open brass vessels, the one pierced at the bottom, and the other without any orifice below. They then measured the quantity of water which flowed from the upper vessel, in the interval between two successive risings of some one remarkable star, situated in or near the ecliptic; then at the rising of the same star on any subsequent night, they unclosed the orifice, and the zodiacal star which appeared in the horizon when one-twelfth of the water had run off, indicated that one sign had risen; and this operation being repeated, at the proper periods, the particular stars which terminate each of the twelve divisions were found. But the Chaldeans seem to have been unaware of the fact, that equal depths are not left dry in equal times.

As it is evident, from the *Astronomicon* of Manilius, and other sources, that the Romans adopted the Hellenic zodiac, there occurs a difficulty respecting Libra and Scorpio's having been included in one sign by the Greeks; and the reader is referred to Vol. II., p. 327, for an explanation of this. The *twelve* divisions were, however, so prevalent, that astronomers received them as an article of faith, though various squeamish philosophists objected to the heathen tendency of the details. Many amendments were consequently proposed; ages before Julius Schiller had rebaptized the planets, and reformed the constellations by assigning Scriptural names to them, our Venerable Bede had already enlisted the twelve apostles, in order to displace the profane signs of the zodiac. Sir W. Drummond wished to show that the Hebrew Scriptures are merely a collection of astronomical emblems, and thereby make a zodiacal lodgment for a dozen patriarchs; but his theory was demolished by the Rev. G. Townsend, in a clear proof, on Drummond's own reasoning, that those signs actually represented the twelve Cæsars. Philip de Thaun, who wrote his astronomical poem *Des Créatures*, in the twelfth century, allegorizes the zodiac into religious indications with becoming piety, and divine assistance, *od le aie de Dé;* but herein his zeal and devotion are not to be compared with the fervid elucidations of his *Bestiary*. A frigid amateur may here become impatient on being thus dragged into the mists of olden lore; but there are numbers who justly perceive, that astronomy is essentially a science of antiquity. Coke's sage precept to read ancient books, and raise new corn in the old fields, cannot be better applied: "veteres interea a majoribus olim conscriptas non negligat, quia certo certius est, quod ex antiquis agris nova et læta seges oriri debeat." But this, after all, however neatly expressed, is but Coke upon Chaucer:

> For out of the olde fieldes, as men saithe,
> Cometh all this newe corn fro yere to yere;
> And out of olde bookes, in good faithe,
> Cometh all this newe science that men lere.

From the statements of Macrobius, and other sources, it may be presumed that the zodiacal divisions were named with regard to the seasons; and while the *annus vagus* was employed for religious purposes, the tropical year related exclusively to agriculture. This led M. Dupuis, who dearly loved a paradox, to an investigation of the subject, and it was in a manner connected with his ingenious theory respecting the origin of the Greek months; as he concluded that the real configurations of the asterisms, could not have been the basis of the figures, or their names, but that this representation of the heavens was a calendar at once astronomical and rural*. He therefore proceeded to *systematize* so as to produce a correspondence of the labours of husbandry with the zodiacal signs; and by passing the summer colure over Capricorn, and the vernal equinox under Libra, he *proved* that Egypt was the country where the Via Solis had been divided 15,000 years before. Proud of this important discovery, Dupuis proceeded to explain the whole theogony and theology of the ancients, and in 1794, his great work, *L'Origine de tous les Cultes*, appeared. But the basis on which he established his mythological system was by no means original. Olaus Rudbeck, in 1698, claimed scientific honours for the hyperborean regions. With a truly patriotic zeal, he makes the signs of the zodiac correspond with the Runic calendar, and they are therefore symbolical of the Swedish seasons. This he demonstrates beyond contradiction by commencing the year with Capricorn, by which all the other signs fit in, and everything becomes downright Scandinavian imagery; as for example, the VIth, or naked Twins,—when the sun comes to this sign, the water is so warm that the children may then freely bathe,—Virgo, the IXth or harvest month, is their August, "nor can any southern men, with solid reason, say that those things belong to them."

Dupuis, and his Memoirs to the Academy, and his *Cultes*, after several years of attack and defence, were sinking into oblivious repose, when the discovery of the astronomical sculptures in Egypt, by the French expedition, revived the discussion.

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* Many of the early stories present such allegory that it is rather difficult to work the kinks out of them. In comparatively recent times it is equally hard to unravel the meaning of various astrologers; and even in stricter matters, the figurative has led to confusion. Thus in the case of that "Euclid of his day," Christopher Schlüssel, surnamed Clavius, who was reported to have been killed in the streets of Rome by a bull; instead of which he died, as Baron de Zach says, *très doucement dans son lit;* and the report arose from a brother Jesuit's comparing his death, in some elegaic verses, to the sun's being obscured in Taurus, because that very year (1612) there occurred a solar eclipse in that sign!

Dupuis was delighted, for the views of M. Remi Raige, and other members of the "Commission d'Egypte," supplied him with "une preuve irrécusable d'une de ses premières hypothèses." The strictures now elicited were very interesting, and though there was rather too much warmth of argument, the strength of the respective combatants was ably displayed; notwithstanding, like other matters on which fierce wars have been waged, the conditions of the dispute remain much at a muchness. The planispheres of Denderah, Esneh, and Deïr, throw no light on the truly astronomical constellations; nor indeed ought any to be expected from the works of a people who could not tell the time within the quarter of an hour. Yet that they actually had made considerable advance in astronomy is indubitable, for the marking of zodiacal signs, and the classification of stars into constellations, as is admitted, shows their knowledge not to have been merely hypothetical.

Dr. Young, whose admirable researches in Egyptian lore formed a beacon for Champollion to steer by, assumed as a principle in determining the epoch of any monument from the astronomical symbols it may bear, that those symbols represent the state of the heavens with respect to the seasons of the year at the epoch sought. In applying this principle to the problem of the Egyptian sculptures, he arrived at the conclusion, that from 120 years till 11 B.C., Virgo must have been the leading sign of the zodiac, or the sign preceding that in which the sun was on the first day of the month *Thoth;* that Libra must have been the leading sign from the year 249 to 130 B.C., and so on in the retrograde march. On talking over some of the discussions with this distinguished scholar and philosopher, in 1828, he informed me that he was about to re-consider the relations of the case; his unexpected death quashed the intention.

Perhaps the general reader should be reminded, that the term *sign* means astronomically a constellation; but latterly it is an ideal constellation of the zodiac only, serving to mark the course of the sun in the ecliptic, while the constellation itself continues applied to its appropriate group of stars. Each sign of the zodiac extends over thirty degrees, but the astronomical sign must not be mistaken for the constellation which bears the same name; thus, for instance, the well known sign of Aries, by the gradual precession of the equinoxes, in about two thousand years, has moved to the westward from the original point of the stellar Ram, and occupies the former place of the constellation of Pisces. The distance of the signs from their respective asterisms, now amounts almost to 33°; and the tropics of Cancer and Capricorn are now really become the tropics of Gemini and Sagittarius. If, in round numbers, we assume it to be 30°, and the amount of the precession during a century to be 1° 23′ 30″, by reducing each to seconds, and dividing the one by the other, we find, that about twenty-one centuries ago, the sign of Aries must have coincided with the first point of the constellation so called; and Hipparchus has left testimony that such was the fact. The Great, or Platonic year, in which a sign makes a whole revolution round the ecliptic, is about 258 centuries, or more than 25,000 years. This computed cycle, the comparison of the Egyptian with the tropical or sidereal years, and a proper *cooking* of the *annus vagus*, constitute the key to the Denderah discussions.

It is now advisable to recapitulate a portion of the arguments already advanced; and he who is about to apply them to practice, will not have to complain of the repetition. Indeed, I hope by the method which is followed, to relieve the amateur from considerable misgivings as to the apparent complexity of motions in the heavenly bodies.

Though it may be hardly necessary, the reader is here reminded, that as the ecliptic is a great circle which cuts the equator angularly, half of its signs must be in one hemisphere and half in the other; those from the tropic of Capricorn to that of Cancer being the *ascending*, and those from the tropic of Cancer to that of Capricorn the *descending* signs. When the constellations and the signs were coincident, the nodes were at the first points of Aries and Libra; but the change just mentioned, occasioned since the days of Hipparchus by the precession of the equinoxes, may be thus exhibited:

Signs.		Hours Æ.		Constellations.		Hours Æ.	
1. N.	Aries - -	0.	I.	2. N.	Aries - -	II.	III.
2. N.	Taurus -	II.	III.	3. N.	Taurus -	IV.	V.
3. N.	Gemini -	IV.	V.	4. N.	Gemini -	VI.	VII.
4. N.	Cancer -	VI.	VII.	5. N.	Cancer -	VIII.	IX.
5. N.	Leo - -	VIII.	IX.	6. N.	Leo - -	X.	XI.
6. N.	Virgo - -	X.	XI.	7. S.	Virgo - -	XII.	XIII.
7. S.	Libra - -	XII.	XIII.	8. S.	Libra - -	XIV.	XV.
8. S.	Scorpio -	XIV.	XV.	9. S.	Scorpio -	XVI.	XVII.
9. S.	Sagittarius	XVI.	XVII.	10. S.	Sagittarius	XVIII.	XIX.
10. S.	Capricornus	XVIII.	XIX.	11. S.	Capricornus	XX.	XXI.
11. S.	Aquarius -	XX.	XXI.	12. S.	Aquarius -	XXII.	XXIII.
12. S.	Pisces - -	XXII.	XXIII.	1. N.	Pisces - -	0.	I.

Nothing can be more simple, clear, and apparently accurate, than the figures of the zodiacal signs in the beautiful large plates of the grand *Description de l'Egypte* of the French. The art of the engraver seems to be exhausted in doing justice to the elaborate drawings of MM. Jollois and Devilliers, and the effect of the burin is superb; *mais hélas!* no one will vouch for their fidelity. Still they are substantially identical with the plate in the Atlas to Mr. W. R. Hamilton's *Ægyptiaca*, one of the most valuable of the many works on the subject. The monstrous antiquity of this "maze of mysteries," has long occupied the attention of the learned and unlearned; but the views of the *Moderadoes*, in whose ranks such men as Laplace, Delambre, Young, Littrow, Visconti, Cuvier, Lalande, and Biot, were found, prevailed in the public eye; and MM. Letronne, Hamilton, Champollion, Halma, and Gau, have shown, from authentic inscriptions in the temples of Denderah and Esneh, that the first of those edifices was erected or completed in the time of Tiberius, and the latter during the reign of the Antonines. This opens another argument. It is known that under the Ptolemies and Romans, the Egyptians continued to raise temples in honour of their deities, which were consecrated and decorated as had immemorially been customary; moreover, architects observed that the temple of Denderah is built upon the foundation of one still more ancient. The high-antiquity-advocates therefore assume, that the present planispheres are copies from others of a like kind, which may be presumed to have existed on the original structures. Under this conjecture, though these sculptures determine nothing respecting the time of building the temples, yet they may still serve as indications of early science.

Visconti and Letronne insisted, that astronomy had no existence among the Egyptians until the Greek zodiac was presented to them, a paradox ably combated by Lalande and A. W. von Schlegel; and the warfare was carried on with a very different spirit from the narrow-minded conceptions of various system-mongers of the same period. To the latter we recommend a hint from Mr. Hamilton: "The interior of the pronaos or portico of the temple of Denderah," says that gentleman, "is adorned with sculptures, most of them preserving part of the paint with which they have been covered, and representing priests, offerings, and deities, as usual. Those on the ceiling are peculiarly rich and varied; they are all illustrative of the union between the astronomical and religious creeds of ancient Egypt: yet, though each separate figure is well preserved, and perfectly intelligible, we must be much more intimately acquainted with the real principles of these sciences, as they were then taught and believed, before we can interpret the signs of them."

The Egyptian planispheres, with their signs and catasterisms, were enjoying repose, when, in 1836, the *Leçons d'Astronomie professées à l'Observatoire Royal, par M. Arago*, appeared. In looking over these lectures, I was somewhat surprised to find that this distinguished philosopher considers all the discussions above alluded to, as terminated by a *late* fiat of the Egyptian Institute, and the names of the zodiacal signs are recognised as being allegories connecting celestial and terrestrial phenomena in Egypt. His express words are: "L'explication étymologique de ces diverses dénominations a donné lieu à de nombreuses discussions, auxquelles les recherches de l'Institut d'Egypte sont venues mettre fin, en faisant voir que ces noms, adoptés aujourd'hui par tous les peuples qui s'occupent d'astronomie, ont été tirés de comparaisons faites par les Egyptiens entre les phénomènes célestes et des phénomènes terrestres, purement locaux, pour la plupart, et appartenant exclusivement à une partie de leur pays. Voici un abrégé de ce beau travail qui ne peut manquer d'intéresser le lecteur." This is an exact rendering of the *beau travail;* without answering for the authenticity of the Coptic names, or the purity of the Arabic.

I. Capricorn (*Caper*) ♑.

It is the first month of summer: it extends from the 20th of June to about the 20th of July.

In Greek. Επιφι, επηφι. (Alberti, *Fabricii Menologium.*)

Coptic. *Epep.* (Lacroze, *Lexicon Ægyptiano-Latinum.*)

Arabic. *Hebbébi, hebbéb.*

Latin. The definition of these different names may be thus conceived: *Caper, dux gregis, qui cæpit, species apparens aquæ, evigilatio, motio hùc et illùc, aurora.*

The Arabic verb *hebheb*, or *habeb*, signifies *cæpit, evigilavit, experrectus fuit e somno, flavit ventus, vacillavit, hùc et illùc motus fuit, insiliit in favellam.*

Now follows the explanation of the Latin phrases which serve as equivalents to the ideas expressed by the Coptic and Arabic words.

Caper gives name to Capricorn, one of the twelve signs of the zodiac.

Dux gregis, qui cæpit. Capricorn opens and commences the year; he is the leader of the celestial animals, as on earth he is that of the flock to which he belongs.

Species apparens aquæ, commencement of the rising of the Nile, which commonly is not appreciable until ten days after the solstice.

Qui evigilavit, qui experrectus fuit è somno, designates the longest day: the sun, or the animal which represents it, is awakened, and awakes at the hour consecrated to sleep in other seasons.

Qui vascillavit, qui hùc et illùc motus fuit, the sun's hesitating motion when arrived at the solstice.

Qui flavit ventus, north winds which blow for fifteen days at this epoch. The Egyptian almanac announces their arrival.

Aurora. This proves that the Egyptian year began at the aurora of Caper, at the break of the first day of summer.

Finally, according to Herodotus, *Epiphi,* or Epephi, was probably one of the twelve astronomical gods of Egypt, for he says, l. ii., ch. 38, that oxen were sacred to this god.

II. Aquarius ♒.

Aquarius was the second month of summer, and lasted from the 20th of July to the 20th of August.

Greek. Μεσορι, Μεσσορι, Μεσωρη, (*Menalogium.*)

Coptic. *Mésoré.*

Arabic. *Mésour, misr; vas aquæ paulatim lac suum reddens.* The Arabic word *meser* is translated by *præbuit paulatim, emulsit quicquid esset in ubere.* The addition of the final *y,* which personifies *mesouri,* means *aquarium.*

Paulatim lac suum reddens, &c., perfectly suits the figure of the water-bearer in the zodiacs of Esneh and Denderah, where the vase, very slightly inclined, lets the water flow by little and little.

Emulsit quicquid in ubere. It is during this month or thereabouts, that the sources of the Nile give out their full complement of water. The Egyptians considered this fluid as sweet and nutritious as milk. The inundation increases during this month.

III. Pisces ♓.

The Fishes, third month from the 20th of August to the 30th of September.

Greek. Τωθ, *θωυθ, θωθι, φθω.*

Coptic. *Thoout.*

Arabic. *Thohout. Ambulatio piscis, incessus, reciprocatus ultrò, retrôque in se rediens.*

The Arabic verb *tona* is equivalent to *peragravit regionem, opplevit puteum.* From *hout,* a fish, comes the verb *hat circumnatavit.*

The *ambulatio,* &c., exhibits the fishes going and coming in the waters which cover the country.

Opplevit puteum, marks the inundation, covering all the low places, for it is spread over all Egypt; indeed, the festival of Isis has been fixed at the beginning of this month, because it is only then that they celebrate the feast of the Nile by opening the dykes. For this reason the month was sometimes called *fotouh, apertura per terræ superficiem fluentis aquæ,* opening of the dykes.

A passage in Sanchoniatho, preserved by Philo, says that *messori* gave birth to *thoth;* and in fact we see that it is *messori,* or the rise of the Nile, which produces *touhout,* the expanse of water over the surface of Egypt, wherein the fish disport.

IV. Aries ♈.

The Ram is the first month of Autumn; it commences on the 20th of September, and terminates on the 20th of October.

Greek. *Φαωρι, παοφι, παω.*

Coptic. *Paopi.*

Arabic. *Fofo, foafi; hædus, velox, vox quâ greges increpantur.*

The Arabic verb is rendered by *increpuit gregem dicens fafa.* The Hebrew word *fafa* signifies *obtenebrescere.*

Vox quâ greges increpantur. As the waters retire, the Ram again conducts to pasturage the flocks held captive during the inundation.

Obtenebrescere. The day diminishes more and more, as in the month commencing with the autumnal equinox.

V. Taurus ♉.

The Bull, the second month of Autumn, from the 20th of October to the 30th of November.

Greek. Αθωρ, *αθωρι* (*θωωρ, Eusebius*).

Coptic. *Athor.*

Arabic. *Thaur, athour; taurus, tauri.*

The verb *athor, aravit, submovit terram.*

They labour in Egypt only when they have finished sowing in other countries, in the month of November.

VI. Gemini ♊.

The Twins, the third month of Autumn, from the 20th of November to the 20th of December.

Greek. *Χοακ, χονακ, κοακ, κηκος.*

Coptic. *Choïak.*

Arabic. *Chouk; amore flagrantes, amatores.* In the Egyptian zodiacs, this sign is delineated as a youth and a girl: in this month the seeds heat and germinate. The Greeks imperfectly named this sign *διδυμοι.*

VII. Cancer ♋.

The Crab is the first winter month, from the 20th of December to the 20th of January.

Greek. *Τυβι.*

Coptic. *Tobi.*

The verb *teby, amovit, avertit.* The verb *teb, reversus, conversus fuit, respuit.* These roots accord well with the retrograde movement of the sun at the winter solstice.

VIII. Leo ♌.

The Lion, the second month of winter, from the 20th of January to the 20th of February.

Greek. *Μεχιρ Μεχειρ, Μεχος.*

Coptic. *Chery* or *Mechěry.*

The verb *cher, acquisivit, collegit; mecher, pars segetis,* or *mecher, protulio frondes, ramos; amcher, plantas suas extulit terrâ inflatus, turgidus fecit.*

It is in February that the earth presents its most beautiful aspect in Egypt; one part of the harvest is already begun; it is by the king of animals that they symbolize the force and magnificence of nature.

IX. Virgo ♍.

The Virgin, the third month of winter, from the 20th of February to the 20th of March.

Greek. *Φαμενωθ.*

Coptic. *Famenoth.*

Arabic. *Faminoth; Mulier fœcunda et pulchra, quæ vendit spicam, frumentum, et quod portatur inter duos digitos.*

This word is compounded of *famij,* one who sells wheat-ears, and seeds of all kinds, the ear or stalk of which can be carried between two fingers, and of *enoth,* a beautiful fruitful woman. In the Egyptian zodiacs *Famenoth,* or the fruitful woman, holds an ear of corn in her hand. What led the Greeks into the error of calling this sign *παρθενος,* is, that the Egyptian word for fecundity signifies also "endowed with beauty."

X. Libra ♎.

The Scales, the first month of spring, from the 20th of March to the 20th of April.

Greek. *Φαρμουθε.*

Coptic and Arabic. *Faramour; mensura, regula confecta temporis.*

This month answers to the vernal equinox, and to the equality of days and nights.

XI. Scorpio ♏.

The Scorpion, the second month of the spring, from the 20th of April to the 20th of May.

Greek. *Παχων.*

Coptic. *Pachous.*

Arabic. *Bachony; venenum, aculeus Scorpionis, postravit humi venenum aculeus Scorpionis.* This word is compounded of *bach, prostravit, humi stravit,* which signifies *putruit* in all the Oriental languages; *læsit, pravus fuit* or *putrido, malum, morbus,* and of *honniy, venenum, aculeus Scorpionis,* and *terror.* This characterizes the second month from the vernal equinox, when the heat brings forth venomous reptiles, and excites disease and pestilence. The root *hama* signifies also *ferbuit dies,* the days become burning.

XII. Sagittarius ♐.

The Archer, the third month of spring, from the 20th of May to the 20th of June.

Greek. *Παυνι, παωνι.*

Coptic. *Paons.*

Arabic. *Fayne* or *fenni; extremitas sæculi temporis, horæ, Faijnan, fenan, nomen equi, onager varii cursus.*

The root *fann* signifies *propellit, impulit; faijni* signifies *propulsator, impulsator.*

Extremitas. The last month of the Egyptian year.

Nomen equi: onager, the name of a quadruped, of which *propulsator* indicates the action. In the Egyptian zodiac, the figure of this animal has the body of a quadruped, and a head with two faces, one of a lion and the other that of a warrior about to discharge an arrow. He seems to drive forward the animals that precede him, and to check those that follow. All indicates that he is gaining his goal.

Such is the exposition of which there are now several editions in circulation; it seems a fac-simile of that given out by Remi Raige at the commencement of the present century, but derives its claim to this notice, from bearing the valuable stamp of M. Arago. Yet it certainly requires a fuller explanation than is given, since the act of connecting the summer solstice with Capricorn, the winter one with Cancer, the vernal equinox with Libra, and the autumnal one with Aries, is in opposition to the generally received opinions. If the scheme is applicable to the nocturnal risings of the constellations, the date may be about B.C. 762, when the first erratic Egyptian month

Thoth, coincided with Pisces; but if the more usually received matutinal risings of the signs are to be understood, then will the date ascend to 13,000 years earlier, or half a revolutiou of the equinoxes and solstices. But the enormous length of such astronomical periods, while elevating the mind to the loftiest conceptions of which it is capable, is also a check upou hasty conclusions. Though no subject seems more completely beyond human powers than celestial mechanics, no other has attained a nearer approach to perfection; and the motions of the heavenly bodies have been so perseveringly scrutinized, that time has become rather a mere relation than an agent in the inquiry; a result and not a principle.

As the movements with which that science deals are somewhat complicated, a word or two upon those which affect the apparent places of the stars, may be welcome to such persons as cannot take them formally in hand. It may prove a path through a seeming maze of matter, and to clear it the more, I shall only deal in round numbers. Justice to the reader, however, induces me to add, that without a distinct comprehension of the several complexities of precession, aberration, nutation, and refraction, there can be little useful application of inquiry.

First in importance is that continual shifting of the node of the earth's equator on the ecliptic, so that the plane of the ecliptic actually varies, altering the longitude of the stellar host; and even increasing the latitude of stars in certain regions, and diminishing it in the opposite points of the sky, by the amount of the decreasing obliquity of the ecliptic. This singular variation, as already shown, has long been recognised as the Precession of the Equinoxes. Were the position of the earth's axis always accurately parallel to itself, the position of the plane of the ecliptic would also be the same. But this not being the case, an oscillation acts on the plane, and varies its obliquity, from our axis continually altering in inclination, according to a law dependent upon the rotatory motion of the earth around that axis, and the actions of the planetary attractions upon the spheroidal excess about its equator. Sir Isaac Newton, to whose sagacity we are indebted for the discovery of the *cause* of this regression, supposes the spheroidal form of the earth and moon to be owing to their having once been in a fluid state, whence, as a consequence of the rotation, the matter flowed most to the equatorial regions. These two bodies, from their proximity, have most effect on each other; thus, the oscillation of the lunar orbit's inclination to our equator, amounts to 10°, but from our greater size, the oscillation of our ecliptic is very trifling, its obliquity decreasing at present at the yearly value of 0″·43.

But this is purely an apparent effect, for the longitude of the star is annually increased, not by reason of any motion of the star, but because of a falling backwards of the point from which it is measured. Yet the effect of the lunar attraction on us, compared to the sun's, is as four to one; and thus the inequality of the precession of the equinoxes, and the nutation of our axis, are attributable to the several situations of the lunar nodes. But the precession itself is owing to the terrestrial oblateness, since this form hastens our equator's coming into a line with the sun and moon at each return of the equinoxes, by the excess of matter which in that region excites more attraction. As, however, there is an annual difference of about 50″, when we have equal day and night, the sun will not be in a line with exactly the same stars as it was the year before, consequently, in the sidereal year, the shortest and the longest day must also change with the equinox. Those who gaze at phenomena with watches compensated for mean time, should bear in mind that our daily revolution is completed, relatively to sidereal coincidence, in nearly four minutes less than twenty-four hours; so that the stars which were due south of us last evening, at 10 o'clock, for example, will be due south of us to-night at about four minutes before 10, amounting to a difference of rather more than a day in the year. See pages 411 and 413.

The Refraction of the heavenly bodies in altitude is a paramount element of correction, arising from the bending of a ray of light when passing through media of different degrees of density in the atmosphere; the trouble, however, which our aërial ocean thus inflicts, is amply repaid by its supplying us with the means of respiration, and moderating the transitions from light to darkness; it being that beneficent provision of the Creator, by which the earth is rendered habitable for man; and by which the glories of day are made to approach gradually, and gradually to withdraw, in proportion as the observer recedes from the equator towards either pole. Owing to the rays of light' being thus refracted, the objects seen obliquely through the atmosphere are raised above the horizon higher in appearance than they are in reality; for since we always refer objects to a place in the straight line of direction of the ray at the moment it enters the eye, we see them in this case in the prolongation of the tangent to the curve formed by the bent ray at the point where it enters the eye. The effect thus produced gives a false impression respecting the elevation of the object viewed, which must be rectified by ascertaining the amount and direction of the displacement thus produced; for neither the temperature nor density of this fluid is uniform throughout. It is most dense at the surface of the earth; and its refractive power gradually decreases as we rise, until we arrive at a density of air so small that it ceases sensibly to disturb the direct progress of a ray of light. Hence it is inferred that the heavenly bodies are never seen in their true places*, except when in the zenith; refraction having no effect on a vertical ray, which, produced, would go to the earth's centre. Most of my readers, I trust, are competent to correcting the quantities taken from the Table of Refraction by the state of the barometer and thermometer at the assigned moments: to those who have made no great advance, I will add, as a general view, that the several strata of the atmosphere may be considered with respect to each other as different media. Now, as just shown, an object in the zenith will be free from the effects of refraction; which half-way between it and the horizon will amount to nearly 1′; but from thence there is a rapid and very sensible increase, and at the visible horizon it is no less a quantity than 33′. This immense ratio of increase is easily rendered evident, by just drawing an arc of even seven inches radius, and an outer arc of only $\frac{1}{10}$th of an inch more radius, which is the proportion of the atmosphere to

* Every one knows that the sun, when actually below the horizon, appears above it, in consequence of the bending round of his rays towards the spectator. Owing to this illusion, on the 20th of April, 1837, the moon appeared to rise eclipsed before the sun had set.

the earth's diameter: a tangent from the inner to the outer arc, will shew the greater obliquity and refraction of the incident rays at its extremity. There is a very notable difference in the state of the atmosphere, in certain states of the wind and weather; and though the refraction which the atmosphere produces, is for the most part independent of its temperature, and proportional to its density, still I can hardly consider that humidity may not produce an effect, however minutely sensible, on its refractive powers. I, therefore, in numerous cases, as before stated, registered the state of the hygrometer with that of the barometer and thermometer.

The discovery of the Aberration of Light, that beautiful phenomenon which afforded an absolute proof of the orbital motion of the earth, and confirmed the fact of the uniform velocity of light, was a brilliant contribution towards uranographical accuracy. This occurs simply from the earth's motion being a quantity comparable to the velocity of light, when relative to the stars, but becomes a more complicated theory when both bodies are in motion, for according to the law of the composition of forces, there results a mixed effect, showing the star in a different place to what it really is. And however small that difference be, it is requisite to be considered and allowed for in computation. Bradley explains it rather in a different way, although the principle is the same. Fixing our attention upon any supposed stream of light coming into the tube of our telescope, though parallel to it when we first direct our instrument, it will soon fall in an acute angle on the interior preceding or following sides of the tube, if either body be in motion. But in aberration, we have to consider the velocity of the motion, whilst in parallax we have only to get at the amount; so that where the former depends on time, the latter hangs only on space. See Vol. II., p. 401. The apparent difference in declination is proportional to the sine of the star's latitude; therefore those situated near the solstitial colure seem to have wandered farthest north and south at the equinoxes; and whatever their situation, those that culminate in the daytime, seem to tend southward, while those that cross in the night tend northward. In proportion as the distance between two objects be greater, the longer will be the time occupied by the light in reaching us, and the more progress will the earth have made in its orbit. Maupertuis familiarized this subject, by instancing that in firing at a bird flying, the sportsman of course will not aim directly at it, but somewhat further on in the line in which it is going. On hearing this, a sailor exclaimed, "Who would strike *at* a fish, instead of *ahead* of him!"

Aberration may require another word or two. Having sometimes observed a degree of scepticism peep out under the question, "But how can you be sure of all this?" when mentioning definite quantities to amateur star-gazers, I will endeavour, in this instance, to explain the result of observing the eclipses of Jupiter's satellites, as informing us of his distance from the sun. It was remarked that when the earth is at its least distance from Jupiter, both the immersions and emersions of his satellites occur sooner than indicated by calculation; while, on the contrary, they were seen later when the earth was at its greatest distance. Nevertheless, the tables were constructed on a mean of a thousand observations, and prove correct when the earth is at its mean distance. The solution is this: the solar rays which render those satellites visible till the instant of immersion into their primary's shadow, or from the instant of their emersion out of it, have to travel to the satellite, and be reflected thence to our eye. Now Jupiter being five times our distance from the sun, the rays, with all their velocity, will be about 40′ on their return voyage; consequently, the phenomenon takes place that length of time before we become aware of it*.

The Nutation is an element affecting the declination to an amount of about 9″ each way; and has been therefore denominated the nodding of the terrestrial poles. It is owing to an apparent oscillatory or conical motion of the equatorial poles round those of the ecliptic, describing an ellipse whose major axis is about 19″ and minor 16″. This is occasioned by the earth's not being

* In the *Bibliothèque Universelle* of Geneva for last May (1844), is an abstract of papers by M. Houzeau in Nos. 496 and 498 of the *Astronomische Nachrichten*, wherein the errors of the elliptic orbit of 70 Ophiuchi are reduced to a maximum of 0″·164 in distance, by means of an introduced equation for the aberration of light; whereby a parallax results nearly equal to Bessel's for 61 Cygni. It is, however, rather ingenious than conclusive.

truly spherical, whence the protuberant parts near the equator are acted upon by the sun and planets in a manner to which there is no balance in the polar regions: the maximum attractions occurring every nine years, when the moon's node is at the solstices, and the minimum when the same is at the equinoxes; the greatest and least effects not being cotemporaneous with, but following those periods, just as the highest temperature of the day is not felt until long after the sun has culminated. The discovery of aberration and nutation by Bradley, entirely cleared the fixed stars from the errors to which the observations of them had been subject, except such as depend upon their own proper motions; and both effects are so intimately connected, as to render them essential constituent parts of one and the same phenomenon. The admirable inquiries of Laplace, and others, have shown, that a rigorous analysis of this great problem, by an exact estimation of all the acting forces and summation of their dynamical effects, leads to the precise value of the co-efficients of precession and nutation, which observation assigns to them.

The Proper Motions just alluded to, must now be classed among the complex conditions of the stellar host; since, although it may require many ages to produce any uranographical derangement, they already interfere very materially in the deductions arising from changes of apparent place, detected by accurate measurement, in double stars, and other compound objects in the accompanying CYCLE. See p. 430.

Such are the movements which, however sublime in contemplation, worry the practical observer; yet without a strict attention to these delicacies, his observations are mere dross. Although I chiefly address those who are acquainted with the general principles of reducing a meridian observation, yet the corrections required for disencumbering the raw readings from the influences of these motions may be dwelt upon, and prove acceptable to those who wish to reduce their stellar observations to the days on which they are made. M. Bessel's formulæ embrace at once the corrections for precession, aberration, and nutation, and Mr. Baily has tabulated a most useful and varied series of co-efficients, together with an extensive catalogue of the mean apparent places of the principal stars, which was published by the Royal Astronomical Society. With this admirable work, wherein the constants are brought to his hand, and the factors in the *Nautical Almanac*, he is a poor astronomer indeed, who cannot bring the results of former observers up to the same day with his own, and thus afford the advantage of comparison to his own operations. To the very few who desire to get the quantities unmixed, in order to apply rectifying factors, Dr. Pearson's general Tables, constructed from Bessel's Constants, can be used with any other co-efficients that may hereafter be determined.

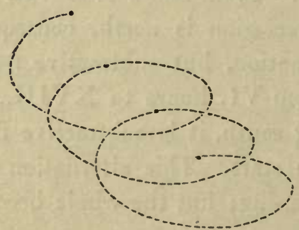
The precession of the equinoxes alters the longitude of the stars by rather less than a minute per annum; but the latitude remains nearly the same, because it is measured from the pole of the ecliptic, which wavers only to the amount of 17″. The precession in right ascension is, with few exceptions, additive, increasing in the regions near the poles of the heavens, but dwindling to zero around the poles of the ecliptic. The small space between these two poles in each hemisphere, affords the exception of the precession's becoming subtractive; hence we shall find these examples in the northern hemisphere, situated in the constellations on either side of XVIII. hours, that being the Æ of the ecliptic pole. In the southern hemisphere, for the same reason, the instances occur in those constellations that culminate, or reach their highest point, about the VIth hour, though the rule, in both cases, is only applicable to those stars which are situated beyond 67° from the equator. The annual precession in declination, however, hangs on the star's right ascension, both as to amount and direction. At VI. hours and at XVIII., it is at zero; at XII. it reaches the southern maximum of 20″; and at XXIV. it reaches a similar northern maximum. From hours 0. to VI., and from XVIII. to XXIV., the precession is north, consequently additive to stars of north declination, but subtractive from those in south declination; and from VI. hours to XVIII., on the contrary, the precession being south, it is subtractive from northern, and additive to southern stars. This alternation it is that renders reductions a little teasing; but the whole becomes familiar on a very short acquaintance.

In strictly studying these several conditions, we find that the *obliquity* of the apparent sidereal paths, evidenced by the annual variation in declination, depends entirely on their right ascension, being most oblique in those stars that culminate at XII. and at XXIV. hours, and nearly horizontal in those at VI. and at XVIII. hours, whether the declination be north or south, great or small. But the curves annually described are large according to the star's proximity to the pole, whatever be the right ascension, only that in proportion to the smallness of precession in Æ, the curves trench upon one another. The introduction of a few diagrams may excite the reader's attention to this comparative progression; but the same may be tangibly illustrated by Professor De Morgan's neat idea—communicated to me *viva voce* at Bedford—of winding a wire around a small cylinder, then slipping it off, and pulling the revolutions more or less asunder as the elements of the various stars may require. By gradually turning the spiral line thus formed, relatively to the eye, it will exhibit the sidereal modifications from year to year. Let us now proceed to the figures:

Examples in North Declination.

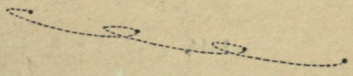
a Ursæ min. Æ $1^h\ 02^m$; *prec.* + 16″·5. Dec. N 88° 27′; *prec.* N 19″·3

This well-known star shows the effect of proximity to the pole; as it causes the star to exhibit the full amount of nutation by its large curves, although the horizontal space is contracted according to the rules of spherical triangles. But it is far away from the pole of the ecliptic.



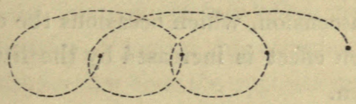
a Tauri. Æ 4^h 27^m; *prec.* + 3″·4. Dec. N 16° 11′; *prec.* N 7″·9.

In Aldebaran we have the singularity of the curves turning downwards, like the generality of stars with south declination. This diversity will be found to begin at the ecliptic instead of the equator, and *β* Libræ is its counterpart in the southern hemisphere.



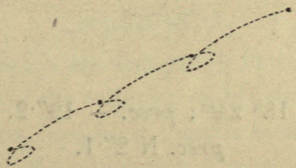
51 Cephei, Hev. Æ 6^h 23^m; *prec.* + 30″·9. Dec. N 87° 16′; *prec.* S 2″·1.

In this star we see the effect of five hours difference in right ascension from Polaris, although nearly in the same declination.



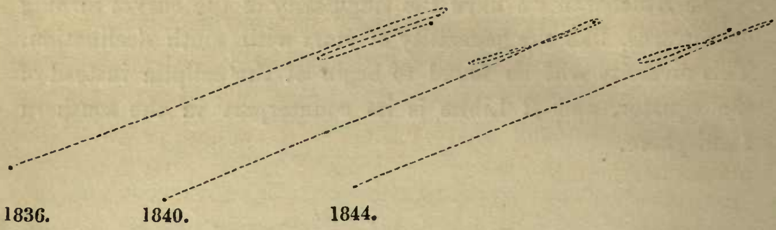
ε Leonis. Æ 9^h 37^m; *prec.* + 3″·4. Dec. N 24° 30′; *prec.* S 16″·3.

Rasalasada exhibits a very strong contrast by its annual descent in declination to Polaris, which will have been observed to rise annually at a still greater rate.



a Leonis. Æ 10^h 0^m; *prec.* + 3″·2. Dec. N 12° 45′; *prec.* S 17″·4.

From the situation of Regulus on the ecliptic, he has a most intricate path during three quarters of the year, and then a straight one during the other. Moreover, his mazes are performed in so small a space, that it is requisite to lay them down on four times the scale adopted for most of the others, the only exceptions being his counterparts in south declination, as *a* Virginis, a^2 Libræ, and *β* Scorpii. There is so much difference also in the *twirls* of this star from year to year, that they are here pourtrayed at three different epochs:

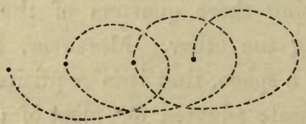


η Draconis. Æ 16^h 22^m; *prec.* + 0″·8. Dec. N 61° 53′; *prec.* N 0″·8.

In η Draconis we have the effect of the least possible precession in right ascension, which occasions the curves to entwine very much; which effect is increased by the little annual difference of declination.

δ Ursæ min. Æ 18^h 24^m; *prec.* − 19″·2. Dec. N 86° 35′; *prec.* N 2″·1.

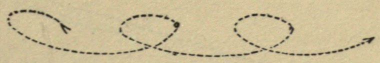
Owing to Yildun's lying between the north pole and the pole of the ecliptic, we see the peculiar effect of great retrocession in right ascension.



Examples in South Declination.

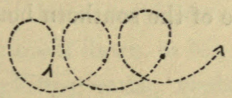
δ Orionis. Æ $5^h\ 24^m$; *prec.* + 3″·1. Dec. S 0° 25′; *prec.* N 3″·2.

As Mintaka is nearly on the equator, and consequently about 23° from the ecliptic, the curves are sensibly large; while its right ascension being nearly VI. hours, the annual progression is almost horizontal.



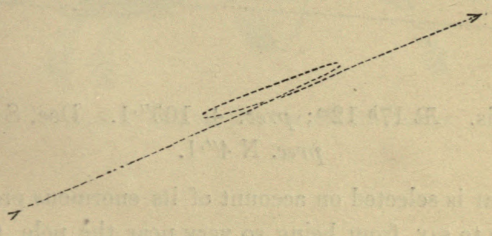
ε Canis maj. Æ $6^h\ 52^m$; *prec.* + 2″·4. Dec. S 28° 45′; *prec.* S 4″·5.

In Adara we have a star nearly on the meridian of Hevelius's 51 Cephei, the curve of which is before given; but being of the opposite declination, it curves downwards, whilst its spirals are smaller because further from the opposite pole of the ecliptic.



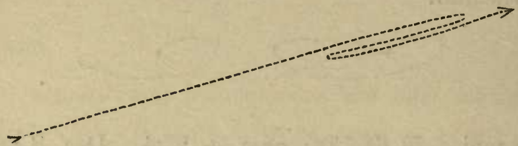
a Virginis. Æ $13^h\ 17^m$; *prec.* + 3″·2. Dec. S 10° 19′; *prec.* S 18″·9.

The curves of Spica are very much flattened, from its being within two degrees of the ecliptic; and it shows great south precession in declination, because it transits soon after XII. hours in Æ, at which period the maximum occurs. On account of the curve's being greatly compressed, it is drawn on the same large scale as that of *a* Leonis.



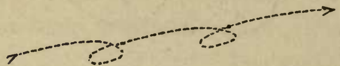
α^2 Libræ. Æ $14^h 42^m$; *prec.* + 3″·3. Dec. S 15° 22′; *prec.* S 15″·2.

Kiffa Australis is now situated with regard to the ecliptic, as Regulus was in 1836, exhibiting a zig-zag instead of a spiral line; but the maze occurs towards the close of the year, instead of the beginning. In order to render this path distinct, it also is represented on four times the general scale.



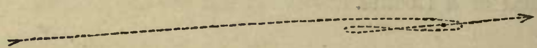
β Libræ. Æ $15^h 08^m$; *prec.* + 3″·2. Dec. S 8° 47′; *prec.* S 13″·7.

Kiffa Borealis exhibits, among the stars of south declination, what Aldebaran does in a corresponding northern situation; its curves are in an opposite direction to those of its companions, being on the north side of the southern boundary of the ecliptic.



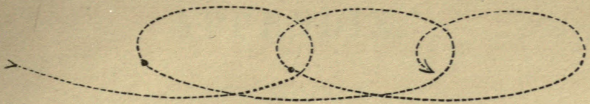
β^1 Scorpii. Æ $15^h 56^m$; *prec.* + 3″·5. Dec. S 19° 22′; *prec.* S 10″·3.

Acrab describes so intricate a course after the first quarter of the year, in consequence of being only a degree and a half from the ecliptic, that four times the general scale scarcely suffices to make it distinct.

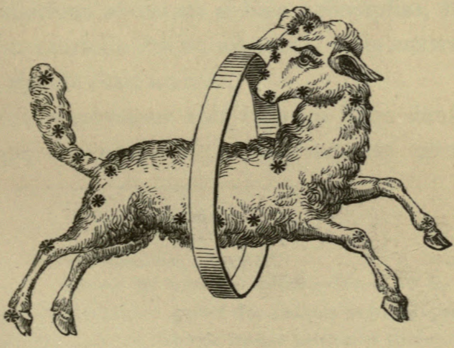


σ Octantis. Æ $17^h 12^m$; *prec.* + 105″·1. Dec. S 89° 16′; *prec.* N 4″·1.

This star is selected on account of its enormous precession in Æ; that is to say, from being so very near the pole, the spacial value of its right ascension in describing so very small a circle, is reduced to the least possible amount.



THE reader who has accompanied me through these *Prolegomena*, will be prepared to enter upon *The Bedford Catalogue*, and feel an interest in the details there submitted to him. Armed with a telescope he may immediately employ his time to advantage; and even if without one, his contemplation of celestial objects must have increased in interest. "Look up," said Richter, "and behold the eternal fields of light which lie around the throne of GOD! Had the stars never appeared in the firmament, to man there would have been no heavens; but he would have laid himself down to his last sleep in a spirit of anguish, as upon a gloomy earth, vaulted over by a material arch, solid and impervious."



Ancient Symbol of Aries and the Colure.

APPENDIX.

I.

Baron de Zach's Account of a Solar Eclipse.

(Alluded to in page 140.)

Éclipse annulaire du Soleil, le 7 *Septembre*, 1820.

Cette fameuse éclipse, dont on a tant parlé, que les savans et les curieux attendaient avec une égale impatience, s'est enfin montrée, exactement comme les astronomes l'avaient prédite.

Cette grande précision dans l'annonce de ce phénomène a frappé les profanes. Les plus ignares ont pu y reconnaître la certitude de cette science sublime et *si naturelle à l'homme.* On en a fait honneur aux enfans hardis de Japhet, et on a confondu un bel esprit de l'antiquité, qui avait dit, que jusque la folie des hommes escaladait le ciel*; mais on a fait voir que la science s'y élance avec succès, et y pénètre avec triomphe.

Il n'y a que les astronomes, qui n'ont point été étonnés de ce que leurs prédictions se soient si bien accomplies, ils l'auraient été, une terreur mortelle les aurait saisis, si le contraire, c'est-à-dire la fin du monde était arrivée.

L'astronome observateur voit tous les jours dans son observatoire, ce que les profanes, les curieux, les ignorans, n'ont

* Audax Japeti genus,

. . . .

Nil mortalibus arduum est,
Cœlum ipsum petimus stultitia.—Lib. i., Od. iii.

Horace voulait-il par hazard parler des ballons aréostatiques? Serait-ce une preuve, *comme tant d'autres,* que ces vessies pleines et vuides en même tems, existaient déjà du tems d'Auguste? Les Imans du Caïre avaient bien dit au Général Bonaparte, lorsqu'il fit monter un ballon pour les étonner, que Mahomet en avait fait autant, et qu'il en est parlé dans l'Alcoran. Bonaparte ne savait donc pas que les Moslems ne s'étonnent de rien, et n'admirent rien. *Nil admirari* est leur devise; l'on voit combien certains génies se rencontrent en tous les pays.

remarqué que le 7 Septembre, 1820. On n'admire que ce qu'on ne connaît pas; mais l'astronome qui connaît, qui vérifie tous les jours et à toute heure, que les lieux du soleil et de la lune, observés avec ses instrumens, sont constamment à peu de secondes près d'accord avec les lieux calculés par les tables prophétiques, à la perfection desquelles il a contribué lui-même, par ses observations assidues, ne peut pas plus s'étonner, que ces astres se soient aussi docilement soumis à la rigueur de son calcul, qu'un habile sculpteur s'étonne que le marbre se soit soumis à la rigueur de son ciseau.

Ce n'est pas pour vérifier et pour perfectionner les tables solaires et lunaires; ce n'est pas non plus, pour déterminer uniquement les longitudes géographiques, que les astronomes se sont tant empressés d'observer cette éclipse, on a d'autres moyens beaucoup plus exacts, et même plus sûrs, pour atteindre ce double but, mais ce sont d'autres points bien plus délicats, encore très-douteux, et peu constatés, qu'ils ont voulu vérifier à l'occasion de ce mémorable phénomène, qui en fournisait les moyens.

Nous l'avons dit dans le troisième volume de cette *Correspondance*, p. 366, que les astronomes mettaient en question l'existence de l'atmosphère de la lune, que certains phénomènes paraissaient indiquer, tandis que d'autres la rejettent. Cependant des grands géomètres ont enterpris de la prouver. Euler dans les *Mémoires* de l'Académie Royale des Sciences de Berlin pour l'an 1748, p. 103, a taché de prouver l'existence d'une atmosphère lunaire, sur les observations de quelques éclipses de soleil, et Dionis du Séjour a cru avoir remarqué la même chose par les effets de la réfraction dans l'éclipse annulaire de l'an 1764.

D'autres astronomes ont attribué ces effets, non pas à une réfraction dans l'atmosphère de la lune, mais à cette *diffraction* ou *inflexion* des rayons de lumière, qui rasent les bords des corps opaques, phénomène dont Newton avait parlé le premier dans la troisième partie de son optique, et dont on attribue mal à propos la découverte au Jésuite Grimaldi. De l'Isle expliquait par là les anneaux lumineux, que l'on a vu autour du soleil dans les éclipses totales, et dont nous avons également parlé page 408.

Un autre philosophe, le Docteur Jurin prétend, que toutes ces apparences ne sont que de simples illusions optiques, qui ne proviennent que d'une vision indistincte et du cercle de dissipation dans lequel se trouvent les corps lumineux, lorsqu'ils s'approchent de trop près.

D'autres encore en cherchent la cause dans l'*irradiation*, ou dans le débordement de la lumière dans des corps très-resplendissants.

Quoiqu'il en soit, l'inflexion, ou la circumflexion des rayons solaires, qui rasent les bords de la lune, a parue démontrée à quelques astronomes, tandis que d'autres en doutent très-fort. Par les observations de l'éclipse annulaire de l'an 1764, que Du Séjour a calculées et discutées avec beaucoup de soin, il a cru avoir trouvé qu'il fallait admettre cette inflexion, pour concilier toutes ces observations, mais elles n'étaient ni assez exactes, ni assez concluantes; tous les élémens de ses calculs n'étaient pas assez sûrs, pour fixer ce point d'une manière rigoureuse et incontestable.

Si cette inflexion des rayons solaires, produite par l'atmosphère de la lune, ou par une autre cause physique quelconque, existe réellement, elle doit nécessairement influer sur les instans du commencement, de la fin, et de la durée des éclipses; elle doit faire retarder le commencement, en rendant les bords des astres visibles par les effets de la réfraction ou inflexion, lorsqu'ils ont cessé de l'être directement. Elle doit faire avancer la fin en rendant les bords visibles, avant qu'ils le soient devenu directement, par conséquent la durée de l'éclipse sera diminué, mais l'éclipse annulaire sera augmentée par cet effet. C'est pour cette raison que quelques astronomes, qui adoptent l'hypothèse de l'inflexion dans leurs calculs des éclipses de soleil, diminuent le demi-diamètre apparent de la lune de 2 à 3 secondes, quantité que Du Séjour a trouvé par ses calculs.

On a cru observer, qu'il se produit autour des corps très-rayonnans une *irradiation*, ou un épanchement de lumière, qui dilate tant soit peu leurs disques réels, ainsi qu'on le remarque dans les phases de la lune, où le croissant lumineux paraît d'un diamètre beaucoup plus grand que celui du disque obscur et visible par sa lumière *cendrée*. Dionis du Séjour pour séparer ces deux effets de l'*irradiation* et de l'*inflexion*, les a considérés dans son grand travail comme deux inconnues, qu'il fallait déterminer simultanément d'après les observations des phases de l'éclipse, et de la mesure des distances des cornes, sur lesquelles ces deux causes n'influent pas de la même manière. Après des calculs immenses il a trouvé que les observations de l'éclipse annulaire du soleil de 1764, ne pouvaient se concilier à moins de supposer dans le demi-diamètre du soleil une *irradiation* de 3 à 4 secondes, et à peu-près autant dans le demi-diamètre de la lune pour l'*inflexion*. Feu M. De la Lande a trouvé de son côté* par le calcul de quelques éclipses de soleil annulaires, qu'il fallait diminuer de 6 secondes les diamètres du soleil et de la lune, donnés par les tables de Mayer.

L'influence de ces petites quantités sur le commencement, la fin et la durée d'une éclipse, n'est pas si légère qu'on le penserait d'abord. M. le Professeur Caturegli a pris la peine de faire le calcul rigoureux de l'éclipse du 7 Septembre. Il a supposé en premier lieu que les demi-diamètres de deux astres étaient tels que les tables astronomiques les assignent; dans une seconde hypothèse, il admet dans le demi-diamètre du soleil, une *irradiation* de 3 secondes et demi. Dans une troisième hypothèse il admet encore cet effet de l'*irradiation*, et y ajoute celui de 2 secondes sur le demi-diamètre de la lune, pour l'effet de l'*inflexion*. Voici le tableau des différences sur les phases de l'éclipse que les deux dernières hypothèses ont donné sur la première.

	Avec l'irradiation sans inflexion.	Avec l'irradiation et l'inflexion.
	"	"
Pour le commencement de l'éclipse - -	10·5	16·5
„ la formation de l'anneau - -	4·7	7·5
„ la rupture de l'anneau - - -	4·8	7·6
„ la durée de l'anneau - - -	9·5	15·1
„ la fin de l'éclipse - - - - -	8·7	13·6
„ la durée de l'éclipse - - -	19·2	30·1

Mais, comme nous l'avons dit, la légitimité de ces corrections est bien loin d'être prouvée, et plus difficile encore de l'être. Nous avons sur les diamètres apparens de ces deux grands lumi-

* *Connaissance des Tems.* Année vii., p. 205.

naires des incertitudes qui ne sont pas dissipées encore, et dont les limites surpassent et englobent ces petites quantités dont il s'agit ici. On sait que plusieurs astronomes munis d'excellens instrumens, ont déterminé ces diamètres avec des différences, qui montent jusqu'à 6 et 7 secondes. On croit, et avec quelque fondement, que le diamètre du soleil observé avec des grandes lunettes paraît plus petit que celui déterminé avec des petites lunettes. Par exemple l'Abbé De la Caille a toujours trouvé le diamètre du soleil 31′ 34″ mesuré avec une lunette de 6 pieds, tandis que De la Lande ne le trouvait que de 31′ 30″·5 avec un héliomètre de 18 pieds.

Enfin, que dire de cette ellipticité et de cette diminution du disque solaire? De la Lande a trouvé le diamètre polaire du soleil 2 secondes plus grand, que son diamètre équatorial*. M. le Baron de Lindenau par deux mille observations de Maskelyne, a trouvé une différence de 4″·72 entre les deux axes du disque, et a reconnu en outre une diminution progressive dans le diamètre du soleil†. M. Delambre a trouvé cette différence dans les axes 3″·145, mais sans diminution‡. Selon la théorie, en supposant la rotation du soleil sur son axe de 25 jours et 10 heures, et sa densité $= \frac{1}{37939}$, la différence entre les deux axes ne serait que de 0″·052.

L'on voit de là combien les recherches des quantités de l'*irradiation* et de l'*inflexion* des rayons de la lumière sont incertaines et précaires, puisqu'elles dépendent absolument de la grandeur des diamètres, qu'on aura pris pour base de calcul; ces diamètres supposés plus petits, auraient seuls suffi pour lever toutes les difficultés. C'est pour discuter ces points aussi délicats, que les

* *Astronomie.* Tom. ii., Art. 1388, p. 113.

† *Corresp. Astron. Allem.*, vol. xix., p. 525; xx., p. 83; xxi., p. 469.

‡ *Corresp. Astron. Allem.*, vol. xxii., p. 193. Un astronome Américain a fait le calcul suivant, pour prouver que le soleil pourrait être sujet à une consommation succesive, sans que nous ayons pu nous en appercevoir depuis que nous observons le ciel. Il suppose le diamètre du soleil = 800,000 milles = 4,204,000,000 pieds, ou en secondes à-peu-près 2000″. Or, nous n'avons encore aucun instrument avec lequel on puisse mesurer le diamètre d'un astre à une seconde près; donc, le soleil peut diminuer de $\frac{1}{2000}$ de son diamètre, ou de 2,102,000 pieds, sans qu'on puisse s'en appercevoir. Supposons que le soleil diminue journellement de deux pieds, il faudrait *trois mille* ans pour rendre visible la consommation d'une seconde de son diamètre.

astronomes se sont tant appliqués de bien observer cette éclipse, surtout dans les endroits où elle était annulaire. Plusieurs d'entre eux ont même entrepis des voyages exprès pour cela. C'est ainsi que M. Tralles de Berlin, où cette éclipse n'était pas annulaire, s'est rendu à Cuxhaven pour l'observer. M. Bouvard de Paris s'est transporté dans la même intention à Fiume, et nous avons fait avec le Capitaine Smyth* le voyage de Bologne dans la même vue.

Nous rapporterons, et nous rassemblerons dans les cahiers subséquens de notre *Correspondance*, toutes les observations de cette éclipse à fur et mesure qu'elles parviendront à notre connaissance. Nous commencerons par donner celles que nous avons faites à Bologne. Nous y arrivâmes deux jours avant l'éclipse, et nous eûmes le plaisir d'y revoir après douze ans, notre ancienne connaissance M. le Professeur Caturegli, directeur actuel de l'observatoire de l'Institut. Nous nous concertâmes sur le mode de faire nos observations. M. Caturegli eut la grande complaisance de me laisser le choix des instrumens, mais je n'étais pas venu pour empêcher un aussi habile astronome, de faire une bonne et complette observation de cette mémorable éclipse. Son organe plus jeune, plus vigoureux et moins usé que le mien, pouvait faire des meilleurs observations; une simple lunette me suffisait, je me contentai d'observer les quatre phases principales de cette éclipse, surtout la formation et la rupture de l'anneau; je fis par conséquent choix d'une lunette acromatique de dix pieds de Dollond, et j'abandonnai la belle lunette parallactique du même artiste, garnie de son héliomètre, à M. Caturegli, qui avec ce superbe instrument pouvait faire un grand nombre d'observations importantes, en mesurant les distances des cornes.

Dans des occasions pareilles les observatoires publics sont toujours molestés par les curieux. M. Caturegli m'avait averti que l'affluence en serait grande. Le grand salon dans la tour, percé sur toutes les plages par des grandes fenêtres et portes

* Le Capitaine Smyth est venu à Gênes avec sa corvette dans le mois d'Août, comme nous l'avons déjà rapporté page 143 de ce cahier. Il n'avait jamais vu d'éclipse annulaire; moi non plus; malgré que je regarde le cie depuis un demi siècle, car en 1769, j'avais déjà observé le passage de Vénus sur le disque du soleil, avec mon professeur de Physique.

vîtrées, était assurément le lieu le plus commode pour faire les observations, mais c'était précisément dans cette salle que l'on devait recevoir *la compagnie;* je demandai par conséquent un lieu écarté où je pourrais me retirer, et faire mon observation en paix. Les fenêtres des petits cabinets attenans à la tour, étaient trop peu élevées pour pouvoir y manœuvrer avec une grande lunette de 10 pieds. Il ne me restait que d'aller me réfugier tout en haut, sur la terrasse découverte de la tour. M. Caturegli eut la bonté d'y faire dresser une tente, sous laquelle les instrumens et les observateurs trouvèrent un abri contre le mauvais tems, dont malheureusement le ciel nous menaçait depuis quelques jours.

J'avais prévu le cas d'une retraite; et malgré que je n'eusse porté aucun de mes instrumens, sachant que l'observatoire en était pourvu, j'eus cependant la précaution de prendre avec moi mon chronomètre sidéral d'Emery, en cas que je fusse obligé de me retirer dans quelque lieu éloigné des pendules de l'observatoire, comme cela effectivement avait eu lieu. En comparant mon chronomètre avec les pendules placées à côté de l'instrument des passages, je pouvais transporter le tems où bon me semblait.

Le soir du 6 Septembre survint un grand orage avec éclairs, tonnerre et des ondées très-fortes. Il y avait plusieurs mois qu'aucune goutte d'eau n'était tombée dans le pays. La pluie continua pendant toute la nuit, et le 7 Septembre jour de l'éclipse, le ciel nous régala pendant toute la matinée des guilées très-abondantes, mais passagères. Encore à midi on ne put prendre le passage du soleil à la lunette méridienne, une grande averse, (heureusement c'était la dernière,) nous en empêcha, mais on avait eu deux étoiles le matin, dans des éclaircies momentannées. Au reste, l'état et la marche de deux excellentes pendules Anglaises, l'une de Graham, on plutôt de son successeur, l'autre d'Ellicot, étaient parfaitement connues.

Vers une heure après-midi, les *éclipsophiles* des deux sexes, et de tous les états, commençaient à s'assembler. Ce fut le signal pour notre retraite. Après avoir comparé le chronomètre avec la pendule sidérale nous nous retirâmes avec le Capitaine Smyth dans notre réduit, où ne furent admis que le général

Russe, Prince Wolkonski* et le Professeur Mezzofanti de Bologne.

Nous étions convenus avec le Capitaine Smyth, que pendant l'éclipse il observerait des distances de Vénus à la lune. Il n'y avait pour cela à l'observatoire qu'un cercle de réflexion de 9 pouces de Le Noir. Mais cet instrument était si mauvais, la lunette grossissait si peu, toutes les pièces en étaient si mobiles, si branlantes, qu'il fut impossible d'obtenir une seule bonne observation; après plusieurs essais, le Capitaine aima mieux y renoncer tout-à-fait, que de faire des mauvaises observations; nous regrettâmes infiniment de n'avoir pas porté avec nous un sextant Anglais, dont le Capitaine avait un si grand nombre à son bord.

Un mécanicien de l'observatoire, nullement accoutumé à cet exercice, s'étant très-mal acquitté de compter les secondes au chronomètre, le Capitaine Smyth, avec un dévouement qui caractérise les bons esprits, s'offrit de suite de renoncer à faire l'observation de l'éclipse, et de compter lui-même les secondes au chronomètre. Son dilemme était péremptoire; il disait: *Ou nous ferons tous les deux de très-mauvaises observations, si cet homme compte, ou nous aurons une bonne observation si je compte.* Nous eumes un combat de générosité, mais comment ne pas céder à l'argument d'un homme, qui avait fait deux fois le tour du monde†! *Vous avez plus d'expérience*, me dit-il, *dans ce genre d'observations, et plus d'habitude que moi de manier cette longue lunette, qui m'embarrasserait, ainsi il vaut mieux que vous fassiez l'observation et que je compte. Je vous assure*, ajouta-t-il, *que je me félicite autant, et peut-être plus que vous, d'avoir contribué à une bonne observation, que de l'avoir faite manquer*. . .

Il fallut bien se rendre à des raisons si généreuses, si libérales, qui font un honneur infini au caractère et à l'esprit de Monsieur

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* J'eus l'honneur de faire à Gênes, la connaissance de ce Prince, infiniment instruit et amateur des sciences, où j'eus l'avantage de la cultiver quelques tems. Lui ayant dit que j'allais à Bologne observer l'éclipse annulaire du soleil, il y vint pour la voir, à son passage pour Rome.

† The Baron has here made a mistake. In conversation I had informed him of my having twice crossed the Pacific Ocean; *i. e.* from Madras by New Holland to Chili, and from Acapulco back again to India. W. H. S.

le Capitaine, surtout auprès de ceux qui savent apprécier la valeur d'un tel sacrifice astronomique. Je fis donc les observations, et le Capitaine Smyth les notait, en comptant et marquant le tems au chronomètre. En verité, je ne sais ce qu'il en aurait été de nos observations sans la complaisance de M. le Capitaine; si elles sont bonnes à quelque chose, c'est bien à M. Smyth qu'on en aura l'obligation.

A une heure et demie les nuages commencèrent à se diviser, le soleil parut dans les éclaircies, et lorsque l'instant du commencement de l'éclipse approchait, il était parfaitement net, en sorte que nous avons très-bien pu observer cette première phase. Il y avait fort-peu de vent, les nuages passaient très-lentement, et couvraient le soleil de tems en tems; quelques gouttes d'eau tombaient par intervalle. Malheureusement à l'instant que l'anneau devait se former, ou que l'éclipse annulaire devait commencer, une nue dense enveloppa tout le disque du soleil, et cette phase importante fut par conséquent manquée. Lorsque le soleil reparut, il n'y avait pas deux minutes que l'anneau s'était formé. C'était désespérant!

Nous fumes plus heureux lors de la rupture de l'anneau, ou pour la fin de l'éclipse annulaire, que nous avons fort bien observée, ainsi que la fin de toute l'éclipse. Voici les vrais momens observés de toutes ces phases.

	Tems sider.	Tems moyen.	Tems vrai.
	h ′ ″	h ′ ″	h ′ ″
Commencement de l'éclipse - -	12 41 32·6	1 35 31·32	1 37 40·32
L'anneau n'était pas formé encore	14 6 11·0	2 59 55·86	3 2 7·16
Nuages.			
L'anneau était déjà formé - -	14 9 57·0	3 3 41·36	3 5 52·78
Fin de l'éclipse annulaire - -	14 11 16·3	3 5 0·32	3 7 11·72
Fin de toute l'éclipse - -	15 28 44·7	4 22 16·03	4 24 28·43

Pendant tout le tems qu'avait duré l'éclipse, nous avons attentivement parcouru et examiné les bords, les disques, et les cornes que formaient ces deux corps célestes, et nous n'avons rien pu y découvrir d'extraordinaire, ou de particulier, qu'aurait pu annoncer ou indiquer une atmosphère, ou un *halo* quelconque autour de la lune; ses bords nous parurent toujours très-nets et bien terminés, sauf les petites aspérités produites par ses montagnes. Les pointes des cornes nous semblaient toujours bien effilées, point d'éclairs, point de corruscations, point de volcans dans la lune.

Le spectacle le plus beau était la fin de l'éclipse annulaire, ou lorsque l'anneau s'est fermé. Les montagnes de la lune se montraient très-distinctement, le bord de cet astre parut tout dentellé, et sur le point de toucher celui du soleil, il parut comme un peigne, ou une scie qui mordait sur ce bord. Avant que l'attouchement parfait des deux bords fut effectué, on voyait, non pas un filet continu de lumière, mais des petits points lumineux, comme autant de grains brillans dans une file de perles, séparés par des interstices obscurs. Ce beau phénomène n'a duré qu'un instant, car le contact des bords et la disparition totale du dernier trait de lumiere était instantanée.

Le soleil était sans taches; trois jours avant l'éclipse il y en avait sur le bord; nous ne pûmes par conséquent faire aucune observation ni de contact, ni sur les nuances de la pénombre de ces taches.

Il m'a semblé quelque fois que le bord inférieur du soleil dans la lunette (le supérieur en realité) était d'une couleur beaucoup plus foncée que le reste du disque, mais cette nuance ne se fit remarquer que lorsque j'avais regardé le soleil pendant quelque tems, je ne la voyais pas d'abord en mettant l'œil à la lunette, je l'attribuais à mon verre colorié qui tirait sur le violet, ou à l'organe trop fatigué. Cela me suggéra l'idée des expériences suivantes. Je fixai pendant une ou deux minutes d'un œil immobile, la manche de mon habit, qui était bleu foncé, puis je mis incontinent l'œil à la lunette, et je vis le disque du soleil de tout autre couleur, que celle dont il m'avait paru auparavant, couleur d'orange, elle me semblait couleur de rose.

Je fixai ensuite de la même manière, mon mouchoir blanc, et la couleur du soleil me parut verdâtre, et quelque fois marbrée. Dès-lors je ne regardais ces coloris que comme des illusions optiques, et comme un jeu du ressort de la rétine.

La planète Vénus fut visible à l'œil nud à $2^h\ 40'$, peut-être aurait-elle été visible plutôt, mais elle était dans les nuages. Pendant l'éclipse, le Capitaine Smyth notait de tems en tems les degrés d'un thermomètre centigrade qu'il avait placé à l'ombre dans la tente à côté du chronomètre. Ces observations indiquent clairement que l'interception d'une partie aussi considérable de la lumière solaire, avait exercée quelque influence sur la température de notre atmosphère. Si le ciel avait été totalement couvert, et l'éclipse invisible, ce thermomètre aurait donné par son échelle, l'instant de $3^h\ 5'$ *t. m.* pour le moment de la plus grande obscuration; c'est précisément celui de la fin de l'éclipse annulaire. Voici les observations de ces températures:

à $1^h\ 28'$	*t. m.*	+ 27°·0	à $3^h\ 27'$	*t. m.*	+ 24°·0
2 28	„	+ 25°·0	3 37	„	+ 24°·5
2 57	„	+ 24°·0	3 47	„	+ 25°·0
3 5	„	+ 23°·5	4 22	„	+ 26°·0

Comme nous avions quitté Bologne incessamment après l'observation de l'éclipse, M. le Professeur Caturegli n'avait pas encore réduit ses observations qu'il avait faites dans un autre local de l'observatoire; il a promis de nous les envoyer à Gênes; comme nous ne les avons pas encore reçues, à la cloture de ce cahier, nous les donnerons dans un autre.

This is the account of the eclipse; but I cannot refrain from adding the Baron's note concerning Professor Mezzofanti:

Ce professeur était-il aussi astronome? Point du tout! Qu'avait-il donc à faire dans cette galère? L'éclipse annulaire du soleil, était une grande merveille pour nous, et M. le Professeur Mezzofanti en était une autre. Ce savant extraordinaire est bien véritablement l'émule du Roi de Pont, bien différent de celui, dont nous avons parlé avec si peu de respect dans le II^e Vol., p. 517, de cette *Correspondance.* Ce professeur parle trente-deux langues vivantes et mortes; non pas à la façon du docte Jésuite Weittenauer, mais comme vous allez voir. M. l'Abbé Mezzofanti, en m'abordant m'adressa la parole en Hongrois, et me fit un compliment si bien tourné et en si bon Magyarùl, que j'en fus interdit et stupéfait au dernier point. Il me parla ensuite en Allemand, d'abord en bon Saxon (la *Crusca* Allemande) et puis en dialecte Autrichien, et souabe avec une vérité dans l'accent, que je fus au comble de l'étonnement, et que je ne pus m'empêcher de rire du change que me donnait la figure et la langue de ce professeur étonnant. Il parlait Anglais avec le Capitaine Smyth, le Russe et le Polonais avec le Prince Wolkonski, non pas en balbutiant, en béguéyant, mais avec la même volubilité, comme s'il avait parlé sa langue maternelle, le Bolognais, espèce de patois*. Je ne pouvais plus quitter le Professeur Mezzofanti. A un dîner chez le Cardinal-Légat Spina, Son Eminence le fit placer à table à côté de moi; après avoir jargonné dans plusieurs langues avec lui, qu'il parlait toutes beaucoup mieux que moi, il me vint en idée, de lui adresser à l'improviste quelques mots en Wallaque. Sans hésiter, sans avoir l'air de s'appercevoir que je lui parlais dans une langue aussi exotique, mon polyglotte me répond sur le champ dans la même langue, il y allait si grand train que je fus obligé de lui dire: eh! doucement, doucement Monsieur l'Abbé n'allez pas si vîte, je ne puis plus vous suivre, je suis au bout de mon Latin-wallaque. Il y avait plus de 40 ans que je n'avais plus parlé, et pas même pensé à cette langue, que je savais fort-bien dans ma jeunesse, lorsque je servais dans un régiment Hongrois, et que j'étais de garnison en Transylvanie. Le professeur était non seulement plus au courant de cette langue, mais il m'apprit à cette occasion qu'il en savait une autre, que je n'avais jamais pu apprendre, quoique je fusse bien plus à portée que lui de le faire, ayant eu des hommes de cet idiome dans mon régiment; c'est la langue des Zigans, ou de cette peuplade, que les Français appellent si improprement des Bohémiens, de quoi les braves et véritables Bohémiens, c'est-à-dire, les habitans du royaume de Bohéme sont bien indignés. Mais comment un abbé Italien qui n'est j'amais sorti de sa ville natale, a-t-il pu appendre une langue qui n'est ni écrite ni imprimée? Un régiment Hongrois, dans les guerres d'Italie, était en garnison à Bologne; le professeur linguiste y découvre un Zigan, il en fait son maître de langue; avec la facilité et la mémoire heureuse que la nature lui a départie, il a bientôt appris cette langue, laquelle, à ce qu'on croit, n'est qu'un patois apparemment encore alteré et corrompu de quelques tribus de Pârias de l'Indostan.

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* M. Mezzofanti est de Bologne, il n'est jamais sorti de sa ville natale.

II.

Professor Henderson on γ Virginis.

(The letter alluded to in the note to page 292.)

Edinburgh, 1 *Hillside Crescent*,
November 18, 1843.

My dear Sir,

You will no doubt think me very inattentive for not sooner replying to your letter of 17th October; but when it arrived, I was immersed in work of different kinds: not only that of the Observatory, sufficient when well performed to take up my whole time, but other avocations which had been accumulating from my absence and other causes. But I never lost sight of your communication, (for which I am much obliged, as it has forced me to study a subject which I had previously read only in a cursory manner,) and expected from day to day to commence its investigation. But it has only been during the last week that, by devoting every spare hour to it, I have satisfied myself regarding it.

The determination of the orbits of double stars from observations, presents practical difficulties, in consequence of the great comparative errors to which the observations are liable. The problem is a similar one to that of the orbits of comets deduced from the most rough estimates of their positions, perhaps erroneous to the extent of 20° or 30°. Cases such as these have frequently occurred in the determination of orbits of ancient comets; and it has consequently happened that different investigators have obtained orbits that bear no resemblance to each other.

The oldest observation of the double star, γ Virginis, that we have, is that of Pound and Bradley in 1718. Sir John Herschel has from it obtained the angle of position 160° 52′. (*Memoirs Astronomical Society*, vol. v., p. 36.) By trigonometrical calculation I find that in 1718 the great circle joining α and δ Virginis was inclined at an angle of 153° 33′ to the horary circle passing through the middle point between them. If we correct this by the quantity mentioned by him, we obtain 150° 50′ for the angle of position of γ Virginis, observed at that epoch.

The next observation is that of the lunar occultation in 1720, observed by Cassini. The moon was then within less than twenty-four hours of the full, and although the actual immersions at the dark limb were no doubt observed, I do not believe it possible that Cassini saw the actual emersions from the bright limb. Indeed, his words do not bear this meaning, but rather that at a certain moment he saw both stars emerged and parallel to the moon's limb. This of itself implies that the stars were at a small distance from the limb. Besides, the occultation was one of short duration; consequently, the stars apparently passed near the top or bottom of the moon's disc. In such situation stars that were seen parallel to the moon's limb could not emerge at the same moment. It may be proper to have this occultation recomputed, in order to ascertain whether the calculated relative positions of the two stars satisfy the conditions of their immerging at the two moments indicated by Cassini, and of their being parallel to the moon's limb and at a small distance from it, at the other time mentioned. But it is probable that the unavoidable errors of the Lunar Tables may have too great influence on the result.

When a good stock of observations has been obtained, I believe that in order to obtain the most probable orbit, we should proceed in a manner similar to that adopted for comets and planets. In the first place, from the requisite number of observations to be selected from the stock, obtain an approximate orbit, to be afterwards corrected so as to represent, as nearly as possible, and within the limits of the probable errors, all the observations. In the first part of the process, Herschel's, Encke's, or Savary's method may be obtained, and distances must be employed, either actually observed, or deduced from the angular velocities; for an attempted solution of the problem at this stage, depending on angles of position alone, would speedily end in a complication of transcendental equations quite unmanageable. If the distances are obtained from the angular velocities, then, according to a remark of Encke, the angles of position from which the velocities are deduced, should be taken at intervals of time neither too great nor too small. I should say that we cannot depend on the angular velocity of γ Virginis obtained from Sir William Herschel's observation of 1781; for not only is it separated from the next of 1802 by too great an interval, but it has no proper one preceding it to give co-operation. I would rather rely on the observed distance of 1781.

When an approximate orbit has been obtained, the differences between the angles of position computed from it and observed, give the materials for obtaining a set of six normal angles, from which a better orbit may be determined. This is the second part of the process, and it may rest on angles of position alone, if the distances are considered to be unsafe in the circumstances. The method of proceeding which I prefer is that of Mädler, in No. 363 of *Astronomische Nachrichten*. Six equations are formed expressing the relations between the differences of the observed and computed normal places, and the corrections of the elements necessary to be applied in order to make these differences disappear. The solution of these equations gives the required corrections of the elements; but should they turn out considerable, in which case the values of their co-efficients in the equations may not have been got with sufficient accuracy, it will be advisable to repeat the process, starting now from the elements corrected. The requisite calculations, if more than one repetition are not necessary, are not laborious, for the calculations are easily made, and great precision need not be affected. In place of Mädler's expressions for the co-efficients of Δe (the correction of the ex-centricity), $\Delta \mu$ (the correction of the mean annual motion), and ΔT (the correction of the time of perihelion passage), I have employed those given by Gauss in the *Theoria Motus Corporum Cœlestium.* Indeed, the calculations are so simple, that in the case of more observations than six, but not too numerous, the method of *minimum* squares may be applied to them all; for if the proper weight can be assigned to each observation depending on its probable error, the orbit to represent best all the observations will be obtained.

I have applied this second part of the process to six selected observations of angles of position of γ Virginis. I assumed for the approximate orbit Mädler's corrected one in the No. of *Astronomische Nachrichten* referred to. Several repetitions would have been spared, if I had started from his more correct one given in No. 452 of *Astronomische Nachrichten.* However, I at last obtained the following orbit:

Time of perihelion passage - - - -	1836·29
Mean annual motion - - - -	– 2° 30′·59
Ex-centricity - - - - - -	0·8590
Perihelion on orbit - - - - -	319° 23′
Inclination - - - - - -	23° 5′
Node - - - - - - -	70° 48′
Time of revolution - - - -	143·44 years.

The following is a comparison between the observed angles of position and those computed in this orbit:

Date.	Angle observed.	Angle computed.	Difference.	Observer.
	° ′	° ′	° ′	
1718·22	150 50	161 16	– 10 26	Pound and Bradley.
1756·29	144 22	141 1	+ 3 21	Mayer.
1781·89	130 44	130 44	0 0	Herschel I.
1803·20	120 19	120 21	– 0 2	"
1822·25	103 24	103 17	+ 0 7	Herschel II. and South.
1825·32	97 24	97 58	– 0 34	Struve and South.
1828·36	91 0	90 26	+ 0 34	Herschel II. and Struve.
1829·30	88 0	87 18	+ 0 42	" "
1830·38	82 5	82 53	– 0 48	Herchel II.
1831·38	74 54	77 41	– 2 47	Smyth.
1832·40	71 24	70 42	+ 0 42	"
1833·34	63 9	61 21	+ 1 48	"
1834·30	47 9	46 27	+ 0 42	"
1835·40	15 0	11 56	+ 3 4	"
1837·21	265 24	266 8	– 0 44	"
1838·28	235 42	235 26	+ 0 16	"
1839·40	217 12	218 23	– 1 11	"
1843·20	192 12	192 38	– 0 26	"

The first two differences are perhaps not greater than might be expected from the modes of observation. The greater difference of 1831 is evidently owing to an error of observation; while that of 1835 may be accounted for by the extreme difficulty in the measurement, owing to the closeness of the stars. I have not computed the observation of 1836, as it must be liable to a very considerable error.

These elements appear to be now so correct, that I believe they may be safely employed as the groundwork of future investigations. They differ very slightly from Mädler's last elements given in No. 452 of *Astronomische Nachrichten*, as the following comparison shows:

	Mädler.	Henderson.
Time of revolution - -	145·409 years	143·44 years.
Mean annual motion - -	— 148″·453	150″·59
Time of perihelion passage -	1836·313	1836·29
Node - - - -	60° 37″·6	70° 48′
Inclination - - - -	24° 39″·2	23° 5′
Perihelion - - -	318° 59″·7	319° 23′
Ex-centricity - - -	0·86815	0·8590

The difference of 10° in the position of the node produces scarcely any sensible effect in the computed angles of position. Hence the place of the node will always be subject to uncertainty.

I have not computed the value of the semi-axis major. This is to be done by comparing the observed and computed distances.

The agreement between the observed and computed places is such, that in my opinion it shows satisfactorily that the motions of these stars are subject to the Newtonian law of gravitation.

The result of this investigation has given me great confidence in Mädler's results for other stars. In this instance he has gone the right way to work, and has obtained a good result.

I remain, my dear Sir,

Yours faithfully,

T. HENDERSON.

P. S. I omitted to say that the six angles of position from which I computed the orbit are those of 1781, 1803, 1822, 1835, 1837, and 1843. I also omitted to say that Mayer observed a lunar occultation of the two stars on April 3, 1757. (Mayer's *Observations*, Part II., p. 18.) Immersions at the dark limb—interval between the two immersions 16 seconds. This observation may yet be calculated. Mädler's last elements, as given in No. 452 of *Astronomische Nachrichten*, are adapted for angles of position numbered 180°, differently from yours, Herschel's, &c.

INDEX.

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