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Leconte

COSMOS:

SKETCH

OF A

PHYSICAL DESCRIPTION OF THE UNIVERSE.

BY

ALEXANDER VON HUMBOLDT.

VOL. III.—PART I.

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

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COSMOS:

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INTRODUCTION.

In pursuance of the aim which I had proposed to myself, as attainable in a degree commensurate with my own powers and with the present state of knowledge, I have considered Nature, in the two volumes of the Cosmos which have already appeared, in a twofold point of view. I have sought to represent her, first, in the pure objectivity of external phænomena, and, next, as the reflex of the image received through the senses on the mirror of man's inner being, his ideas and feelings.

The external world of phænomena has been described under the scientific form of a general picture of Nature in her two great spheres, uranologic and telluric; beginning with the stars which glimmer amidst nebulæ in the most distant regions of space, and descending through our planetary system to the vegetable covering with which the earth is invested, and to the minutest organisms often floating in the air, which escape our unassisted vision. In order to allow us to contemplate with greater clearness the existence of a common bond comprehending the whole of the material universe, the government of never changing laws, and the causal connection of entire groups of phænomena so far as is yet known to us, it was necessary to avoid the accumulation of detached facts. Such care appeared more particularly requisite where, in the telluric sphere of the Cosmos, by the side of the dynamic actions of moving forces, we find manifested the powerful influence of the specific heterogeneity of matter. In the sidereal or uranological part of the Cosmos, the problems, in all that can be reached by observation, are in their nature of admirable simplicity; being by the theory of motion susceptible of rigid calculation, according to the attracting force of matter and the quantity of its mass. If, as I believe, we are justified in regarding the aerolites, or meteoric asteroids, as parts of our planetary system, they, but they only, by falling upon our globe, enable us to recognise diversity of substance in bodies belonging to cosmical space external to our own planet. (1) We have here the reason why terrestrial phænomena have hitherto been less generally, and less successfully, subjected to mathematical development and treatment, than have the movements of the heavenly bodies, with their mutual perturbations and periodical returns, governed, so far as our perceptions extend, only by the one fundamental force of homogeneous matter.

My endeavours in the telluric portion of the description of Nature were directed to the arrangement of the phænomena in significant order, suggestive of their causal connection. The terrestrial globe was described in its form, its mean density, the gradations of its temperature increasing with increasing depth, its electro-magnetic currents and evolution of polar light. On the reaction of the interior of the planet upon its external crust depend all the phænomena of volcanic activity; comprising those of earthquakes in more or less complete circles of waves, as well as their simply dynamic effects, eruptions of gas, hot springs, and mud. The most powerful manifestation of internal terrestrial activity is the elevation of fire-emitting mountains. We have described volcanoes, both central and forming chains, not only as destructive agents, but also as producing or emitting various substances, and still forming under our eyes, for the most part periodically, those classes of rock which we term eruptive rocks; while, in contrast with this formation, we have also shewn the precipitation, likewise still going on, of sedimentary rocks from fluids containing their minute constituent particles in solution or suspension. Such a comparison of that which is still in process of elaboration, with those strata of the crust of the globe which have long since been solidified, conducts to the distinction of geological epochs, and to a secure determination of the successive age of formations, in which lie enveloped, in successive series chronologically recognisable, the remains of extinct races of plants and animals, forming the Floras and Faunas of an earlier world. The modes of formation, alteration, and upheaving of the strata, varying at different geological epochs, are conditions on which all the particular features of the surface of the globe depend: on them depend the distribution of land and water, and the configuration and extent of the continental masses in the vertical as well as in the horizontal direction. These features of the earth's surface constitute, in their turn, conditions on which depend the thermic state of oceanic currents, the meteorological processes of the aerial covering of our planet, and the geographical and typical distribution and extension of animal and vegetable forms. This brief allusion to the order and manner in which the various telluric phænomena are presented, in the view or picture of Nature in the first volume of my work, is, I think, sufficient to shew that the mere bringing together of great and apparently complicated results of observation, may promote insight into their causal connection. On the other hand, the interpretation of Nature is obscured when the description languishes under too great an accumulation of insulated facts.

If, in a carefully designed objective representation of the world of phænomena, completeness in the enumeration of particulars ought not to be desired, neither should it be sought for in the description of the reflex of external nature on the human mind. Here it was needful to draw the limits still closer. The measureless domain of human thought, fertilised for thousands of years by the impulses and powers of mental activity, presents in different races, and at different stages of civilisation, at one time a cheerful, and at another a melancholy, aspect; (2) a delicate appreciation of the beautiful in nature, or a dull insensibility to all that she can display. At an early period we see the human mind directed to the deification of natural forces or powers, and of certain objects of the material universe; at a later period it followed religious impulses of a higher and more purely spiritual character. (3) The internal reflex of external phænomena influences in a variety of ways the mysterious process of the formation of language, (4) a process in which original physical temperament, and the impressions received from surrounding nature, both act as powerful concurrent elements. Man elaborates within himself the rough materials supplied through the senses; and the results or products of such mental processes belong as essentially to the domain of the Cosmos, as do the external phænomena which are reflected in the internal mirror of the mind.

As the image of nature reflected under the influence of excited creative imagination cannot be preserved pure and true, there arises, by the side of what we call the actual or external world, an ideal or internal world, filled with fantastic and partly symbolical myths, and animated by creatures of fabulous shape, whose different parts are borrowed either from various animals of the present creation, or even from the remains of extinct species. (5) Marvellous and fabulous flowers and trees spring from the mythical soil, as in the songs of the Edda, the giant ash, the world-tree, Ygdrasil, whose branches rise above the heavens, while one of its triple roots reaches down to the raging fountains of the lower world. (6) Thus the cloud-land of physical myths is filled, according to the particular character of the race and climate, either with pleasing images or shapes of terror, and these enter into the circles of ideas of later generations, to whom they are bequeathed.

If my published work does not correspond sufficiently to the title, of which I have often acknowledged the imprudent boldness, the reproach of incompleteness must especially attach to that portion which touches on the spiritual life in the Cosmos, or the reflex image of external nature in the domain of human thought and feeling. In this part of my undertaking I have more particularly contented myself with dwelling on the subjects which lay most in the direction of my previously long-cherished studies: on the manifestations of the more or less vivid feeling of nature in classical antiquity, and in modern times;—on the fragments of poetic description of nature, whose tone of colouring has been so materially influenced by individuality of national character, and by the religious monotheistic view of creation;—on the pleasing magic of landscape painting;—and on the history of the physical contemplation of the Universe; *i. e.* the history of the gradual development, in the course of two thousand years, of the recognition of the unity of phænomena, and of the Universe as a Whole.

In a work so comprehensive, and at once scientific and literary in its aim, all that a first and imperfect attempt can aspire to accomplish is, to influence rather by what it may call forth than by what it can itself supply. A book of Nature, which may be worthy of so exalted a title, can only be looked for when the natural sciences, notwithstanding their inherent incapability of absolute completion, shall yet, by continued progress and extension, have reached a higher standing point; and when thus a new and clearer light shall have been thrown alike on the two spheres of the one Cosmos,—the external world perceived by the senses, and its internal reflection in the mind.

I think I have sufficiently indicated the reasons which have determined me not to give to the general picture of Nature a wider extension. It remains for the third and last volume of my work to supply some of the deficiencies of the earlier ones, and to put forward those results of observation which form the principal basis of present scientific opinion. The order of succession in which these results are presented will again be that which, in conformity with previously enounced principles, was followed by me in the general view of Nature. Before, however, proceeding to particular results in the several sciences, I desire still to add a few more general elucidatory considerations. The unexpected favour with which my undertaking has been received, both in my own and in other countries, makes me doubly feel the need of expressing myself once more as distinctly as possible in reference to the fundamental idea of the entire work; and respecting requirements which I have never even attempted to fulfil, because, according to my individual view of our experimental knowledge, their fulfilment could not be contemplated by me. With these considerations, to which I am led by the desire of justifying my manner of proceeding, there are naturally associated historical reminiscences of earlier attempts to discover the idea of the Universe, which should so comprehend its structure as to reduce all phænomena, in their causal connection, to a single principle.

The fundamental principle (7) of my work on the Cosmos, as developed by me more than twenty years ago in lectures delivered in the French and German languages, at Paris and at Berlin, consists in the constant tendency or endeavour to embrace the phænomena of the universe as a natural Whole; to shew how, in particular groups of the phænomena, those conditions which are common to the entire group,—*i. e.* the government of great and comprehensive laws,—have been discovered and recognised, and by what means we ascend from the knowledge of these laws to that of their causal connection. Such a tendency to advance continually towards the comprehension of the plan of the Universe, or the order of Nature, commences with the combination and generalisation of particular facts;—with the recognition of the conditions under which phænomena, *i. e.* the manifestations of physical alterations, are always reproduced in a similar manner: it conducts to the thoughtful consideration of the materials supplied by observation and experiment; but it does not conduct to a "view of the Universe derived from speculation and the development of thought alone, or to a science or doctrine of the unity of Nature apart from experience." We are, I here repeat it, still far from the time, when it may be thought possible to concentrate all the perceptions of our senses into the unity of one comprehensive idea embracing the whole of Nature. The safe path was perceived a full century before Francis Bacon, by Leonardo da Vinci, and indicated by him in a few words:—"Comminciare dall' esperienza, e per mezzo di questa, scoprirne la ragione." (8) In many groups of phænomena we must, indeed, still content ourselves with a deduction of empirical laws; but the highest object of all investigation into nature, though seldom attained, is the discovery of physical causes. (9) This is most satisfactorily and conclusively accomplished, when it is possible to connect the laws of phænomena with the causes which explain them, by the intervention of mathematical reasoning. It is, however, only in some particularly favoured parts of natural science that the "physical description" coincides with the "physical explanation of the universe." The two expressions cannot yet be regarded as identical. The inherent grandeur and solemnity of that mental labour, the boundaries of which are hereby marked, consist in the elevating consciousness of the infinite nature of the object of its efforts,—the comprehension of the unknown and inexhaustible fulness of creation, whether formed or in process of formation, whether existing or to be hereafter developed.

Such efforts, acting throughout all ages, must have led often, and under many various forms, to the illusory hope of having attained the goal, and found the principle by which all that is variable in the material universe, the totality of all the phænomena which are cognizable by the senses, might be explained. After a long period in which, in conformity with the early fundamental mode of contemplation of the Hellenic national mind, the forming, transforming, and destroying forces of nature had been honoured as divine or spiritual powers, clothed in human forms, ([10]) there became developed amidst the physiological fancies of the Ionic school the germ of a scientific contemplation of Nature. The first cause of all phænomena was explained in two different directions ([11]), sometimes according to mechanical, and sometimes according to dynamic views,—from the assumption of concrete corporeal principles called "elements of nature," or from processes of rarefaction and condensation. The hypothesis, primarily perhaps of Indian origin, of four or five substantially different elements, has continued, from the didactic poem of Empedocles to the most recent times, to mingle itself with all systems of natural philosophy, forming an evidence and monument of high antiquity of man's desire to seek for the generalisation and simplification of ideas, not only in forces, but also in the qualitative essences of substances.

In the later development of the Ionic physiology, Anaxagoras of Clazomene passed from the assumption of material forces to the idea of a Spirit, distinct from all matter but intermixed with all its homogeneous ultimate particles. He spoke of the world-regulating Mind (νοῦς) governing the continually progressive formation of the Universe, and being the original cause of all motion, and thus of all physical phænomena. It is by the assumption of a centrifugal revolving movement (12), by whose intermission, previously noticed, he accounts for the fall of meteoric stones, that Anaxagoras explains the apparent motion of the celestial sphere from East to West. This hypothesis indicates the commencement of vortex-theories, which more than two thousand years afterwards became of much cosmical importance by the writings of Descartes, Huygens, and Hooke. This work is not the place in which to enquire whether Anaxagoras means by the "world-regulating Mind" the Godhead itself, or whether he only means to speak pantheistically of a spiritual principle in the general life of Nature. (13)

In marked contrast with the two divisions of the Ionic School, though likewise embracing the whole Universe, is the mathematical symbolism of the Pythagoreans. In the phænomena of the Universe, their regards were fixed exclusively on the dominion of law in the determination of form (the five fundamental forms); and on the ideas of number, measure, harmony, and antithesis. To them, *things* were mirrored in *numbers*, which are as it were an "imitative representation" (μίμησις) thereof. They saw in the illimitability of numbers, inasmuch as they can be endlessly repeated and increased, the character of eternity, and of the infinitude of Nature. They considered that the essence of things may be known by ratios of numbers, and their alterations and transformations by combinations of numbers. Plato's Physics also contain attempts to reduce all the essences of substances in the universe, and their gradations of changes, to corporeal forms; and these to the simplest (triangular) plane figures. (14) But what the ultimate principles (as it were the elements of the elements), may be, "this," said Plato, with modest diffidence, "is known to God alone, and to whomso is beloved by Him among men." This mathematical treatment of physical phænomena, the formation of atomic doctrines, the philosophy of measure and of harmony, have continued to a late period to influence the development of the natural sciences: they have also contributed to lead fanciful discoverers astray from the true road, into by-paths which it may be requisite to notice in the history of the physical contemplation of the Universe. "There dwells a peculiar and fascinating charm recognised by all antiquity in the simple relations of time and space as manifested in tones, numbers, and lines." (15)

The idea of the order and government of the Universe shines forth pure and exalted in the writings of Aristotle. All the phænomena of Nature are described in the "Auscultationes Physicæ" as moving vital activities of a Universal Power. On the "unmoved Motor of the World depend Heaven and Nature," (16)—Nature being the terrestrial sphere of phænomena. The "Orderer," and the final cause of all alterations which can be perceived, must be regarded as imperceptible to sense, as distinct from all matter. (17) Unity in the different manifestations of force in substances is raised by Aristotle to the rank of a leading principle, and these manifestations of force are themselves always reduced to motions. Thus we even find in the book "De Anima" (18) the germ of the undulatory theory of light. The sensation of seeing follows from a movement or vibration of the medium between the sight and the object seen, not from effluxes either from the object or from the eye. Hearing is compared with seeing, as sound is also a consequence of concussion of the air.

In inculcating the exercise of thoughtful reason in the search after that which is general or universal amidst the particular facts perceived by the senses, Aristotle always comprehends the whole of Nature, and the internal connection not only of forces but also of organic forms. In the book which treats of the parts (organs,) of animals, he clearly enounces his belief in the gradual chain of beings ascending from lower to higher forms. Nature proceeds in uninterrupted progressive development from the inanimate (elementary,) through plants to animals: advancing first to "what indeed is not properly an animal, but so nearly allied thereto that it is on the whole but little distinguished from one." (19) In the transition of forms "the intermediate steps are almost insensible." (20) The unity of Nature is to the Stagirite the great problem of the Cosmos. He says, with singular vivacity of expression, "In Nature nothing is isolated; there is no want of connection as in a bad tragedy." (21)

In all the physical writings of this profound, sage, and accurate observer of nature, we cannot fail to recognise the philosophical tendency to subordinate all the phænomena of the one Cosmos to a single principle of explanation; but the defective state of knowledge, and ignorance of the method of experimenting, (*i. e.*, of calling forth phænomena under definite conditions), prevented even small groups of physical processes from being comprehended in their causal connection. All was reduced to ever recurring antitheses of cold and heat, moisture and drought, primitive density and rarity; and even to the effecting of alterations in the material world by means of a kind of internal antagonism (antiperistasis), which reminds us of our present hypotheses of opposite polarities and the contrasts of + and —. [22] Aristotle's supposed solutions of problems do but reproduce the facts themselves in disguise; and in explaining meteorological and optical processes, his elsewhere ever powerful and concise style often passes into self complacent diffuseness or Hellenic verbal redundancy. As the mind of Aristotle was but little directed to diversity of substances, but chiefly to the consideration of motion, we see the fundamenal idea of ascribing all telluric natural phænomena to the impulse of the motion of the heavens, (*i. e.* the revolution of the celestial sphere), recurring continually, always indicated and cherished with special partiality, but not presented with definiteness or precision. [23] The impulse here spoken of imports only the communication of motion as the ground of all terrestrial phænomena. Pantheistic views are excluded: the Godhead is the highest "presiding Unity, regulating all things, revealing Himself in all spheres of the entire Universe, giving to each creature its destination, and holding all together by His absolute power." [24] The ideas of purpose and adaptation are not so much applied to the subordinate processes of nature, (those of inorganic elementary nature), as by preference to the higher organisations [25] of the animal and vegetable worlds. It is remarkably striking that in the teaching of Aristotle, as if he had been aware of the distribution of masses and the existence of perturbations, the Deity employs a number of astral Spirits to maintain the planets in their eternal appointed courses. ([26]) The stars display the image of the Divinity in the visible world. The small pseudo-Aristotelian book of the Cosmos, which is certainly of Stoic origin, is not mentioned here, notwithstanding its name. It presents, it is true, in a descriptive manner, and often with animated rhetoric and vivacity of colouring, both the heavens and the earth, and the currents of the ocean and of the atmosphere; but it manifests no tendency to reduce the phænomena of the Cosmos to general physical principles, *i. e.*, to principles founded in the properties of matter.

I have dwelt the longer on the most brilliant epoch of antiquity, as respects views of Nature, in order to place in opposition the earliest and the more recent attempts at generalisation. In the intellectual movement which has taken place in the course of centuries, and which in reference to the enlargement of the domain of cosmical contemplation was described in another portion ([27]) of the present work, the end of the 13th and beginning of the 14th centuries were particularly distinguished; but the Opus Majus of Roger Bacon, the Mirror of Nature of Vincentius of Beauvais, the Physical Geography (Liber Cosmographicus) of Albertus Magnus, the Picture of the World (Imago Mundi) of Cardinal Petrus de Alliaco, (Pierre d'Ailly), are works which, however powerfully they may have influenced their cotemporaries, do not correspond in their contents to the titles which they bear. Among the Italian opposers of Aristotle's Physics, Bernardino Telesio of Cosenza was the founder of a "Rational" system of natural science, in which he regarded all the phænomena of matter, itself passive, as the effects of two incorporeal principles, (activities, forces, or powers,) heat and cold. Even the whole of organic life, ("animated" plants and animals) is the production of these two eternally-divided forces, one of which, heat, belongs to the celestial, and the other, cold, to the terrestrial sphere.

With fancy still more unregulated, but gifted with a profound spirit of research, Giordano Bruno of Nola attempts in three works entitled "De la Causa Principio e Uno," "Contemplationi circa lo Infinito, Universo e Mondi innumerabili," and "De Minimo et Maximo," to embrace the entire Universe. (28) In the "Natural Philosophy" of Telesio, a cotemporary of Copernicus, we perceive at least the endeavour to reduce the variations of matter to two of its fundamental forces, "which are indeed imagined as acting from without," yet are similar to the fundamental forces of attraction and repulsion in the dynamic doctrines of Boscovich and Kant. The cosmical views of Giordano Bruno are purely metaphysical; they do not seek the causes of sensible phænomena in matter itself, but touch on "the infinity of space filled with self luminous worlds, the animation of these worlds by souls, and the relations of the highest Intelligence, God, to the universe." Although himself but scantily furnished with mathematical knowledge, Giordano Bruno was, nevertheless, up to the time of his dreadful martyrdom, (29) an enthusiastic admirer of Copernicus, Tycho Brahe, and Kepler. Although a cotemporary of Galileo, he died before the invention of the telescope by Hans Lippershey and Zacharias Jansen, and could not therefore witness the discovery of Jupiter's satellites, the phases of Venus, and the nebulæ. With daring confidence in what he termed "lume interno, ragione naturale, altezza dell' intelleto," he gave himself up to happy conjectures respecting the movement of the fixed stars, the planetary nature of comets, and the deviation of the figure of the Earth from that of a perfect sphere. ([30]) Grecian antiquity is also full of such uranological divinations, which have been subsequently realised.

In the development of thought respecting cosmical relations of which the leading forms and epochs have been here enumerated, it was Kepler who, fully 78 years before the publication of Newton's immortal work of the "Principia Philosophiæ naturalis," came nearest to a mathematical application of the doctrine of gravitation. Although the Eclectic Simplicius expressed in a general manner that "the non-falling of the heavenly bodies was caused by the centrifugal force having the upper hand of the proper falling force, the downward traction;"—although John Philoponus, a disciple of Ammonius, the son of Hermeas, ascribed the movements of the heavenly bodies "to a primitive impetus and to the continued tendency to fall;"—and although Copernicus, as was noticed in an earlier part of the present work, describes the merely general idea of gravitation, as it acts in the Sun as the centre of the planetary world, and in the Earth and Moon, in these remarkable words: "Gravitatem non aliud esse quam appetentiam quandam naturalem partibus inditam a divina providentia opificis universorum, ut in unitatem integritatemque suam sese conferant, in formam globi coëuntes;" yet it is in Kepler, in the Introduction to the book "De Stella Martis," ([31]) that we first find numerical quantities assigned to the attracting forces which the Earth and the Moon exercise upon each other in the ratio of their masses. It distinctly adduces the ebb and flow of the sea ([32]) as a proof that the attracting power of the Moon, (virtus tractoria) extends as far as the Earth; and he even says that this force, "similar to that which the magnet exercises upon iron," would deprive the Earth of water, if the Earth itself ceased to attract the water. Unfortunately, ten years later, in 1619, this great man, perhaps out of deference to Galileo, who ascribed the ebb and flow to the rotation of the Earth, gave up the true explanation, and in the Harmonice Mundi described the Earth as a living animal whose whale-like respirations, in periodical alternations of sleeping and waking dependent on the solar time, cause the swelling and sinking of the ocean. The profound mathematical genius, recognised by Laplace, which shines forth in one of Kepler's writings (33), makes us regret that the discoverer of the three great laws of all planetary movement did not persevere in the path, in which his views respecting the attraction of masses had led him to enter.

Descartes, furnished with a greater variety of knowledge in the natural sciences than Kepler, and himself the founder of several parts of a mathematical system of physics, undertook to embrace the whole world of phænomena, the celestial sphere, and all that he knew of animate and inanimate terrestrial Nature, in a work to which he gave the names of "Traité du Monde" and "Summa Philosophiæ." The organization of animals, and particularly that of man, for the understanding of which he pursued for eleven years a systematic course of anatomical study, (34) was to form the concluding portion of the work. In his correspondence with Father Mersenne, we find many complaints of the slow progress of the undertaking, and of the difficulty of arranging and combining such numerous materials. This Cosmos, which Descartes always called his World (son

Monde), was finally to have been sent to press at the conclusion of 1633; but the report of the sentence passed upon Galileo in the Inquisition at Rome (which was only made known four months later, in October, 1633, by Gassendi and Bouillaud), arrested its progress, and deprived the world of a great work, executed with so much labour and care. The motives for its non-publication were the love of a quiet and peaceful life in his retirement at Deventer, and a pious anxiety not to shew himself disrespectful to the Pope's decree against the Earth's planetary motion. (35) It was not until 1664, fourteen years after the philosopher's death, that some fragments of the work were printed under the strange title of "Le Monde, ou Traité de la Lumière." (36) The three chapters which treat of Light hardly form a fourth part of the whole. On the other hand the sections which belonged originally to Descartes' Cosmos, and contained considerations on the motion and solar distance of the planets, on terrestrial magnetism, on tides, and on earthquakes and volcanoes, were transferred to the third and fourth parts of the celebrated work entitled "Principes de la Philosophie."

The "Kosmotheoros" of Huygens, which was not published until after his death, notwithstanding its high-sounding and significant name, hardly deserves to be mentioned in this enumeration of cosmical essays. It contains the dreams and conjectures of a great man on the vegetable and animal worlds of distant heavenly bodies, and especially on the altered forms under which mankind may appear there. One seems to be reading Kepler's "Somnium Astronomicum," or Kircher's "Ecstatic Journey." As Huygens already, like the astronomers of the present day, allowed to the Moon neither air nor water, (37) he finds the supposed existence of lunar men present to him still greater difficulties than that of the inhabitants of the remoter planets "rich in clouds and vapour."

The immortal author of the Philosophiæ Naturalis Principia Mathematica, succeeded, by the assumption of a single all-governing fundamental moving force, in embracing the whole uranological portion of the Cosmos in the causal connection of its phænomena. Newton first raised physical astronomy to a mathematical science, and made it the solution of a great problem of mechanics. The quantity of matter in each heavenly body gives the measure of its attracting force, a force which acts in the inverse ratio of the square of the distance, and determines the magnitude of the perturbing actions which not only the planets, but all the heavenly bodies in space, exert upon each other. But the Newtonian theorem of gravitation, so admirable for simplicity and generality, is not limited in its cosmical application to the sphere of uranology; it governs also terrestrial phænomena in directions still partly uninvestigated; it gives the key to periodic movements in the ocean and in the atmosphere, (38) to the solution of problems of capillarity, endosmose, and many chemical electro-magnetic and organic processes. Newton himself (39) already distinguished the "attraction of mass," as it manifests itself in all celestial bodies and in the phænomena of the tides, from "molecular attraction," which acts at infinitely small distances and in the closest contact.

Thus among all human efforts to reduce all variations taking place in the world known to us through our senses to a single fundamental principle, the doctrine of gravitation shews itself the most comprehensive and the most rich in cosmical promise. It is indeed true, notwithstanding the brilliant progress made in modern times in Stœchiometry (calculation of chemical elements and of the ratios of volume in compound gases), we are not yet able to reduce all theories of substances to a mathematical explanation. Empirical laws have been discovered, and in following the widely extended views of the atomic or of the corpuscular philosophy, many things have been rendered more accessible to mathematical treatment; but from the boundless heterogeneity of matter, and the multifarious conditions of aggregation of what are called the particles of mass, the demonstrations of these empirical laws can as yet by no means be derived from the theory of "contact attraction," with the same certainty as is effected by the establishment of Kepler's three great laws on the basis of the theory of "mass attraction" or gravitation.

Yet, after Newton had recognised all the motions of the heavenly bodies as consequences of one single force, he did not, with Kant, regard gravitation itself as an essential property of matter, (40) but as either derived from a higher force still unknown to him, or as the result of a "revolving of the Ether which fills all space, and is more rare in the intervals between the particles of mass, and increases in density outwards." The latter view is developed in detail in a letter to Robert Boyle, (41) dated 28th February, 1678, which ends with the words, "I seek in the Ether the cause of gravitation." Eight years later, as may be seen from a letter to Halley, Newton gave up this hypothesis of denser and rarer Ether altogether. (42) It is a striking circumstance that, in 1717, nine years before his death, in the extremely short preface to the second edition of his Optics, he thought it necessary to declare explicitly that he by no means regarded gravitation as an "essential property of bodies": (43) while more than a century before, in 1600, Gilbert had viewed magnetism as a force inherent in all matter. So much did the most profound of thinkers, Newton himself, who ever leaned so strongly to experience, hesitate in respect to the "ultimate mechanical cause" of motion.

The establishment of a science of Nature, from the laws of gravity up to the formative impulse in animated bodies, as one organic Whole, is no doubt a brilliant problem, and one worthy of the human intellect; but the imperfect state of so many parts of our knowledge places insuperable difficulties in the way of its solution. The impossibility of complete experimental knowledge, in a boundless sphere of observation, renders the problem of explaining all the changes of matter from the powers of matter itself an "indeterminate problem." What is perceived is far from exhausting what is perceivable. If, to recall only the progress of the time nearest to our own, we compare the imperfect knowledge of nature possessed by Gilbert, Robert Boyle, and Hales with the present, and if we remember that the rate of progress is a rapidly increasing one, we may have some idea of the periodical endless transformations which still await all the physical sciences. New substances and new powers will be discovered. Even though many natural processes, as those of light, heat, and electro-magnetism, being reduced to movement (undulations), have become accessible to mathematical treatment, yet there remain the often referred to, and perhaps unconquerable, problems of the cause of chemical diversity of substance, and of the order and proportions, seemingly not reducible to any laws, of the magnitudes, densities, inclinations of axis, and eccentricities of orbit of the planets, the numbers and distances of their satellites, the form of continents, and the position of their loftiest mountain chains. All these circumstances (having reference to space geographical or celestial), which are here instanced merely as examples, can as yet only be regarded as natural facts, of which we know the existence but not the explanation. But although neither the causes nor the connection of these facts are yet known to us, I do not therefore term them in any sense accidental. They are doubtless the results of events or occurrences in space at the time of the formation of our planetary system, and of geological phænomena which accompanied or preceded the elevation of the outermost strata of our globe into continents and mountain chains. Our knowledge of the early period of the physical history of the Universe does not reach back far enough to enable us to describe that which exists in its process of formation. ([44])

But although it has not yet been possible in all cases fully to recognise the causal connection between phænomena, no part of the domain of the natural sciences can be excluded from the study of the Cosmos, or the physical description of the Universe. Rather that study comprehends the whole of such domain, the phænomena of both spheres, celestial and telluric; but it does so only under the single point of view of the tendency towards the recognition of the Universe as a Whole. ([45]) As, in the description of what has taken place in the moral and political sphere, the historian ([46]) cannot directly discern, according to man's view, the plan of the government of the world, but can only divine it through the ideas by which it manifests itself; so the investigator of nature, in seeking to present cosmical relations, is penetrated by the conviction that the number of impelling, forming, and producing powers or forces of the material universe, is far indeed from having been exhausted by the results hitherto obtained, either by immediate observation, or by the analysis of phænomena.

A.

RESULTS OF OBSERVATION IN THE URANOLOGICAL PORTION OF THE PHYSICAL DESCRIPTION OF THE UNIVERSE.

We commence afresh with the depths of space and with the remote sporadically-scattered clusters of stars which present themselves to telescopic vision as faintly shining nebulæ. We descend step by step to the double stars, often of two different colours, which revolve around a common centre of gravity; to the nearer strata of stars, one of which appears to include our planetary system; and lastly, through this planetary system to the air- and sea-surrounded spheroid which we inhabit. I have noticed in an earlier volume, in the introduction to the general picture of Nature, (47) that this order is the only one which is suitable to the particular character of a work which treats of the Cosmos; in contradistinction to an arrangement more directly accordant with the immediate perceptions of sense, which should begin with our terrestrial dwelling-place and the organic creation by which its surface is enlivened, and should proceed from the apparent to the real motions of the heavenly bodies.

The uranological domain, as opposed to the telluric, divides itself conveniently into two portions: one of which includes Astrognosy, or the heaven of the fixed stars; and the other, our solar and planetary system. The imperfect and unsatisfactory character of this nomenclature and these definitions need not be again dwelt on here. Names were introduced into the natural sciences before the true differences and distinctions between objects were sufficiently known.(48) Such questions are, however, of less importance than the connection of ideas, and the order in which the objects are to be treated; whilst novelties in the names of groups, and the diversion of names in frequent use from the signification they have hitherto borne, are objectionable, as tending to perplexity and confusion.

a. *Astrognosy (heaven of the fixed stars).*

Nothing in space is in repose; not even what are called the fixed stars, as Halley(49) first attempted to shew in the case of Sirius, Arcturus, and Aldebaran, and as has been proved incontestably in modern times in the case of many other stars. In the course of 2100 years of observation (since Aristillus and Hipparchus), the bright star Arcturus has altered its place, relatively to the neighbouring fainter stars, as much as two and a half times the diameter of the moon. Encke remarks that the star μ in Cassiopea would appear to have moved three and a half times, and the star 61 Cygni six times, the diameter of the moon from their respective places, if we regard the old observations as sufficiently exact to justify the conclusion. Inferences based on analogies support the conjecture that progressive, and probably also rotatory, motion exists everywhere. The name "fixed star" leads to erroneous suppositions; whether it be taken in its first signification among the Greeks of set or fixed in the crystal firmament, or according to the later and more Roman interpretation of steadfast, resting, and immoveable. One of these ideas necessarily implied and led to the other. In Grecian antiquity (at least going back as far as Anaximenes, who belonged to the Ionic school, or as the Pythagorean Alcmæon), all the stars or heavenly bodies were divided into moving (*ἄστρα πλανώμενα* or *πλανητά*) and non-moving stars (*ἀπλανεῖς ἀστέρες* or *ἀπλανῆ ἄστρα*). (50) Besides this latter generally employed term, which Macrobius latinises in the Somnium Scipionis by Sphæra aplanes,(51) we find in Aristotle repeatedly (as if he wished to introduce a new technical term) the name of *ἐνδεδεμένα ἄστρα*, instead of *ἀπλανῆ*. (52) From this form of expression there followed, with Cicero, sidera infixa cœlo; with Pliny, stellas quas putamus affixas; and with Manilius, even astra fixa, just like our "fixed stars." (53) The idea of being fixed or set in the solid sky, led to the secondary implied idea of immobility, or "remaining fixed in one place;" and thus, in Latin versions, throughout the whole middle ages, the original meaning of the word infixum or affixum sidus, was gradually set aside, and the idea of immobility alone retained. We find the impulse to this already given in the highly rhetorical passage of Seneca (Nat. Quæst. vii., 24), on the possibility of discovering new planets: "credis autem in hoc maximo et pulcherrimo corpore inter innumerabiles stellas, quæ noctem decore vario distinguunt, quæ aëra minime vacuum et inertem esse patiuntur, quinque solas esse, quibus exercere se liceat; *ceteras stare fixum et immobilem populum?*" This "quiet, immoveable people" is nowhere to be found.

In order to divide conveniently into groups the principal results of actual observation, and the conclusions or conjectures to which they lead, I propose to distinguish, in the astrognostic portion of the description of the Universe, the following heads:—

I. Considerations on space, and on what is supposed to occupy it.

II. Natural and telescopic vision; the scintillation of stars; the velocity of light; and photometric experiments on the intensity of sidereal light.

III. The number, distribution, and colour of stars; clusters of stars; and the milky way, in which are only a few nebulæ.

IV. Newly appeared stars; vanished stars; and stars which vary periodically.

V. The proper motion of the fixed stars; the problematical existence of dark bodies; the parallax and measured distance of some fixed stars.

VI. Double stars, and their periods of revolution round a common centre of gravity.

VII. Nebulæ, which in the Magellanic clouds are intermixed with many clusters of stars; and the black spots or patches in the sky ("coal-bags").

I.

COSMICAL SPACE, AND CONJECTURES RESPECTING WHAT APPEARS TO OCCUPY THE INTERVALS BETWEEN THE HEAVENLY BODIES.

We may in some respects view a commencement of the physical description of the Universe, by the consideration of what fills the intervals between the stars in the remote regions of space and remains inaccessible to our organs, in the same light as mythical commencements of the world's history. In infinite space, as in infinite time, everything appears in uncertain and often illusive twilight. Imagination is then doubly stimulated to draw from her own abundance, and to give to the indeterminate and varying forms outline and duration. ([54]) Such an avowal may, I hope, suffice to shield me from the reproach of having confounded what direct observation or measurement have raised to mathematical certainty, with what rests only on very imperfect induction. Wild reveries belong to the romance of physical astronomy: nevertheless, minds exercised in scientific labour may dwell, not without pleasure, on questions which, in connection with the present state of our knowledge and the hope which this state excites, have been deemed by some of the most distinguished astronomers of the present day worthy of serious examination.

It may be assumed with great probability that we are in communication, through the influence of gravitation and through light and radiant heat,(55) not only with our own sun, but also with all the other shining suns of the firmament. The important discovery of the measurable resistance opposed by a space-filling fluid to a comet of a five years' period of revolution, has been completely confirmed by exact numerical accordances. Inferences founded on analogies may serve to fill a part of the wide chasm which separates the assured results of a mathematical natural philosophy, from conjectures directed to the extreme, and therefore obscure and desert, boundaries of all scientific development of thought.

From the infinity of Space, which indeed was doubted by Aristotle,(56) follows its immeasurability. Only separate parts have been accessible to measurement; and the results, which surpass all our powers of realisation, are brought together with complacency by those who take a childish pleasure in large numbers, and even imagine that, by means of images of physical magnitude creating astonishment, they peculiarly enhance the sublimity of astronomical studies. The distance of the star 61 Cygni from the sun is 657000 semi-diameters of the earth's orbit,—a distance which light takes rather more than ten years to traverse, whilst it comes from the sun to the earth in 8 minutes 17·78 seconds. Sir John Herschel conjectured, from an ingenious combination of photometric estimations, (57) that, supposing stars of the milky way which he saw glimmer in his twenty-foot telescope to be newly formed luminous bodies, they would have required 2000 years thus to have sent us their first ray of light. All attempts to bring such numerical relations home to our imaginations fail, either from the vastness of the unit of measure employed, or from the vastness of the number of its repetitions. Bessel said very truly ([58]) "that the distance which light travels in one year can no more be rendered sensible to us than the distance which it traverses in ten years: no endeavours to bring home to our imagination a magnitude far exceeding all magnitudes accessible on the earth are ever successful." We find the oppressive power of numbers exceeding what our conceptions can grasp, alike in the smallest organized beings of animal life, and in the galaxy of self-luminous suns which we term fixed stars. What a mass of Polythalamia are contained, according to Ehrenberg, in a thin stratum of chalk! Of the microscopic Gaillonella distans, according to the same great inquirer into nature, a cubic inch of the Bilin polishing slate, which forms a dome 40 feet high, contains 41000 millions of individuals. Of Gaillonella ferruginea, one cubic inch contains upwards of 1 billion 750000 millions. ([59]) Such estimations remind us of the Arenarius (ψαμμιτης) of Archimedes, of the grains of sand which might fill Space! If, in considering the starry heavens, impressions of vast magnitudes in space and time, which numbers convey but imperfectly, remind man of his smallness of stature, his physical weakness, and the ephemeral duration of his earthly existence,—he is, on the other hand, cheered and invigorated by the consciousness, that the application and development of the human intellect have already made known to him such important portions of the subjection of nature to definite laws, and so much of the sidereal order of the universe.

If we assume that the spaces between the heavenly bodies are not a vacuum, (60) but are filled with some kind of matter, —as not only the propagation of light, but also a particular effect of its enfeeblement, as well as the influence of a resisting medium on the period of revolution of Encke's comet, and the dissolution of many vast tails of comets, appear to shew,—it is necessary to take the precaution of reminding the reader that the term "ether" now employed, and which has come to us from the earliest south and west Asiatic antiquity, has not during so many centuries always conveyed the same ideas. With the Indian philosophers the æther (âkâ'sa) is one of the "pantschatâ" or five elements, a fluid of infinite rarity pervading the entire universe, and the exciter of life, as well as the medium of the propagation of sound.(61) Etymologically, "âkâ'sa" signifies, according to Bopp, "shining," and therefore in its original meaning approaches the æther of the Greeks as nearly as "shining" does "burning."

This æther (αιθηρ), according to the dogmas of the Ionian philosophy, and according to Anaxagoras and Empedocles, was altogether different from the thicker (denser), vapour-filled, true air (ἀηρ), which surrounds the earth "and perhaps extends to the moon." It was "of a fiery nature, a pure fiery atmosphere, bright beaming(62), of great tenuity (rarity) and eternal serenity." The etymological derivation from "burning" (αιθειν) accords perfectly with this definition. Singularly enough, out of predilection for mechanical views, and referring to the constant revolving motion, it was subsequently changed by Plato and Aristotle, by a play upon words, into another derivation, αει θεῖν.(63) The idea of the rarity and thinness of this upper air, the æther, does not appear to have been a consequence of the knowledge of the purer mountain air, comparatively free from heavy terrestrial vapours; or of the diminishing density of the strata of air with increasing height. As the "elements" of the ancients signify not so much diversity, or even simplicity or indecomposability of substance, as "states of matter," the idea of the upper æther (the fiery celestial atmosphere) had its root in the first and normal antitheses of "heavy" and "light," "under" and "upper," "earth" and "fire." Between these two extremes are two "middle elementary states:" water, more nearly akin to the heavy earth; and air, nearer to the light fire.(64)

As a space-filling medium, the æther of Empedocles has no analogy, excepting by its tenuity and rarity, with the ether by whose transverse vibrations modern physical science has succeeded so happily in explaining, by pure mathematical deduction, the propagation of light and all its properties (double refraction, polarisation, and interference). In the natural philosophy of Aristotle it was also taught that the æthereal substance pervaded and penetrated all organic beings, plants, and animals; that it became in them the principle of vital heat, and even the germ of a psychical principle, which, preserving itself distinct from the body, awakened men to self-activity.(65) These imaginations draw down the æther from upper space into the terrestrial sphere; they present it as an exceedingly fine substance constantly pervading and penetrating both the atmosphere and solid bodies, as does the ether in the undulatory theory of light, according to the views of Huygens, Hooke, and our present physicists. But that which most directly distinguishes the two hypotheses, the ancient Ionian æther and the modern ether, from each other, is the original assumption (not altogether shared, however, by Aristotle), in regard to the former, of self-luminosity. The upper fiery atmosphere of Empedocles is expressly called "bright beaming" (*παμφανόων*), and in certain phænomena was supposed to be seen by the inhabitants of the earth as the brightness of fire through clefts and rents (*χάσματα*) opened in the firmament. (66)

In the intimate relations between light, heat, electricity, and magnetism, now so much examined, it is deemed probable that, as the transverse undulations of the space-filling ether produce the phænomena of light, so thermic and electro-magnetic phænomena depend on analogous kinds of motion (currents). Great discoveries on these subjects are no doubt reserved to future times. Light, and radiant heat inseparable from light, are, to the non-luminous cosmical bodies, and to the surface of our own planet, a principal source of motion and of all organic life. (67) Even remote from the surface, in the interior of the crust of the earth, the heat which penetrates inwards calls forth electro-magnetic currents, which exercise their exciting influence on combinations and decompositions of substances, upon all formative activity in the mineral kingdom, and on the disturbance of equilibrium in the atmosphere, as well as on the functions of vegetable and animal organisms. If electricity moving in currents developes magnetic forces,—if, according to an earlier hypothesis of Sir William Herschel, (68) the sun itself is in the condition "of a perpetual Aurora" (I should say of an electro-magnetic storm), it would not appear an inappropriate conjecture to suppose that in space also, the light of the sun, propagated by vibrations of the ether, may be accompanied by electro-magnetic currents.

It is true that in terrestrial magnetism direct observation of the periodical variations of declination, inclination, and force, has not as yet disclosed with certainty any influence from the different positions either of the sun or of the nearer moon.* The magnetic polarity of the earth does not shew oppositions which relate to the sun, and are sensibly affected by the precession of the equinoxes. (69) Only the remarkable varying direction of the cone of light which streamed from Halley's comet, and which Bessel observed from the 12th to the 22d October, 1835, and sought to interpret, had persuaded that great astronomer of the existence of a polar force,—"of the action of a force differing materially from gravitation or the ordinary attracting power of the sun, since those portions of the comet which form the tail experience the effect of a repelling force from the body of the sun." (70) The fine comet of 1744, which was described by Heinsius, had also given occasion to similar conjectures on the part of my deceased friend.

The action of radiant heat is regarded as less problematical than electro-magnetic agencies in space. According to Fourier and Poisson, the temperature of space is the result of the radiation of heat from the sun and all the heavenly bodies, diminished by the absorption which the heat suffers in traversing space filled with "ether." (71) The "heat of the stars" was spoken of on many occasions by the ancients (the Greeks and Romans); (72) not merely because, accord-

* [Since this passage was printed in the German original, the Philosophical Transactions for 1849 have reached M. de Humboldt, containing a memoir in which it is shown that the magnetic observations made in different hemispheres, (at Toronto in Canada, and at Hobarton in Van Diemen Island), concur in indicating that the terrestrial magnetism does undergo an annual variation connected with the sun's position relatively to the earth.—Ed.]

ing to a widely prevalent opinion, the stars belonged to the region of the fiery æther, but because they are themselves of a fiery nature :(73) and Aristarchus, of Samos, even taught that the fixed stars and the sun are of the same nature. In very recent times, through the influence of the two great French mathematicians who have just been named, the interest of an approximate determination of the temperature of space has been more strongly felt, as it has at length been perceived how important, on account of the radiation of heat from the earth's surface to the heavens, was this determination in respect to all thermic relations, and, one might even say, to the habitability of our planet. According to Fourier's analytical theory of heat, the temperature of space (des espaces planétaires ou célestes) is somewhat below the mean temperature of the Pole, or perhaps even somewhat below the lowest temperature hitherto observed in the Polar regions. Fourier estimates it accordingly at from −50° to −60° Cent. (−58° to −76° Fah.) The point of greatest cold (pôle glacial) no more coincides with the pole of the earth than does the "thermal equator" (which connects the warmest points on all meridians) with the geographical equator. Arago concluded the temperature of the north pole, from the gradual decrease of mean temperatures, to be −25° Cent. (−13° F.); the maximum cold observed by Captain Back, in January 1834, at Fort Reliance (lat. 62° 46′), was −56°·6′ C. (−69°·88 F.) (74) The lowest known temperature is, I believe, that which Neveroff observed on the 21st of January, 1838, at Jakutsk (lat. 62° 2′). The accurate Middendorff had compared the observer's instruments with his own. Neveroff found the temperature on the day in question, −60° Cent. (−76° F.)

Among the many grounds of uncertainty in respect to a numerical result for the thermic condition of space, is the circumstance, that we cannot yet obtain a mean of the points of greatest cold of the two hemispheres, as we are still so little acquainted with the meteorology of the southern hemisphere, which must bear its part in determining the mean annual temperature. Poisson's view, that, owing to the unequal distribution of heat-radiating stars, different regions of space must have a very different temperature, and that, from the movement of the whole solar system, our globe in traversing warm and cold regions has received its internal heat from without, (75) appears to me to have a very low degree of physical probability.

The question whether the thermal condition of space, or the climates of its several regions, are exposed in the course of long periods of time to great changes of temperature, depends principally on the solution of a question proposed and discussed with great animation by Sir William Herschel: viz. are the nebulæ subject to progressive processes of formation, by condensation taking place according to the laws of attraction around one or several nuclei? If such a condensation of cosmical nebulous matter take place, there must be, in every transition of gaseous or fluid substances to solids, disengagement of heat. (76) If, according to the latest views, and from the important observations of the Earl of Rosse and Mr. Bond, it becomes probable that all nebulæ, even those which have not yet been entirely resolved by the greatest power of optical instruments, are thickly crowded clusters of stars, the belief in this perpetually-arising production of heat will indeed be somewhat shaken. But even small solid bodies, seen in telescopes as distinguishable shining points, may also alter their density in combining into larger masses; and many phænomena which our own planetary system presents lead to the supposition that the planets have been condensed from a state of vapour, and that their internal heat is owing to this process.

At first sight it seems hazardous to assert that a temperature of space so very low as between the freezing points of mercury and of spirits of wine, can be deemed, even indirectly, *beneficial* to the habitable climates of the globe, and to the life of plants and animals; but in order to be satisfied of the correctness of the expression it is sufficient to reflect on the influence of the radiation of heat from the earth. The surface of our globe warmed by the solar heat, and the atmosphere up to its outermost stratum, radiate freely towards space. The loss of heat which they suffer arises from the difference of temperature between the air and space, and the feebleness of the return which they receive. How enormous would be the loss (77) if space, instead of the temperature which we express by $-60°$ Cent. ($-76°$ F.), had, for example, a temperature of $-800°$ Cent. ($-1408°$ F.), or even several thousand degrees lower!

There still remain to be developed two more considerations in reference to the existence of a fluid throughout space: one, less well-established, relates to a "limit to the transparency of space;" the other, based on direct observation, and affording numerical results, to the regular diminution of the period of revolution of Encke's comet. Olbers of Bremen, and, as Struve has remarked, Loys de Cheseaux at Geneva, eighty years before, (78) called attention to the dilemma,—that as in infinite space no point can be imagined which should not present a fixed star (*i. e.* a sun), either the entire vault of heaven, if light arrived to us quite unenfeebled, must appear as luminous as our sun; or, if this be not so, that we must assume an enfeeblement of light in its passage through space, or a decrease of the intensity of light greater than in the inverse ratio of the square of the distance. Now, since we do not see such an almost uniform brightness covering the heavens (to which Halley (79) also alludes in reference to an hypothesis which he rejects), therefore, in the view of Cheseaux, Olbers, and Struve, we must assume that space is not absolutely and perfectly transparent. Results which Sir William Herschel derived from his star gaugings, (80) and from ingenious investigations on the space-penetrating power of his great telescope, appear to establish that, if the light of Sirius lost only $\frac{1}{800}$ on its way to us in passing through a gaseous or ethereal fluid, this loss, which would give the measure of the density of a light-enfeebling fluid, would suffice to explain phenomena as they present themselves. Amongst the grounds of doubt which the illustrious author of the new "Outlines of Astronomy" opposes to the supposition of Olbers and Struve, one of the most important is, that in the greater part of the milky way, in both hemispheres, his twenty-foot telescope shews him the smallest stars projected on a black ground. (81)

A better proof of the existence of a resisting fluid, (82) and one, as I have already said, founded on direct observation, is furnished by Encke's comet, and by the ingenious and highly important conclusions to which it has conducted its discoverer. The impeding medium must, however, be conceived to be different from the all-penetrating ether whose undulations propagate light, because resistance implies non-penetration of what is solid. The observations require for the explanation of the diminished period of revolution, (the diminished major axis of the ellipse), a *tangential force;* and this is supplied in the most direct manner by the assumption of a resisting fluid. ([83]) The greatest effect shows itself in the twenty-five days next before the passage of the comet through its perihelion, and in the twenty-five days which follow the passage. Thus the value of the constants is somewhat different, because near the sun, the so rare, but yet gravitating, strata of the resisting fluid are denser. Olbers ([84]) was of opinion that the fluid could not be in repose, but must rotate from right to left round the sun; and, therefore, the resistance to retrograde comets, like Halley's, must be quite different from the resistance to a comet whose motion is direct, as Encke's. The calculation of perturbations in comets of long period, and the differences of masses and magnitudes of the comets, complicate the results, and mask what may be due to particular causes.

The nebulous or vaporous matter which forms the ring of zodiacal light, may be, perhaps, as Sir John Herschel expresses it, only the denser part of the comet-resisting medium itself. ([85]) Even supposing it were already proved that all nebulæ are only imperfectly-seen crowded clusters of stars, there yet remains the fact, that innumerable comets, by the dissolution of their tails of more than fifty millions of miles in length, fill space with a material substance. Arago has ingeniously shown from optical considerations, ([86]) that the variable stars which in their periodical phases always show white light, without any trace of colour, might furnish a means of determining the superior limit of the density ascribable to the ether, if we assume it to resemble terrestrial gaseous fluids in its powers of refraction.

Connected with the question of the existence of a space-filling ethereal fluid, is the one proposed with so much animation by Wollaston, ([87]) of the limit of the atmosphere,—a limit which must exist at the height where the specific elasticity of the air and the attraction of gravitation are in equilibrium. Faraday's ingeniously devised experiments upon the limit of an atmosphere of mercury,—on the height which vapour of mercury tested by amalgamation with gold-leaf scarcely appears to reach in air,—have given increased weight to the hypothesis of a definite surface of the atmosphere, "similar to the surface of the sea." May gaseous substances from space mix with our atmosphere and produce meteorological changes? Newton ([88]) has touched this question, leaning to the affirmative side. If shooting stars and meteoric stones are regarded as planetary asteroids, we may well hazard the conjecture that, with the streams of myriads of shooting stars which traversed the sky in the month of November, ([89]) in the years 1799, 1833, and 1834, and when Auroras were observed at the same time,—the atmosphere received from space something which was extraneous to itself, and which might excite electro-magnetic processes.

II.

NATURAL AND TELESCOPIC VISION—SCINTILLATION OF STARS —VELOCITY OF LIGHT—RESULTS OF PHOTOMETRY.

It is only within the last two centuries and a half that the artificial telescopic enhancement of the visual power of the eye,—the organ by which we contemplate the Universe,—has afforded the grandest of all aids and instruments for the recognition of the contents of space, and for the discovery of the form, physical constitution, and mass of the planets and of their satellites. The first telescope was constructed in 1608, seven years after the death of the great observer Tycho Brahe. Jupiter's satellites, the solar spots, the phases of Venus, Saturn's ring, telescopic clusters of stars, and the nebula in Andromeda, (90) had already been successively discovered by means of the telescope, when, in 1634, the French astronomer Morin (worthy of honourable mention in reference to observations of longitude), thought of attaching a telescope to the alidade of a measuring instrument, and looking for Arcturus in the day-time. (91) The improvement of the graduation of the limbs of instruments would have failed, either wholly or in great part, in attaining its principal object, viz. greater precision in observation, if optical means had not been adopted for augmenting the exactness of the reading commensurately with that of the measurement. The construction of micrometers with fine threads stretched in the focus of the telescope, the application of which first gave to more exact graduation its peculiar and indeed inestimable value, was devised six years afterwards, in 1640, by the young and talented Gascoigne. (92)

While, therefore, in astronomical researches, telescopic observation and measurement include only 240 years, we may reckon, (without reference to the Chaldeans, Egyptians, and Chinese, and counting only from Timochares and Aristillus (93) to the discoveries of Galileo), more than nineteen centuries in which the position and movements of the heavenly bodies were observed with the naked eye. Seeing the numerous interruptions to which the progress of civilisation and knowledge among the nations surrounding the Mediterranean was exposed during that long period, we must regard with surprise and admiration the recognition by Hipparchus and Ptolemy of the intricate movements of the planets, of the two principal lunar inequalities, and of the places of the stars; the perception, by Copernicus, of the true system of the universe; and the improvement, by Tycho Brahe, of practical astronomy and its methods,—all antecedent to the invention of the telescope. Exactness of observation may doubtless have been somewhat increased by the employment of long tubes, used most probably by the ancients and certainly by the Arabs, and arranged so that the object was seen through dioptra or narrow apertures. Abul Hassan speaks decidedly of tubes having eye and object dioptra attached to the extremities; and this arrangement was also employed at the observatory established by Hulagu at Meragha. If looking through tubes facilitates the finding of stars in the twilight,—in other words, if, in the evening twilight, stars are earlier visible to the naked eye with tubes than without,—the reason, as Arago has remarked, is, that the tube, when the eye is kept close to it, cuts off a large portion of the disturbing diffused light (rayons perturbateurs) of the atmospheric strata which intervene between the star and the eye. In like manner, even in a dark night, the tube is useful in preventing the lateral impression of the faint light which the particles of air receive from all the other stars in the sky; the intensity of the luminous image and the size of the star thus appear increased. In a much amended, and often contested, passage of Strabo, in which there is a reference to looking through tubes, the enlarged appearance of the stars, or heavenly bodies, is expressly mentioned, although erroneously attributed to refraction.(94)

Light, from whatever source it may proceed,—whether from the sun, as solar light, or as reflected by the planets; from the fixed stars; from rotten wood; or as the product of vital activity in glow-worms and other luminous animals,—always shows the same refractive properties. (95) But the prismatic coloured images, or spectra, from different sources of light, (from the sun and from the fixed stars), show a difference in the position of the dark lines, which were first discovered by Wollaston in 1808, and of which Fraunhofer determined the position with great exactness twelve years later. Fraunhofer had counted 600 dark lines (properly speaking, interruptions, or defective parts, of the coloured image or spectrum): in the fine experiments of Sir David Brewster with nitrous acid gas, in 1833, their number rose to above 2000. It had been remarked that, at certain seasons of the year, particular lines were wanting; but Brewstet has shewn that this is a consequence of the different heighr of the sun, and the different absorption of the rays of light in their passage through the atmosphere. In the coloured spectra given by the reflected light of the Moon, Venus, Mars, and the Clouds, we find, as would no doubt have been expected, all the characteristics of the solar spectrum. On the other hand, the dark lines of the spectrum of Sirius differ from those of Castor or of other fixed stars. Castor himself shows other lines than those shown by Pollux and Procyon. Amici has confirmed these differences, which had already been indicated by Fraunhofer, and has called attention to the fact that, in fixed stars of at present equal and perfectly-white light, the dark lines are not the same. There still remains here a wide and important field for future research,(96) in order to separate what is certain from what is rather to be termed accidental—dependent on the absorbing effect of the atmosphere.

There is another phænomenon deserving to be here noticed, in which the specific character of the source of light has a powerful influence. The light of glowing solid bodies and that of the electric spark show great variety in the number and position of Wollaston's dark lines. According to Wheatstone's remarkable experiments with revolving mirrors, the light of friction-electricity appears also to have a velocity greater than that of solar light, in the ratio of at least 3 to 2 (or fully 83920 geographical miles in a second of time).

A new life has animated all departments of optics from the time when (in 1808) the reflection of the light of the setting sun from the windows of the Palais du Luxembourg accidentally led the acute Malus to the important discovery of polarisation. [97] Since that event, the more deeply-examined phænomena of double refraction, ordinary (Huygenian) polarisation and coloured polarisation, interference, and diffraction, have furnished the investigator with unexpected means of distinguishing between direct and reflected light [98], of penetrating the secret of the constitution of the Solar orb and his luminous envelopes [99], of measuring the pressure and the minutest aqueous contents of the atmosphere, of discerning the bottom of the sea and its shoals by the aid of a plate of tourmaline [100], and even of comparing, according to Newton's example, the chemical [101] composition of several substances [102] with their optical effects. It is sufficient to mention the names of Airy, Arago, Biot, Brewster, Cauchy, Faraday, Fresnel, John Herschel, Lloyd, Malus, Neumann, Plateau, Seebeck . . . . . to recall to the recollection of the scientific reader a series of brilliant discoveries, and of the happiest applications of each newly-discovered step. The great works of Thomas Young, marked with the stamp of genius, more than prepared the way for these important labours. Arago's polariscope, and the observed position of coloured diffraction-fringes (consequences of interference), have become of great and varied use in the investigation. Meteorology has profited no less than physical astronomy by the opening of this new path of research.

Different as is the power of vision with the naked eye in different men, yet here also there is a certain mean degree of organic capability, which was the same among the ancient Greeks and Romans as in the present day. The Pleiades furnish the proof of this, showing that some thousand years ago, as now, stars which astronomers call of the 7th magnitude are not visible to the naked eye in persons of ordinary powers of vision. The group of the Pleiades consists of a star of the 3rd magnitude, Alcyone; two of the 4th magnitude, Electra and Atlas; three of the 5th, Merope, Maia, and Taygeta; two between the 6th and 7th, Pleione and Celæno; one between the 7th and 8th, Asterope; and several very small telescopic stars. I employ the present denominations and order of magnitudes, for among the ancients some of these names were assigned to other stars. It was only the six first-named stars, of the 3rd, 4th, and 5th magnitudes respectively, that could be easily seen. ([103]) Ovid says (Fast. iv. 170): "Quæ septem dici, sex tamen esse solent." It was supposed that one of the daughters of Atlas, Merope, the only one who had married a mortal, remained veiled through bashfulness, or even that she had entirely disappeared. She was probably the star of almost the 7th magnitude, which we now call Celæno; for Hipparchus remarks, in the commentary to Aratus, that in clear moonless nights seven stars could really be perceived. It was then Celæno which was seen as the seventh Pleiad; Pleione, which is of equal brightness, being too near Atlas (a star of the 4th magnitude) to be distinguished.

The small star Alcor (which, according to Priesnecker, is at a distance of 11′ 48″ from Mizar, in the tail of the Great Bear) is, according to Argelander, of the 5th magnitude, but overpowered by the brightness of Mizar. It was called by the Arabs "Saidak," "the tester;" because it was the custom, as the Persian astronomer Kazwini([104]) informs us, "to test a man's power of sight by it." Notwithstanding the low altitude of the constellation of the Great Bear within the tropics, I have seen Alcor with the naked eye with great distinctness every evening on the rainless coast of Cumana, and on the high plateaus of the Cordilleras at elevations of twelve thousand feet; but I have recognised it only rarely and uncertainly in Europe, and in the dry air of the steppes of Northern Asia. The limit within which it is possible, with the naked eye, to separate two objects very near to each other in the heavens, depends, as Mädler has very justly remarked, on their relative brightness. The two stars of the 3d and 4th magnitudes, marked α Capricorni, which are six and a half minutes apart, are separated without difficulty. Galle thinks it possible, in a very clear atmosphere, to separate with the naked eye ε and 5 Lyræ, though only three and a half minutes apart, because they are both of the 4th magnitude.

The too great comparative brightness of the neighbouring planet is also the principal reason why Jupiter's satellites, (one of which, and not all, as is often erroneously stated, is equal in its light to stars of the 5th magnitude), remain invisible to the naked eye. According to recent estimations and comparisons with neighbouring stars by my friend, Dr. Galle, the third satellite, which is the brightest, may correspond to stars from the 5th to the 6th magnitude; whilst the others correspond, as their light varies, to stars from the 6th to the 7th magnitude. Only occasional instances have been cited of persons of extraordinary keenness of vision, (persons who could perceive distinctly with the naked eye stars below the 6th magnitude), having seen any of Jupiter's satellites without a telescope. The angular distance of the third and brightest satellite from the centre of the planet is 4′ 42″; that of the fourth, which is only 1-6th smaller than the largest, 8′ 16″; and all Jupiter's satellites have at times, as Arago states, (105) an intenser light, on equal surfaces, than the planet: at times, on the other hand, they appear on the face of Jupiter, as recent observations inform us, as gray spots.

The rays, which appear to our eyes to issue from the planets and from the fixed stars,—and which from the earliest times have been employed in pictorial representations, particularly among the Egyptians, to designate the shining heavenly bodies,—have a length of at least five or six minutes. Hassenfratz declares them to be focal lines, "intersections de deux caustiques," on the crystalline lens. "The image of stars seen by us with the naked eye is enlarged by diverging rays: by reason of this extension it occupies a larger space on the retina than if it were concentrated in a single point. The impression on the nerve is weaker. A very dense cluster of stars, in which all the single stars hardly attain the 7th magnitude, may, on the other hand, become visible to the naked eye, because the images of the many single stars overlap each other on the retina; so that, as in the case of a concentrated image, every sensible point of the latter is more strongly excited." (106).

Telescopes, unfortunately, also give, though in a much less degree, an untrue or spurious diameter to stars: from the examinations of William Herschel, (107) however, these diameters decrease with increased magnifying power. This acute observer, with the enormous magnifying power of 6500, still estimated the apparent diameter of α Lyræ at 0″·36. In terrestrial objects, besides the illumination, the form of the object helps to determine the smallest visual angle under which it can be seen by the naked eye. Adams remarked very justly, that a long thin rod can be seen at a much greater distance than could a square, whose side should be equal to the thickness of the rod. A line is seen much further than a point, even if the breadths of the two are equal. Arago examined the influence of form in this respect by angular measurements of the lightning conductors visible from the Paris Observatory. Determinations of the smallest optical angle of vision under which terrestrial objects can be recognised by the naked eye have always continued to advance progressively to smaller and smaller quantities;—from Robert Hook, who declared a full minute to be absolutely necessary, to Tobias Mayer, who required 34″ for a black spot on white paper, and further to Leuwenhoek's spiders' threads, which can be seen by persons of very ordinary powers of vision under an angle of 4″·7. In the most recent and very exact experiments of Hueck on the motion of the crystalline lens, it was barely possible to see white lines on a black ground at an angle of 1″·2, a spider's thread at 0″·6, and a fine shining wire at 0″·2. The problem does not admit of a strict numerical solution, as the result depends on the shape of the objects, their illumination, their contrast with the back ground from which they detach themselves, and the movement or stillness, as well as the nature, of the intervening atmospheric strata.

I was much impressed by a circumstance which occurred during my stay at a beautiful country-seat belonging to the Marques de Selvalegre, at Chillo (not far from Quito), from whence the long extended ridge of the Volcano of Pichincha was seen at a horizontal distance, trigonometrically measured, of 85000 Paris (90590 Eng.) feet. My fellow-traveller Bonpland, who was then engaged alone on an expedition to the Volcano, was recognised by the Indians standing near me as a white point moving along the face of a black basaltic precipice, before we, who were looking for him with telescopes, discovered him. In a short time my companion (the ill-fated son of the Marques, Carlos Montufar, who afterwards fell a victim in the civil war) and myself were also able to distinguish the white moving figure with the naked eye. Bonpland was wrapped in a white cotton mantle, the poncho of the country. Allowing from 3 to 5 feet for the breadth of the shoulders, as the mantle sometimes clung close, and sometimes seemed to fly loosely in the wind, and taking the known distance, we have from 7″ to 12″ as the angle under which the moving object was distinctly seen. White objects on a black ground are seen, according to Hueck's repeated experiments, at a greater distance than black objects on a white ground. The weather was clear, and the ray passed through the stratum of thin air, proper to an elevation of 14412 French (15360 Eng.) feet above the level of the sea, to our station at Chillo, itself 8046 (8575 Eng.) feet high. The distance from the eye to the object was 85596 (91225 Eng.) feet, or 14·8 geographical miles. The heights of the barometer and thermometer at the two stations were very different: at the upper, probably, 194 lines (17·23 English inches), and 8° Cent. (46°.4 Fahr.); and at the lower, by exact observation, 250·2 lines (22·22 English inches), and 18·7 Cent. (65·66 Fahr.) Gauss's heliotropic light, which has become so important an auxiliary in our German trigonometrical measurements, reflected from the Brocken to the Hohenhagen, was seen there at a distance of 213000 French feet (227008 Eng.),—more than 36 geographical miles; and often at points at which the angle subtended by a three-inch mirror only amounted to 0″·43.

The visibility of distant objects is modified by the absorption of the rays proceeding from the terrestrial object, and arriving at the unassisted eye at different distances, through strata of air more or less dense, and more or less charged with aqueous vapour; by the intensity of the diffused light radiated from the particles of air; and by many still imperfectly explained meteorological circumstances. According to old experiments of the accurate Bouguer, a difference of 1-60th in the intensity of the light is necessary for visibility. We see, as he expresses it, only in a negative manner, hill and mountain summits which radiate but little light, and detach themselves as dark masses against the sky. We see them only by the difference of the thickness of the atmospheric strata, which extend in the one instance to the object, and in the other to the extremest horizon. On the other hand, bright or shining objects, as snowy mountains, white limestone rocks, and cones covered with pumice, are seen in a positive manner. The distance at which high mountain summits can be recognised at sea is not without interest in navigation, when exact astronomical determinations of the ship's place are wanting. I have treated this subject in detail in another place,[108] when discussing the distance at which the Peak of Teneriffe may be visible.

The power of seeing stars with the naked eye in the day-time from the shafts of mines, or on very lofty mountains, has been a subject of examination with me from early youth. I was aware[109] that Aristotle had affirmed that stars could sometimes be seen from vaults and reservoirs, as well as through tubes. Pliny, also, mentions this, and notices at the same time the circumstance that stars can be clearly distinguished in the day-time during solar eclipses. In the course of my professional engagements as a mining engineer, I for some years passed a large portion of every day under ground, looking up from the bottom of deep shafts to the zenith, but without ever seeing a star; nor have I since found an individual in Mexican, Peruvian, or Siberian mines, who had ever heard of stars being seen in the day-time, although in such different latitudes as those embraced by my inquiries and experience in both hemispheres, a sufficient number of zenith stars must have presented themselves advantageously. This entirely negative evidence renders very remarkable the highly credible testimony of a celebrated optician who, in early youth, saw the stars during bright day-light through a chimney.(110) Phænomena whose visibility depends on an accidental concurrence of favourable circumstances must not be denied because they are of rare occurrence.

This principle also applies, I think, to the statement of the always careful and accurate Saussure, in reference to stars being seen with the naked eye on the ascent of Mont Blanc, at a height of 11970 (12757 Eng.) feet. He says, "Quelques-uns des guides m'ont assuré avoir vu des étoiles en plein jour; pour *moi je* n'y songeois pas, en sorte que je n'ai point été le témoin de ce phénomène; *mais l'assertion uniforme des guides ne me laisse aucun doute sur la réalité.*(111) Il faut d'ailleurs être entièrement à l'ombre, et avoir même au-dessus de la tête une masse d'ombre d'une épaisseur considérable, sans quoi l'air trop fortement éclairé fait évanouir la foible clarté des étoiles." The conditions are, therefore, almost entirely the same as those presented by the reservoirs of the ancients and the chimney before referred to. I have not found this remarkable statement (bearing date the morning of the 2nd of August, 1787) repeated in any subsequent journey in the Swiss mountains. Two highly informed and excellent observers, the brothers Hermann and Adolph Schlagintweit, who have recently explored the eastern Alps to the summit of the Grosglockner (12213 Fr., or 13016 Eng. feet*), were never able to see stars in the day-time, nor did they hear any statement to that effect among the herdsmen and chamois hunters. I spent several years in the Cordilleras of Mexico, Quito, and Peru, and was very often, together with my friend Bonpland, in clear weather on heights of upwards of fifteen or sixteen thousand (English) feet; and neither we, nor subsequently Boussingault, could ever recognise stars in the day-time, although the azure of the sky was so deep and dark, that with the same cyanometer of Paul of Geneva with which Saussure had read 39° on Mont Blanc, I should have found under the tropics, at elevations between 16000 and 18000 (17052 and 19184 Eng.) feet, 46° at the zenith. (112) Under the magnificent, ethereally pure and serene sky of Cumana, on the plain of the sea-shore, after the observation of occultations of Jupiter's satellites, I have several times with ease found the planet again with the naked eye, and seen him most distinctly whilst the sun's disk was 18° or 20° above the horizon.

This is the proper place in which to notice, at least in a cursory manner, another optical phænomenon which, among my many ascents of mountains, was only observed by me once—viz. on the 22nd of June, 1799, before sunrise, on the declivity of the Peak of Teneriffe. Being in the Malpays, 10700 (11404 Eng.) feet above the sea, I saw with the naked eye stars low down near the horizon in strange

[* Since given more correctly by Messrs. H. and A. Schlagintweit 12158 French or 12958 English feet, in their Physicalische Geographie der Alpen.—Ed.]

fluctuating movement. Luminous points rose upwards, moved sideways, and fell back to their former places. The phænomenon lasted only seven or eight minutes, and ceased long before the edge of the sun appeared above the sea horizon: it was seen equally through a telescope, and there was no doubt that the apparent movement was that of the stars themselves. ([113]) Did this change of place belong to the much contested question of the *lateral* refraction of rays? Does the undulation of the rising solar disk, small as it is found by measurement, present, in the lateral alteration and motion of the sun's limb, any analogy to what has been described? We know, apart from this question, that the disturbance of the sun's disk would appear larger from being near the horizon. Almost half a century later this same phænomenon has been observed, both with the naked eye and through a telescope, in exactly the same spot in the Malpays, and similarly before sunrise, by a well-informed and very attentive observer, Prince Adalbert of Prussia. I found the observation entered in his manuscript journal without his having been aware, before his return from the River Amazon, that an entirely similar appearance had been seen by me. ([114]) Neither on the ridges of the Andes, nor in the frequent mirage of the hot plains (Llanos) of South America, notwithstanding the excessive variety of admixture of unequally heated strata of air, could I ever find any trace of lateral refraction. As the Peak of Teneriffe is so near to us, and is often visited before sunrise by scientific travellers provided with instruments, I may hope that my renewed request for the observation of the lateral fluctuation of stars may not be without effect.

I have already drawn attention to the fact, that long before the great epoch of the invention of telescopes and their application to celestial observation,—before therefore the memorable years 1608 and 1610,—an exceedingly important part of the astronomy of our planetary system was already established. The inherited treasures of Greek and Arabian knowledge were augmented by the careful and extensive labours of George Purbach, Regiomontanus (Johann Müller), and Bernhard Walther of Nuremberg. Their efforts were followed by the bold and comprehensive intellectual development of the Copernican system; and to this succeeded an abundant mass of exact observations by Tycho Brahe, and the acuteness in combination, and indomitable perseverance in calculation, of Kepler. Two great men, Kepler and Galileo, stand at the most important epoch which the history of practical astronomy presents,—that which separates observation with the naked eye, but with greatly improved measuring instruments, from telescopic vision. Galileo was then 44, and Kepler 37 years old; Tycho Brahe, the most exact practical astronomer of that great period, had been dead seven years. I have already remarked in the 2nd volume of Cosmos (English edition, p. 324), that Kepler's three great laws, which have made his name for ever illustrious, did not receive the praise of any one of his cotemporaries,—not even of Galileo. Discovered by a purely empirical path, but more rich in consequences to science at large than the isolated discovery of previously unseen celestial bodies, they belong entirely to the period of natural vision,—to the period of Tycho Brahe, and even to the Tychonian observations; although the printing of the "Astronomia nova, seu Physica cœlestis de Motibus Stellæ Martis" was not completed until 1609, and the third law, according to which the squares of the periodic revolutions of two planets are in the ratio of the cubes of their mean distances, was first developed in the "Harmonice Mundi," in 1619.

The transition from natural to telescopic vision, which marks the first ten years of the seventeenth century,—and forms an epoch in astronomy, or the knowledge of celestial space, even more important than 1492 had been to the knowledge of terrestrial space,—not only enlarged indefinitely our view into creation, but also, by proposing for solution new and intricate problems, became the means of raising mathematical knowledge to a degree of brilliancy never before attained. Thus the strengthening of the organs of sense reacted upon the world of thought, leading to the invigoration of the intellectual power, and to the ennoblement of humanity. We owe to the telescope alone, within the space of two centuries and a half, the knowledge of 13 new planets, and 4 new systems of satellites (4 belonging to Jupiter, 8 to Saturn, 4, perhaps 6, to Uranus, and 1 to Neptune); of the solar spots and faculæ; of the phases of Venus; of the form and elevation of the mountains in the moon; of the winter polar zones of Mars; of the belts of Jupiter and Saturn; the ring of Saturn; the interior (planetary) comets of short periods of revolution; and of many other phænomena which, like these, escape the perception of the unassisted eye. If our solar system, which was so long limited to 6 planets and 1 satellite, has been thus enriched within the last 240 years, what is called the "heaven of the fixed stars" has, during the same period, received a still more unexpected extension. Thousands of nebulæ, clusters of stars, and double stars, have been catalogued. The variable position of the double stars which revolve around a common centre of gravity, as well as the proper motion of all the fixed stars, show that gravitating forces prevail in those distant regions of space, as well as in the narrower sphere of the mutually perturbing orbits of the planets of our system. From the time that Morin and Gascoigne combined optical powers with measuring apparatus (which was not, however, until twenty-five or thirty years after the invention of the telescope), it has been possible to obtain more delicate and precise determinations of the alterations of place of the heavenly bodies. In this manner it has become possible to measure with the greatest precision the present position of a heavenly body, the aberration-ellipses of the fixed stars and their parallaxes, and the distances apart of the double stars, though only amounting to a few tenths of a second of arc. The astronomical knowledge of the solar system has gradually expanded into that of the system of the Universe.

We know that Galileo made his discoveries of Jupiter's satellites with a magnifying power of 7, and that he was never able to employ a higher power than 32. One hundred and seventy years afterwards, we see Sir William Herschel employ, in his investigations on the magnitude of the apparent diameters of Arcturus and α Lyræ, magnifying powers of 6500. From the middle of the 17th century men vied with each other in attempting telescopes of great length. Although as late as 1655 Christian Huygens discovered the first of Saturn's satellites, (Titan, the sixth in distance from the centre of the planet), with a telescope of only 12 feet, he subsequently employed in astronomical observations telescopes of 122 feet; but the three of 123, 170, and 210 feet focal distance, in the possession of the Royal Society of London, which had been made by his brother Constantine Huygens, were tried by Christian, as he himself expressly says, [115] on terrestrial objects. Auzout, who as early as 1663 constructed colossal telescopes without tubes, and, therefore, without a solid or rigid connection between the object-glass and the eye-piece, completed an objective which, with a focal length of 300 feet, would bear a magnifying power of 600. [116] Dominic Cassini made great use of such object-glasses attached to poles, in the successive discovery, between 1671 and 1684, of the eighth, fifth, fourth, and third of the satellites of Saturn He employed the object-glasses which Borelli, Campani, and Hartsoeker had ground: the latter were of 250 feet focal length. Those of Campani, which enjoyed the highest reputation under the reign of Louis XIV., have been often in my hands at the Paris Observatory during my long residence in that city. If we remember the faint light of the satellites of Saturn, and the difficulty of managing such apparatus, [117] which could only be moved by the aid of cords, we cannot sufficiently admire the skill and perseverance of the observer.

The advantages which were then supposed to be attainable exclusively by means of gigantic lengths, led great minds, as is often the case, to form extravagant hopes. Auzout thought it necessary to refute Hooke, who, in order to see animals in the moon, had proposed telescopes 10000 feet, or almost 2 geographical miles, in length. [118] The practical inconvenience of optical instruments of more than 100 feet focal length, gradually led to the introduction, in England especially, and through Newton himself (according to the precedents set by Mersenne and by James Gregory of Aberdeen), of the shorter reflecting instruments. Bradley's and Pound's careful comparison of 5-feet Hadleyian reflectors with the refractor already noticed of Constantine

Huygens of 123 feet focal length, proved entirely to the advantage of the former. Short's costly reflectors were now everywhere adopted, until the successful practical solution, (1759), by John Dollond, of the problem of achromatism proposed by Leonhard Euler and Klingenstierna, again turned the scale in favour of refractors. The apparently incontestable rights of priority of the mysterious Chester More Hall, of Essex (1729), were first made known to the public when John Dollond obtained a patent for his achromatic telescopes. ([119])

But this victory of the refracting instruments was not of long duration: eighteen or twenty years after the publication of John Dollond's accomplishment of achromatism by a combination of crown and flint glass, new fluctuations of opinion were induced by the merited tribute of admiration paid, both in England and elsewhere, to the ever memorable labours of a German, William Herschel. The construction of his numerous 7-feet and 20-feet telescopes, to which magnifying powers of 2200 to 6000 could be successfully applied, was followed by the construction of his 40-feet reflector, by means of which were discovered, in August and September 1789, the two innermost of the satellites of Saturn,—the second, Enceladus; and soon after Mimas, the first or nearest to the ring. The discovery of the planet Uranus (1781) was made with the 7-feet telescope of Herschel. The satellites of Uranus, which have such feeble light, were first seen by him, in 1787, in his 20-feet instrument arranged for the "front view." ([120]) The previously unattained degree of perfection which this great man was able to impart to his reflecting telescopes, in which the light was reflected only once, led, by the uninterrupted labours of more than forty years, to the most important extension of all parts of physical astronomy, in the planetary system as well as in the nebulæ and double stars.

A long reign of reflectors was again followed, in the first twenty years of the nineteenth century, by a happy emulation in the construction of achromatic refractors and heliometers, moved equatorially by clock-work. For object-glasses of extraordinary size, a homogeneous flint glass, free from striæ, was supplied in Germany by the Munich establishment of Utzschneider and Fraunhofer, subsequently of Merz and Mahler; and in Switzerland and France (for Lerebours and Cauchoix), in the manufactories of Guinaud and Bontems. It is sufficient for the purpose of this historical review, to name here, as instances, the great refractors made, under Fraunhofer's superintendence, for the observatories of Dorpat and Berlin, having 9 Parisian inches free aperture, with a focal length of 13½ (14 Engish) feet; the refractors of Merz and Mahler, in the observatories of Pulkova, and Cambridge in the United States of North America, (121) both furnished with object-glasses of 14 Parisian inches aperture, and 21 feet focal length (14·9 English inches, and 22 English teet 4·6 inches).* The heliometer of the Königsberg Observatory, which was for a long time the largest in existence, has 6 Parisian inches aperture, and has become celebrated by the memorable labours of Bessel. The short dialytic refractors, advantageous in respect of light, which Plösl, in Vienna, was the first to execute, the merits of which were recognised almost at the

* [The exact focal length of the refractor at Cambridge, U.S. is 22 English feet 6 inches.—Ed.]

same time by Rogers in England, deserve to be constructed of larger dimensions.

During the same period in which these endeavours were made,—to which I have thus referred because they have so materially influenced the enlargement of cosmical views,—mechanical improvements in measuring-instruments (zenith sectors, meridian circles, and micrometers) did not remain behind the progress made in optical instruments, and in those employed for measuring time. Amongst the many distinguished names of the present or recent times, I will mention only the following:—for measuring instruments, those of Ramsden, Troughton, Fortin, Reichenbach, Gambey, Ertel, Steinheil, Repsold, Pistor, Oertling; for chronometers and astronomical clocks — Mudge, Arnold, Emery, Earnshaw, Breguet, Jürgensen, Kessels, Winnerl, Tiede. In the valuable and extensive investigations into the distances apart and the periodic movements of double stars, which we owe to William and John Herschel, South, Struve, Bessel, and Dawes, we specially remark this proportionate and simultaneous advance in the perfection at once of sight and of measurement. Struve's classification of double stars contains, of those which are less than 1′ apart, about 100, and of those between 1′ and 2″ apart, 336,—all by frequently repeated measurements. ([122])

Within the last few years, two men who, by station and circumstances, were far removed from such occupations with a view to pecuniary profit, the Earl of Rosse, at Parsonstown (fifty miles west of Dublin), and Mr. Lassell, at Starfield, near Liverpool, animated by a noble love of astronomy, have, with devoted liberality and under their own immediate direction and superintendence, accomplished the completion of two reflecting telescopes which have raised to the highest degree the expectation of astronomers. (123) With Lassell's telescope, which has only 2 feet aperture and 20 feet focal length, there have been already discovered a satellite of Neptune and an eighth satellite of Saturn, besides the rediscovery of two satellites of Uranus. Lord Rosse's new colossal telescope has 6 feet clear aperture and 53 feet focal length. It is placed in the meridian between two piers, each 12 feet distant from the tube, and from 47 to 54 feet in height. Many nebulæ which no previous instrument could resolve, have, by this magnificent telescope, been resolved into clusters of stars, and the forms of other nebulæ have now for the first time been shown in their true outlines. The quantity of light reflected from the surface of the mirror is truly wonderful.

Morin, who, with Gascoigne, and before Picard and Auzout, first combined the telescope with measuring instruments, conceived, about 1638, the idea of observing stars telescopically in full daylight. He says himself (124) that he "was led to a discovery which may become important for the determination of longitudes at sea, not by Tycho Brahe's great labours on the positions of the fixed stars,—as, in 1582, and therefore twenty-eight years before the invention of the telescope, he compared Venus with the sun in the day-time and with the stars at night,—but merely by the simple thought that it might be possible, as with Venus so also with Arcturus and other fixed stars, once having them in the field of view of the telescope before sunrise, to continue to follow them in the heavens after sunrise." No one, he said, before him "had been able to find the fixed stars in the broad daylight." Since the establishment of great meridian telescopes by Römer in 1691, day observations of the heavenly bodies have been frequent and highly serviceable : they are sometimes usefully applied even to the measurement of double stars. Struve ([125]) remarks, that with the Dorpat refractor, employing a magnifying power of 320, he had determined the smallest distances apart of exceedingly faint double stars during a twilight so bright that one could read conveniently at midnight. The Pole star has a companion of the 9th magnitude only 18″ from itself; in the Dorpat refractor Struve and Wrangel have seen this companion in the day-time, ([126]) as have also (once) Encke and Argelander.

The reason of the powerful effect of telescopes at a time when, by multiplied reflection, the diffused light ([127]) of the atmosphere is injurious, has given occasion to a variety of doubts. As an optical problem it was regarded with the most lively interest by Bessel. In his long correspondence with me he often returned to the subject, and acknowledged that he could find no solution which was entirely satisfactory to him. I think I may reckon on the thanks of my readers for the introduction in a note ([128]) of the views of Arago, as contained in one of the many manuscripts which I was permitted to use when at Paris. According to his ingenious explanation, high magnifying powers facilitate the finding and recognition of the fixed stars, because, without sensibly enlarging their image, they conduct a greater quantity of intense light to the eye, whilst they act according to a different law on the aerial field from which the star detaches itself. The telescope, by magnifying the distance between the illuminated particles of air, darkens the field of view, or diminishes the intensity of its illumination; and it is to be remembered that we see only by the difference between the light of the star and that of the aerial field, *i. e.* the mass of air which surrounds it, in the telescope. The case of the simple ray of the image of a fixed star differs from that of planetary discs; the latter, under the magnifying power of the telescope, losing in intensity of light by dilatation equally with the aerial field from which they detach themselves. It is also to be noticed that high magnifying powers increase the apparent rapidity of motion in the fixed stars as well as in the planets. In instruments which are not mounted equatorially, and made to follow the movement of the heavens by means of clock-work, this circumstance may facilitate the recognition of objects in the day-time. New points on the retina are successively stimulated. Very faint shadows, as Arago has remarked elsewhere, first become visible by being put in motion.

Under the serene sky of the tropics in the driest season of the year, I have often been able to find the pale disc of Jupiter, in a Dollond's telescope, with the low magnifying power of 95, when the sun was already 15° or 18° above the horizon. The faintness of the light of Jupiter and Saturn seen in the day-time in the large Berlin refractor, and contrasted with the brighter, though equally reflected, light of the planets nearer to the sun, Mercury and Venus, has repeatedly surprised Dr. Galle. Occultations of Jupiter's satellites have sometimes been observed in the day-time with powerful telescopes (by Flaugergues, 1792; and Struve, 1820). Argelander, at Bonn (7th December, 1849), saw very clearly three of Jupiter's satellites a quarter of an hour after sunrise with a 5-feet Fraunhofer. He could not recognise the fourth satellite. His assistant, Herr Schmidt, saw still later the emersion from behind the dark limb of the moon of all the satellites including the fourth, in the

8-feet heliometer. The determination of the limits of telescopic visibility of small stars during daylight, in different climates and at different elevations above the level of the sea, has both an optical and a meteorological interest.

Among the phænomena belonging to natural and telescopic vision which are remarkable in themselves, and of which the causes are much contested, is the nocturnal sparkling (twinkling or scintillation) of the stars. According to Arago,(129) there are two things to be essentially distinguished in the scintillation: 1. alteration in the intensity of the light by a sudden decrease, amounting even to extinction, and rekindling; 2. alteration of colour. Both alterations are even stronger in reality than they appear to the naked eye; for when the several points of the retina are once excited, they retain the impression of light which they have received; so that the disappearance of the star, its obscuration, and its change of colour, are not felt by us in their full measure. Still more striking is the phænomenon of scintillation seen through a telescope, if the latter is shaken. Fresh and fresh points of the retina are excited, and there appear coloured and often interrupted circles. In an atmosphere composed of constantly varying strata of different temperature, moisture, and density, the principle of interference explains how, after a momentary coloured flash, there follows an equally momentary disappearance or obscuration. The undulation theory teaches in general that two rays of light (two systems of waves) proceeding from one source (one centre of vibration) by the inequality of their paths destroy each other; that the light of one ray, added to that of the other ray, produces darkness. When one system of waves is so far behind the other as amounts to an uneven number of semi-undulations, the two systems of waves strive to impart to the same molecule of ether, at the same instant, equal but opposite velocities; so that the effect of their union is the repose of the molecule, or darkness. In some cases it is rather the refrangibility of the different atmospheric strata traversed by the rays of light, than the different length of their paths, which performs the principal part in the phænomenon.(130)

The degree of scintillation is strikingly different in different fixed stars; not dependent solely on their altitude or their apparent magnitudes, but also, it would seem, on the nature of their particular light. Some, for example α Lyræ, twinkle less than Arcturus and Procyon. The absence of scintillation in the planets with the largest discs is to be ascribed to compensation, and to the mixture of the colours proceeding from different points of the disc. The disc is to be regarded as an aggregation of stars, which mutually restore the light neutralised by interference, and recombine the coloured rays into white light. Thus traces of scintillation are most rare in Jupiter and Saturn, but are seen in Mercury and Venus, whose diameters diminish to 4″·4 and 9″·5. The diameter of Mars, at the time of conjunction, may be as small as 3″·3. In the clear cold winter nights of the temperate zone, the scintillation of the stars enhances the impression of the lustre of the starry heavens from the circumstance that, as we see stars of the 6th and 7th magnitudes shine forth suddenly here and there, we are led to imagine that we perceive more shining points than the unassisted eye can really distinguish. Hence arises the popular surprise at the few thousands of stars noted in accurate catalogues as visible to the naked eye. That the trembling light of the fixed stars distinguishes them from the planets, was early known to the Grecian astronomers; but Aristotle, in accordance with the emanation and tangential theory of vision to which he adhered, singularly enough ascribed the trembling and twinkling of the fixed stars merely to an effort or straining of the eye. "The fixed stars," said he,(131) "sparkle, but the planets do not: for the planets are near, so that the sight is able to reach them; but in the fixed stars (*πρὸς δὲ τους μένοντας*) the eye, by reason of the distance and the effort, falls into a tremulous movement."

In Galileo's time, between 1572 and 1604,—in an epoch of great events in cosmical space, and when three new stars(132), brighter than stars of the first magnitude, appeared suddenly, and one of them, in Cygnus, continued to shine for twenty-one years,—Kepler's attention was particularly drawn to scintillation as the probable criterion of a non-planetary body; but the state of optics at that period did not permit him to rise above the ordinary ideas of vapours in motion. (133) Also, among the newly-appeared stars mentioned in the Chinese annals, according to the great collection of Ma-tuan-lin, the strong degree of scintillation is sometimes noticed.

In and near the tropical zone, from the more uniform character of the atmospheric strata, the comparative or entire absence of scintillation in the fixed stars to within twelve or fifteen degrees of the horizon, gives to the vault of heaven a peculiar character of repose and tranquil brilliancy. In several of my descriptions of nature, I have spoken of this characteristic of the tropics, which had not escaped the observation of La Condamine and Bouguer in the Peruvian plains, and of Garcin (134) in Arabia, India, and on the coasts of the Persian Gulf, near Bender Abassi.

As the aspect of the starry heavens at the season of perpetually clear and perfectly cloudless tropical nights had for me a peculiar charm, I took the pains of always noting in my journals the altitude above the horizon at which the scintillation ceased with different hygrometrical readings. Cumana, and the rainless part of the Peruvian sea-coast, before the season of Garua or fog, were particularly suited for such observations. According to the mean results of my observations, the larger fixed stars would appear for the most part to scintillate only when below 10° or 12° from the horizon. At greater altitudes they shed a mild and planetary light. The difference is best recognised by following the same star in its gradual ascent or descent, measuring at the same time its angle of altitude, or calculating it, if the latitude of the place and the time be known. Sometimes, in equally clear and equally calm nights, the region of scintillation extends to 20° and even 25° of altitude; yet there could hardly ever be traced any connection between these differences, and the state of the thermometer and hygrometer as observed in the lowest, and only accessible, atmospheric stratum. I have seen in successive nights, after considerable scintillation of stars between 60° and 70° high, with Saussure's hair hygrometer at 85°, the scintillation cease entirely at 15° above the horizon, although the humidity of the air had so much increased that the hygrometer had advanced to 93°. It is not the quantity of aqueous vapour which the atmosphere holds in solution, but the unequal distribution of vapour in the superimposed strata, and the upper currents of cold and warm air, not perceptible in the lower regions, which modify the intricate compensatory movement of the interferences of the luminous rays. The presence of a very thin orange-coloured mist, which tinged the sky a short time before earthquake shocks, increased the scintillation of the stars at high altitudes in a striking manner. All these remarks apply to the perfectly clear, cloudless, and rainless season of the tropical zone 10 or 12 degrees north and south of the equator. The changes which take place in the phænomena of the light of the stars at the commencement of the rainy season, during the passage of the sun through the zenith, depend on very general and almost tempestuous meteorological causes. The sudden slackening of the north-east trade wind, and the interruption of the regular upper currents from the equator to the poles, and of the lower currents from the poles to the equator, produce the formation of clouds, and the daily occurrence, at certain hours, of thunder and heavy rain. I have remarked in several successive years, in places where the scintillation of stars is at other times a rare occurrence, that the approach of the rainy season is announced many days beforehand by the tremulous light of stars high in the heavens. Sheet lightning, and single flashes in the distant horizon, without visible cloud, or in narrow perpendicularly rising columns of cloud, are accompanying signs. In several of my works I have tried to describe these changes in the physiognomy of the heavens, which are the characteristic precursors of the rainy season.

On the subject of the velocity of light, and the probability that it requires a certain time for its propagation, we find the earliest view expressed by Francis Bacon, in the second book of the Novum Organum. He speaks of the time required by a ray of light to traverse the immensity of space, and throws out the question whether the stars still exist which we now see sparkle.(136) One is astonished at finding so happy a conjecture in a work whose celebrated author was so far below some of his cotemporaries in mathematical, astronomical, and physical knowledge. The velocity of the reflected solar light was measured by Römer (November 1675) by comparison of the times of occultation of Jupiter's satellites; and the velocity of the direct light of the fixed stars by Bradley's great discovery of the aberration of light (made in the autumn of 1727),—that demonstration to our senses of the earth's movement of translation in its orbit; viz. of the truth of the Copernican system. In very recent times a third method of measurement has been proposed by Arago, by the phænomena of the light of a variable star; for example, Algol in Perseus. (137) We have to add to these astronomical methods a terrestrial measurement, which has very recently been executed with great ingenuity and success by M. Fizeau, in the neighbourhood of Paris. It recals to recollection an attempt of Galileo's with two lanterns, which did not lead to any result.

From Römer's first observations of Jupiter's satellites, Horrebow and Du Hamel estimated the time occupied in the passage of light from the sun to the earth, at their mean distance apart, at 14′ 7″; Cassini, at 14′ 10″; Newton(138), which is very striking, much nearer to the truth, at 7′ 30″. Delambre,(139) by taking into account, among the observations of his time, only those of the first satellite, found 8′ 13″·2. Encke has very justly remarked how important it would be, with the certainty of obtaining the more accordant results which the present perfection of telescopes would afford, to undertake a series of occultations of Jupiter's satellites, for the express purpose of deducing the velocity of light.

From Bradley's observations of aberration, recently rediscovered by Rigaud of Oxford, there follows, according to the investigation of Dr. Busch (140) of Königsberg, for the passage of light from the sun to the earth, 8′ 12″·14; for the velocity of the light of the stars 167976 geographical miles in a second; and for the constant of aberration, 20″·2116: but, from the more recent aberration-observations of Struve, made for eighteen months with the large transit instrument at Pulkova,(141) it appears that the first of these numbers must be considerably increased. The result of Struve's great investigation is 8′ 17″·78; whence, with the aberration-constant, 20″.4451, with Encke's correction of the sun's parallax made in 1835, and with the value of the earth's semi-diameter given by him in the Jahrbuch for 1852, we have for the velocity of light 166196 geographical miles in a second. The probable error of the velocity scarcely amounts to eight geographical miles. Struve's result for the time which light requires to reach the earth from the sun differs $\frac{1}{110}$ from that of Delambre (8′ 13″·2), which latter was employed by Bessel in the Tabulæ Regiomontanæ, and has been used hitherto in the Berlin Astronomical Almanack. The discussion of this subject cannot be regarded as completely terminated; but the earlier entertained supposition, that the velocity of the light of the Pole-star was less than that of its companion in the ratio of 133 : 134, remains subject to great doubts.

A physicist distinguished for his knowledge as well as for his great delicacy in experimenting, M. Fizeau, has succeeded in executing a terrestrial measurement of the velocity of light, by means of an ingeniously devised apparatus, in which the artificial star-like light of oxygen and hydrogen is returned to the point from whence it came, by a mirror placed at a distance of 8633 mètres (28324 English feet), between Suresne and La Butte Montmartre. A disc, furnished with 720 teeth, which made 12·6 revolutions in a second, alternately stopped the ray of light, and allowed it to pass freely between the teeth of the limb. From the indications of a counter (compteur) it was inferred, that the artificial light traversed 17266 mètres (56648 Eng. feet), or twice the distance between the stations, in $\frac{1}{18000}$ of a second of time; whence there results a velocity of 167528 geographical miles in a second. (142) This result comes nearest to that of Delambre derived from Jupiter's satellites, which is 167976 geographical miles in a second.

Direct observations, and ingenious considerations on the absence of any alteration of colour during the change of light of variable stars, (a subject to which I shall presently return), have led Arago to the conclusion that, (in the language of the undulatory theory), rays of light which have different colours, and therefore very different lengths and rapidities of transverse vibration, move through space with equal velocities; but that in the interior of the different bodies through which the coloured rays pass, their rates of propagation and their refractions are different. (143) Arago's observations have shown that in the prism the refraction is not altered by the relation which the velocity of light bears to that of the Earth's motion. All the measurements accord in the result, that the light of the stars towards which the Earth is advancing has the same index of refraction, as the light of the stars from which the Earth is receding. Speaking in the language of the emission hypothesis, the celebrated observer we have just named said, that bodies send forth rays of all velocities, but that among these different velocities there is only one which can awaken the sensation of light. (144)

If we compare the velocities of solar, sidereal, and terrestrial light, which all comport themselves exactly in the same manner in the prism, with the velocity of the current of friction-electricity, we are inclined to assign to the latter, according to the experiments devised with admirable ingenuity by Wheatstone, a velocity superior to the former in the ratio of at least 3 to 2. According to the lowest results of Wheatstone's optical rotating apparatus, the electric current traverses 288000 English statute miles, or 250000 geographical miles, in a second. (145) If, then, we reckon with Struve for sidereal light in the aberration-observations 166196 geographical miles in a second, we get a difference of 83804 geographical miles in a second for the greater velocity of the electric current.

This result appears to contradict the previously mentioned view of William Herschel, which regarded the light of the sun and of the fixed stars as perhaps the effect of an electro-magnetic process,—a perpetual Aurora. I say appears to contradict; for it cannot be deemed impossible that, in the different luminous bodies of space, there may be several magneto-electric processes very different in kind, and in which the light produced by the process may have a different rate of propagation. To this possible conjecture must be added the uncertainty of the numerical result obtained with

Wheatstone's apparatus, which result he himself regards as "not sufficiently established, and as requiring fresh confirmation" in order to be compared satisfactorily with the deductions from aberration- and satellite- observations.

Later experiments made by Walker in the United States of North America on the velocity of the propagation of electricity, on the occasion of his telegraphic determinations of the longitudes of Washington, Philadelphia, New York, and Cambridge, have excited a lively interest in the minds of physical enquirers. According to Steinheil's description of these experiments, the astronomical clock of the Observatory at Philadelphia was connected with Morse's writing apparatus on the line of telegraph in such manner, that the clock's march noted itself by points on the endless strip of paper of the apparatus. The electric telegraph carries each of these points instantaneously to the other stations, and gives them the Philadelphia time by similar points on their moving strips of paper. Arbitrary signals, or the instant of the passage of a star, may be noted in the same manner by the observer, by merely touching or pressing an index with his finger. The material advantage of this American method consists, as Steinheil expresses it, "in its making the determination of time independent of the connection of the two senses, sight and hearing; as the clock's march notes itself, and the instant of the star's passage is given direct (to within a mean error of the 70th part of a second, as Walker states) by the movement of the observer's finger. A constant difference between the compared clock-marks of Philadelphia and Cambridge is produced by the time which the electric current requires to traverse twice the closed circuit between the two stations."

Measurements made with conductors 1050 Eng. statute miles, or 968 geographical miles, in length, gave, from 18 equations of condition, the rate of propagation of the hydro-galvanic current at only 18700 statute or 16240 geographical miles in a second; ([146]) *i. e.* fifteen times slower than the electric current in Wheatstone's rotating disc apparatus! As in Walker's remarkable experiments two wires were not used, but half the conduction, according to the common expression, took place through the moist body of the earth, it might seem a justifiable supposition that the velocity of the propagation of electricity is dependent on the nature as well as on the dimensions ([147]) of the medium. In the voltaic circuit bad conductors become more heated than good conductors, and electric discharges are very variously complicated phenomena, as appears by the latest experiments of Riess. ([148]) The now prevailing views respecting what is commonly called "connection through the Earth" are opposed to the view of linear molecular conduction between the two ends of the wire, and to the conjectures of impediments to conduction, and of accumulation and discharges in a current; as that which was once regarded as intermediate conduction in the Earth is now supposed to belong only to an equalisation or to a restoration of electric tension.

Although, according to the present limits of exactness in this kind of observation, it is probable that the aberration-constant, and therefore the velocity of light, of all the fixed stars, is the same, yet the possibility has more than once been spoken of, that there may be luminous bodies in space whose light does not reach us because, from their enormous mass, gravitation constrains the luminous particles to return. The emission theory gives to such fancies a scientific form: ([149]) I only allude to them here, because I shall subsequently have to notice certain peculiarities of motion ascribed to the star Procyon, which appear to point to a perturbation by dark bodies. It is the object of this part of my work to touch on matters which, during the time in which it has been in progress, have influenced the direction which science has pursued, and thus to mark the individual character of the epoch in regard to the study of Nature, whether in the sidereal or the telluric sphere.

The photometrical relations, or relative brightness, of the self-luminous bodies which fill space, have formed a subject of scientific observation and estimation for more than two thousand years. The description of the starry heavens included not only the determinations of place, the measurement of the angular distances of the heavenly bodies, and of their paths relatively to the apparent course of the sun and the diurnal movement of the celestial vault, but also the relative intensity of light in different stars. It was no doubt the subject which earliest drew the attention of men; single stars received names before they were combined with others into imaginary groups or constellations. Among the small savage tribes inhabiting the densely wooded districts of the Upper Orinoco and Atabapo, in places where the impenetrable thickness of the forest usually obliged me to observe only high culminating stars for determinations of latitude, I often found single individuals, especially old men, who gave particular names to Canopus, Achernar, the feet of the Centaur, and the principal star in the Southern Cross. Supposing the list of constellations which we have under the name of the Catasterisms of Eratosthenes really to possess the high antiquity so long ascribed to it, (between Autolycus of Pitane and Timocharis, almost a century and a half, therefore, before Hipparchus), we should possess in the astronomy of the Greeks an indication of the time when the fixed stars were not yet classed according to their relative brightness. In the Catasterisms, in speaking of the stars which make up a constellation, there is often a notice of the number of those which are "brightest" or "largest" among them, while others are said to be dark or little noticeable, ([150]) but nothing is said of the stars in one constellation relatively to those in another. According to Bernhardy, Baehr, and Letronne, the Catasterisms are two centuries more modern than the Catalogue of Hipparchus, and are a mere compilation made without much care, an extract from the Poeticum astronomicum ascribed to Julius Hyginus, if not from the Ἑρμῆς of the ancient Eratosthenes. The Catalogue of Hipparchus, which we possess in the form given to it in the Almagest, contains the first and important determination of the classes of magnitude (degrees of brightness) of 1022 stars, or about 1-5th of all the stars visible to the naked eye in the whole heavens between the 1st and 6th magnitudes inclusive. Whether the estimations are exclusively Hipparchus's own, or whether they do not rather belong in part to the observations of Timocharis or Aristyllus which Hipparchus so often used, remains uncertain.

This work formed the foundation on which the Arabians and the whole of the middle ages continued to build; and even the habit which has been carried on into the 19th century, of limiting the number of stars of the 1st magnitude to 15 (Mädler counts 18, and Rümker, after a careful examination of the southern heavens, above 20), is derived from the classification of the Almagest at the close of the Table of Stars in the 8th book. Ptolemy, with reference to unassisted vision, called all stars "dark" which were fainter than his 8th class, of which class singularly enough he gives only 49, almost equally distributed in the two hemispheres. Considering that the table includes about a fifth part of the stars visible to the naked eye, it ought, according to Argelander's investigations, to have given 640 stars of the 6th magnitude. The nebulous stars (νεφελοειδεῖς) of Ptolemy, and of the Catasterisms of the Pseudo-Erastosthenes, are mostly small clusters of stars ([151]) which, in the purer air of southern skies, appear as nebulæ. I rest this conjecture more particularly on the mention of a nebula in the right hand of Perseus. Galileo, to whom, as well as to the Greek and Arabian astronomers, the nebula in Andromeda, although visible to the naked eye, was unknown, said, in the Nuncius sidereus, that "stellæ nebulosæ" are no other than clusters of stars, which as "areolæ sparsim per æthera fulgent."([152]) The expression "order of magnitude" (τῶν μεγάλων ταξις), although referring only to brilliancy, yet led, as early as the 9th century, to hypotheses respecting the diameters of stars of different degrees of brightness; ([153]) as if the intensity of the light did not depend on the distance, the volume, the mass, and the peculiar nature or character of the surface of the body, as more or less favourable to the luminous process or production of light.

At the time of the Mogul Power in the 15th century, when, under Ulugh Beig, the descendant of Timour, astronomy flourished in the highest degree at Samarcand, photometric determinations received such an impulse, that each of the six classes or orders of magnitude of Hipparchus and

Ptolemy were divided into three subdivisions; distinguishing, for example, small, middling, and large, of the second magnitude; reminding us of the attempts of Struve and Argelander, in our own day, to introduce decimal gradations.(154) In the tables of Ulugh Beig, this photometric advance, or more exact determination of different degrees of light, is ascribed to Abdurrahman Sufi, who had published a work specially "on the knowledge of the fixed," or fixed stars, and who first noticed the existence of one of the magellanic clouds under the name of the "White Ox." Since the introduction of telescopic vision, and its gradual improvement, estimations of successive gradations of light have extended far beyond six classes or magnitudes. The desire of comparing with the light of other stars the newly-appeared stars in Cygnus and Ophiuchus, (the first of which continued to shine for 21 years), at successive stages of their increasing and decreasing light, gave a stimulus to photometric considerations. The so-called "dark" stars of Ptolemy, or those below the 6th magnitude, received numerical denominations corresponding to the relative intensity of their light. "Astronomers," says Sir John Herschel, "who are accustomed to the use of powerful space-penetrating telescopes, pursue the descending gradations of light from the 8th down to the 16th magnitude." (155) But with such faint degrees of light, the denominations of the different classes of magnitude sometimes become very uncertain; and Struve occasionally reckons as belonging to the 12th or 13th magnitude stars which John Herschel calls of the 18th or even 20th.

This is not the place for examining in a critical manner the very different methods which have been applied to photometric determinations, during the last century and a half, from Auzout and Huygens to Bouguer and Lambert; and from William Herschel, Rumford, and Wollaston, to Steinheil and John Herschel. It is sufficient, according to the object of this work, to notice them in a brief and general manner. They include comparison with the shadows of artificial lights differing in number and distance; diaphragms; plane glasses of different thicknesses and colours; artificial stars formed by reflection on glass globes; two 7 feet telescopes so placed that the observer could pass from one to the other in scarcely more than a second of time; reflecting instruments, in which two stars which were to be compared could be seen at once, after the telescope had been so arranged that the star which was seen direct had given two images of equal intensity; ([156]) apparatuses with a mirror adapted to the objective, and with shades, the degree of intensity being measurable on a ring; telescopes with divided object-glasses, each half of which received the star's light through a prism; and astrometers, ([157]) in which the image of the Moon, or of Jupiter, is reflected by a prism, and this image is concentrated by a lens, at different distances, into a brighter or fainter star. The distinguished astronomer, who in modern times has most zealously pursued in both hemispheres the numerical determination of the intensity of light in different stars, Sir John Herschel, owns, notwithstanding what he has himself accomplished, that the practical application of exact photometric methods must still be regarded as a "desideratum in astronomy," and that "photometry or the measurement of light is still in its infancy." The increasing interest taken in variable stars, and a new cosmical event in the extraordinary augmentation of light in a star of the ship

Argo, in 1837, have made the want of better photometric processes more than ever felt.

It is material to distinguish between the mere successive arrangement of stars in the order of their brilliancy, but without numerical estimations of the intensity of light, (the Scientific Manual for Naval Officers, published by the British Admiralty, contains such a list), and classifications with numbers appended expressing the intensity of light, either under the form of so-called relations of magnitude, or by the more hazardous assignment of the quantities of radiated light. ([158]) The first numerical series, founded on estimations with the naked eye, but progressively improved by a careful revision of the materials, ([159]) probably deserves, in the present very imperfect state of photometric apparatus, the preference among the different approximate methods; although the exactness of the estimations is no doubt impaired by differences in the individual powers and habits of different observers,—the clearness of the atmosphere,—the different altitudes of the stars which are to be compared, and which can only be so by means of many intermediate links,—and, above all, by inequalities of colour. Very bright stars of the 1st magnitude, Sirius and Canopus, α Centauri and Achernar, Deneb and α Lyræ, though they have all white light, are much more difficult to compare with each other by estimation with the naked eye, than are stars of fainter light,—as, for example, those below the 6th and 7th magnitudes. But the difficulty is still greater with stars of very intense light, when yellow stars like Procyon, Capella, or Atair, are to be compared with red ones like Aldebaran, Arcturus, and Betelgeuze. ([160])

Sir John Herschel, by means of a photometric comparison of the Moon with the double star α Centauri in the southern heavens, the third in brightness of all the fixed stars, has attempted to determine the ratio between the intensity of the solar light, and the light of a star of the 1st magnitude; fulfilling thereby (as had been earlier done by Wollaston) a wish expressed by John Michell ([161]) in 1767. From the mean of 11 measurements made with a prismatic apparatus, Sir John Herschel found the full moon 27408 times brighter than α Centauri. Now the light of the Sun is, according to Wollaston, ([162]) 801072 times greater than that of the full moon; whence it follows that the light which the Sun sends to us is to that which we receive from α Centauri about as 22000 millions to 1. Hence it would follow with great probability that, if we take into account the distance of α Centauri according to its parallax, its inherent (absolute) light would be 2·3 times as great as that of our Sun. Wollaston found the brightness of Sirius 20000 million times less than that of the Sun; and according to what is now supposed to be known in respect to the parallax of Sirius, (0″·230), its actual (absolute) light would be 63 times greater than that of the Sun. ([163]) Our Sun would thus be, in regard to the intensity of its light, one of the fainter of the fixed stars. Sir John Herschel estimates the light of Sirius as equal to that of nearly two hundred stars of the 6th magnitude. As from analogy with what we already know it is very probable that all cosmical bodies change their place in space, as well as the strength of their light,—though it may be only in very long and unmeasured periods of time,—and remembering the dependence of all organic life on temperature and the strength of the Sun's light, the improvement of photometry appears deserving of being regarded as a great and serious object of scientific investigation. This improvement can alone render it possible to leave to future generations numerical determinations respecting the light of the heavenly bodies. Many geological phænomena which connect themselves with the thermic state of our atmosphere, and relate to the former distribution of plants and animals on the surface of our globe, may be elucidated thereby. More than half a century ago such considerations had not escaped the great investigator William Herschel, who before the close connection between electricity and magnetism had been discovered, compared the ever luminous cloud-envelopes of the solar orb, to the Polar Light of the terrestrial globe. (164)

Arago recognised in the complementary condition of coloured rings seen by transmission and reflection, the most promising means of a direct measure of the intensity of light. I give in a note (165) in my friend's own words a statement of his photometric method, to which he has also added the optical principle on which his cyanometer rests.

The so-called relative magnitudes of the fixed stars now given in our Catalogues and Star Maps are partly belonging to the same epoch, and partly include alterations of light belonging to different epochs. We cannot, however, as was long assumed, take as a safe criterion of such changes, the succession of the letters of the alphabet appended to the stars in the Uranometria Bayeri, which has been in such extensive use since the beginning of the 17th century. Argelander has shewn that we cannot infer relative brightness from alphabetical order, and that Bayer allowed himself to be guided in the choice of letters by the shape and direction of the constellations. (166)

III.

NUMBER, DISTRIBUTION, AND COLOUR OF THE FIXED STARS—CLUSTERS OF STARS.—MILKY WAY, IN WHICH A FEW NEBULÆ ARE INTERSPERSED.

I HAVE already alluded, in the first section of this fragmentary Astrognosy, to a consideration which was first proposed by Olbers. (167) If the whole vault of heaven were covered with a countless succession of starry strata one behind another, forming an unbroken starry canopy, then, supposing also their light to be unenfeebled in traversing space, no single constellation could be recognised amidst the universal brightness. The Moon would be seen as a dark disk, and the Sun would be known only by his spots. I have been forcibly reminded of a state of the heavens which, totally opposite in its cause, would be equally disadvantageous to human knowledge, by what takes place during a portion of the year on the Peruvian plain between the shores of the Pacific and the chain of the Andes. A thick mist covers the sky for several months during the season called "el tiempo de la garua." No planet, not one even of the brightest stars of the Southern Hemisphere, neither Canopus, nor the Southern Cross, nor the two bright stars of the Centaur, are visible. Often one can hardly conjecture the place of the Moon. If, occasionally during the day-time it is possible to distinguish the outline of the Sun's disk, it appears rayless; shorn of its beams, as if viewed through a coloured glass; usually of a yellowish red or orange colour; now and then white, or most rarely bluish green. Navigators, driven by the cold oceanic current flowing from south to north, and unable to obtain observations for latitude, sail past the harbour which they desire to enter. It is only, as I have shown elsewhere, by the use of the dipping needle ([168]) that, thanks to the direction of the magnetic lines in that part of the globe, they may be enabled to avoid error.

Bouguer and his coadjutor, Don Jorge Juan, complained long before me of the "unastronomical sky of Peru." A grave consideration is suggested by the character of this atmospheric stratum, which is so unfavourable to the transmission of light, and so unfitted for electric discharges, that thunder and lightning are unknown there, and which veils the plains in constant mist, while above, the Cordilleras raise aloft, free and unclouded, their elevated plains and snowy summits. According to the conjectures which modern geology leads us to form respecting the ancient history of our atmosphere, its primitive state, in respect to composition and density, must have been but little favourable to the passage of light. If, then, we think of the many processes which may have been in operation in the early state of the crust of the globe, in the separation of solid, liquid, and gaseous substances, we are impressed with a view of how possible it must have been, that we should have been subjected to conditions and circumstances very different from those which we actually enjoy. We might have been surrounded by an untransparent atmosphere, which, while but little unfavourable to the growth of several kinds of vegetation, would have veiled from us the whole starry firmament. Man's investigating spirit would then have been deprived of all knowledge of the structure of the Universe. Creation would have appeared to us limited either solely to our own Globe, or comprising, at the utmost, the Sun and Moon besides. Universal space would have seemed to us to be occupied only by a triple star, consisting of Sun, Earth, and Moon. Deprived of a great, and, indeed, of the most sublime part of his ideas of the Cosmos, Man would have been without the inducements, which have unceasingly stimulated him during thousands of years to the solution of difficult and important problems, and have exercised so beneficial an influence on the most brilliant advances in the higher departments of mathematics. Before proceeding to the enumeration of that which we have already attained, it may be permitted to us thus briefly to glance at a danger from which we have been preserved, and which might have opposed impassable physical barriers to the full intellectual development of our race.

In the consideration of the number of heavenly bodies which fill space, three questions are to be distinguished:—How many fixed stars are seen with the naked eye? how many of these have been progressively catalogued, together with the determination of their places (in latitude and longitude, or in declination and right ascension)? and what is the number of stars, from the 1st to the 9th and 10th magnitudes, which have been seen through telescopes in all parts of the heavens? These three questions admit of being answered, approximately at least, according to the materials already supplied by observation. Of a different class are the conjectures which, founded on the "star-gaugings" of particular parts of the Milky Way, touch the theoretical solution of the question—How many stars would be distinguished over the whole heavens by Herschel's 20-foot telescope, comprehending all those stars whose light is believed(169) to have required 2000 years to reach the Earth?

The numerical data which I here publish on this subject are chiefly taken from the final results obtained by my highly esteemed friend Argelander, Director of the Astronomical Observatory at Bonn. The author of the "Review of the Northern Heavens" has carefully examined for me afresh, at my request, the data supplied by Star-catalogues up to the present time. In the lowest class of stars visible to the naked eye some uncertainty is occasioned by the difference of estimation caused by organic differences in individual observers, stars between the 6th and 7th magnitudes being found among those of the 6th magnitude. By a variety of combinations we obtain, as a mean number, from 5000 to 5800 as the number of stars visible to the unassisted eye, throughout the entire heavens. The distribution of the fixed stars in descending magnitudes down to the 9th, is given by Argelander (170) approximately as follows:—

1st magnitude.	2nd magnitude.	3rd magnitude.	4th magnitude.	5th magnitude.
20	65	190	425	1100

6th magnitude.	7th magnitude.	8th magnitude.	9th magnitude.
3200	13000	40000	142000

The number of stars which can be clearly distinguished by the naked eye (4022 above the horizon of Berlin, 4638 above that of Alexandria), appears at first sight astonishingly small.([171]) If we take the mean semi-diameter of the moon at 15′ 33″.5., 195291 surfaces of the full moon would cover the whole heavens. Assuming an equable distribution, and taking the entire number of stars of all classes from the 1st to the 9th in round numbers at 200000, we should have about one such star for every full-moon surface. This result explains to us why in any given latitude stars visible to the naked eye are not oftener occulted by the moon. If the calculation of occultations was extended to stars of the 9th magnitude, there would be, according to Galle, on the average an occultation every 44½ minutes; as in this time the moon passes over a fresh piece of the heavens equal to its own area. Pliny (who was certainly acquainted with Hipparchus's list of stars, and who calls it a bold undertaking in Hipparchus to seek to "bequeath to posterity the starry heavens as an inheritance") reckoned in the fine sky of Italy 1600 stars,([172]) having descended in this estimation to stars of the 5th magnitude; half a century later, Ptolemy recorded only 1025 stars, down to the 6th magnitude.

Since the fixed stars ceased to be distinguished merely in respect to the constellations to which they belonged, but have been tabulated according to their relations to the great circles of the Equator or the Ecliptic, and therefore according to determinations of their places, the number as well as the exactness of such entries have constantly increased with the progress of science and the increased perfection of instruments. No catalogue has come down to us from Timocharis and Aristyllus (283 B. C.); but even though their observations, as Hipparchus says in his fragments "upon the length of the year," quoted in the 7th book of the Almagest (cap. 3,

p. 15, Halma), were very incomplete (πάνυ ὁλοσχερῶς), yet there can be no doubt that they both determined the declination of many stars, and that these determinations preceded by almost a century and a half Hipparchus's Table of Fixed Stars. It is known (although we have only Pliny's statement of the fact) that Hipparchus was stimulated by the appearance of a new star to pass the heavens in review and to determine the places of the stars. This statement has, however, more than once been regarded as merely the echo of a tale invented after the period to which it relates; (173) and it is certainly remarkable that Ptolemy does not allude to it in the slightest degree. It is, however, incontestably true that it was the sudden appearance of a bright star in Cassiopeia (November, 1572) that occasioned Tycho Brahe to undertake his great star-catalogue. According to an ingenious conjecture of Sir John Herschel,(174) a star which appeared in the constellation of Scorpio in the month of July, 134 years before our Era (according to the Chinese annals under the reign of Wou-ti, of the Han Dynasty), may very well be the same which Pliny mentions. Its appearance falls six years before the epoch at which (according to Ideler's researches) Hipparchus prepared his catalogue. Edouard Biot, of whom science has been too early deprived, discovered the notice of this cosmical event in the celebrated collection of Ma-tuan-lin, which contains all the appearances of comets and unusual stars between the years 613 B.C., and A.D. 1222.

The tripartite didactic poem of Aratus, (175) to which we owe the only writing of Hipparchus which has come down to us, belongs to about the period of Eratosthenes, Timocharis, and Aristyllus. The astronomical (not meteorological) part of the poem is founded on the description of the heavens given by Eudoxus of Cnidos. The star-table of Hipparchus has unhappily not been preserved to us: according to Ideler (176) it probably formed the principal part of the treatise, cited by Suidas, on the arrangement of the heaven of the fixed stars and the other heavenly bodies, and contained 1080 positions for the year 128 before our Era. In Hipparchus's Commentary, all the positions, determined probably by equatorial armillæ rather than by the astrolabe, are referred to the equator by right ascension and declination; in the star-table of Ptolemy, which is supposed to be altogether imitated from Hipparchus, and which, including five so-called nebulæ, contains 1025 stars, they are referred to the Ecliptic (177) by assigned longitudes and latitudes. If we compare the number of fixed stars in the Almagest, (ed. Halma, T. ii. p. 83),

1st mag.	2nd mag.	3rd mag.	4th mag.	5th mag.	6th mag.
15	45	208	474	217	49

with the numbers of Argelander in a previous page, we see (with a neglect of stars of the 5th and 6th magnitudes which was to be expected,) a remarkable fulness in the 3rd and 4th magnitudes. The indeterminateness of estimations of the degree of light in ancient and modern times does, indeed, throw great uncertainty on every direct comparison.

If the catalogue of the fixed stars, which bears the name of Ptolemy, only comprises a fourth part of the stars visible to the naked eye at Rhodes and Alexandria,—and if, from the erroneous reduction for precession, it gives positions as if they had been determined in the year 63 of our Era,—we have in the next sixteen centuries only three original, and for their epoch complete, star-catalogues: that of Ulugh Beig (1437), of Tycho Brahe (1600), and of Hevelius (1660). In the short intervals of repose which intervened between the devastations of war and wild intestine revolutions, practical astronomy flourished among the Arabians, Persians, and Moguls, from the middle of the 9th to that of the 15th centuries,—from Al-Mamun, son of the great Harun Al-Raschid, to the Timuride, Mohammed Teraghi Ulugh Beig, son of the Shah Rokh,—in a degree never before witnessed. The astronomical tables of Ebn-Junis (1007), called the Hakemite Tables in honour of the Fatimite Caliph Aziz Ben-Hakem Biamrilla, testify,—as do also the Ilkhanic Tables ([178]) of Nassir-Eddin Tusi, the builder of the great observatory of Meragha, not far from Tauris (1259),—to the more advanced knowledge of the planetary movements, the improvement of measuring instruments, and the multiplication of methods differing from those of Ptolemy, and superior to them in exactness. In addition to Clepsydras, Pendulum oscillations ([179]) now began to be used as a measure of time.

The Arabians have the great merit of having shewn how by the intercomparison of observations and tables the latter might be greatly improved. The star-catalogue of Ulugh Beig (originally written in Persian), with the exception of a part of the southern stars of Ptolemy not visible ([180]) in the latitude of 39° 52′ (?), was prepared in the Gymnasium at Samarcand from original observations. It contained at first only 1019 positions of stars, which are reduced to the year 1437. A later commentary furnishes 300 additional stars observed by Abu-Bekri Altizini in 1533. Thus we come, through Arabians, Persians, and Moguls, down to the great epoch of Copernicus, and almost to that of Tycho Brahe.

Since the beginning of the 16th century the extension of navigation in tropical seas and high southern latitudes has operated powerfully in enlarging the knowledge of the firmament, though it has done so in a less degree than has the employment of telescopes, began a century later. By both, new regions of space before unknown have been opened to our view. I have noticed in a previous volume [181] what was related of the magnificence of the Southern Hemisphere, first by Amerigo Vespucci, and next by Magellan and by Elcano's companion Pigafetta, and how the black patches (Coal sacks) were described by Vicente Yañez, and the Magellanic Clouds by Anghiera and Andrea Corsali. Here, also, contemplative astronomy preceded measuring astronomy. The riches of the firmament near the South Pole,—a region which is really, as is now well known, comparatively poor in stars,—were described with such exaggeration, that Cardanus Polyhistor said that Vespucci saw there 10000 stars with his unassisted eyes. [182] The first persons who seriously began the task of observing the stars of the Southern Hemisphere were Friedrich Houtmann and Petrus Theodori of Emden (who, according to Olbers, was the same person as Dircksz Keyser). They measured distances of stars at Java and Sumatra, and the most southern stars were now entered in the celestial maps of Bartsch, Hondius, and Bayer, as well as, by the diligent care of Kepler, in the Rudolphine star-catalogue of Tycho Brahe.

Scarcely half a century after Magellan's circumnavigation of the globe, Tycho Brahe began his admirable examination of the position of the fixed stars,—a work surpassing in exactness anything which practical astronomy had yet furnished, even the careful observations of the fixed stars by the Landgrave Wilhelm IV. at Cassel. Tycho Brahe's Catalogue, revised by Kepler, contains, however, only 1000 stars, of which $\frac{1}{4}$th at the utmost are of the 6th magnitude. This catalogue, and the less used one of Hevelius, having 1564 determinations of places of stars for the year 1660, are the last which (owing in the latter case to the obstinate aversion of the Dantzig astronomer to the application of telescopes to measuring instruments) were drawn up from observations made with the unassisted eye.

The combination of the telescope with measuring instruments made it at length possible to determine the places of stars below the 6th magnitude, and especially between the 7th and 12th magnitudes. Astronomers now first began to approach the time when they might be said to take possession of the world of fixed stars. But the enumeration of the feebler telescopic stars, and the determination of their places, have not only, by extending the horizon of the field of observation, given us to know more of the contents of the remoter regions of space,—but they have also, which is yet more important, exercised indirectly a material influence on our knowledge of the structure of the Universe and of its form, on the discovery of new planets, and on the more rapid determination of their paths. When William Herschel conceived the happy thought of, as it were, casting the sounding lead into the depths of space, and in his star gaugings ([183]) counting the stars which passed through the field of his great telescope at different distances from the Milky Way,—the law of the increasing quantity of stars in approaching the Milky Way was discovered, and brought with it the idea of the existence of great concentric rings filled with millions of stars, forming the Galaxy. The knowledge of the number and relative position of the fainter stars, as has been shown by Galle's prompt and happy discovery of Neptune, and by that of several of the smaller planets, facilitates the discovery of planetary bodies which change their place, moving amidst fixed points. Another circumstance shows, in a still clearer light, the importance of very complete star-catalogues. When once a new planet has been discovered in the celestial vault, the difficult calculation of its path is aided by its rediscovery in a catalogue of older date. The fact of a star having been formerly registered, and being now missing in the position assigned to it, has thus often effected more than, from the slowness of the planet's motion, could be gained by the most carefully-repeated measurement during several successive years. Thus for Uranus, the star No. 964 in the Catalogue of Tobias Mayer, and for Neptune, the star 26266 in the Catalogue of Lalande, ([184]) have been of great importance. We now know that Uranus was observed 21 times before it was known to be a planet: once by Tobias Mayer, 7 times by Flamsteed, once by Bradley, and 12 times by Le Monnier. We may say, that the increasing hope of future discoveries of planetary bodies rests partly on the excellence of our present telescopes (Hebe, when discovered in July 1847, was equal to a star of between the 8th and 9th magnitudes, but in May 1849 was only of the 11th magnitude), and partly, and perhaps still more, on the completeness of our catalogues and the care of our observers.

Subsequent to the epoch when Morin and Gascoigne combined telescopes with measuring instruments, the first star-catalogue which was published was that of Halley's southern stars. It was the fruit of a short visit to Saint Helena in 1677 and 1678, but it contained no determination of any star below the 6th magnitude. (185) It is true that Flamsteed had previously undertaken his great Star Atlas, but the work of that celebrated man was not published until 1712. It was followed by the observations of Bradley (1750 to 1762), which led to the discovery of aberration and nutation, and received a further lustre from our Bessel, in his Fundamenta Astronomiæ (1818); (186) and by the star catalogues of Lacaille, Tobias Mayer, Cagnoli, Piazzi, Zach, Pond, Taylor, Groombridge, Argelander, Airy, Brisbane, and Rümker.

We cite here only works which embrace large masses, (187) and present to us an important part of the contents of space in stars between the 7th and 10th magnitudes. The catalogue which is known under the name of Jérôme de Lalande, but which is founded on observations made by his nephew, Le Français de Lalande, and Burckhardt, between 1789 and 1800, has lately, though for the first time, received a great acknowledgment. In the state to which it has been brought by the careful reduction, editorship, and publication, for which astronomy is indebted to Francis Baily and the British Association for the Advancement of Science, it contains 47390 stars, many of which are of the 9th, and several rather below the 9th magnitude.* Harding, the dis-

[* The star-catalogues of Lalande and Lacaille, the first containing upwards of 47000 stars (as stated in the text), and the second above 10000 stars, were reduced, catalogued, and prepared for publication at the cost of the British Association for the Advancement of Science, the first under the superintendence of Mr. Francis Baily, and the second under that of Professor coverer of Juno, has entered above 50000 stars in 27 sheets. Bessel's great work of the observations of Zones of the Heavens, comprising 75000 observations, and which extended, in the years 1825—1833, from $-15°$ to $+45°$ of declination, has been continued by Argelander of Bonn, from 1841 to 1844, with a care deserving of the highest praise, and has been carried by him to $+80°$ of declination. From Bessel's Zones, between $-15°$ and $+15°$ of declination, Weisse of Cracow, at the request of the Academy of St. Petersburg, has reduced 31895 stars (of which 19738 are of the 9th magnitude) to the year 1825. (188) Argelander's "Review of the Northern Heavens from $+45°$ to $+80°$ of declination," contains 22000 well-determined places of stars.

I think that I cannot refer to the great work of the star maps of the Berlin Academy more worthily than by introducing, in Encke's own words, an extract on the subject of this undertaking from his comprehensive discourse in memory of Bessel. "With the completion of catalogues is connected the hope that, by continued careful comparison of the stars marked as fixed points with the aspect of the heavens at the time of observation, we shall be enabled to

Henderson. But the expense of *printing* these two catalogues was defrayed by Her Majesty's Government, in consequence of a representation of their importance to the purposes of practical Astronomy made by the British Association to the late Sir Robert Peel.

The catalogues of Lelande and Lacaille are distinct from the "British Association Catalogue," not noticed in this part of the text of Cosmos, but frequently referred to in the course of the volume. The "British Association Catalogue" was also prepared under the superintendence of Mr. Francis Baily, but in its case the cost of printing, as well as that of preparing for publication, was defrayed by the contributions of the members of the British Association.—Ed.]

note all heavenly bodies which change their place, but whose movements, from the faintness of their light, it would be scarcely possible to perceive directly by the eye; and in this manner we may anticipate the discovery of all that still remains unknown to us in our solar system. As Harding's excellent Atlas offers a complete picture of the heavens, so far as Lalande's Histoire Celeste, on which it is founded, is capable of affording such a picture, so Bessel, in 1824, after finishing the first section of his Zones, formed the plan of founding thereupon a still more detailed representation of the sidereal heavens, which should have for its object, not merely the reproduction of observation, but the systematic attainment of a degree of completeness which should permit every new phenomenon to be immediately recognised. The star maps of the Berlin Academy of Sciences, sketched upon Bessel's plan, although they have not yet completed the first proposed cycle, have already attained their object in the discovery of new planets in the most brilliant manner, as up to the present time (1850) they have been the principal, though not the exclusive, means of the discovery of seven new planets. ([189]) Of the 24 sheets which are to represent the heavens within 15 degrees on either side of the Equator, our Academy has now published 16. They contain, as nearly as possible, all stars down to the 9th, and partially down to the 10th magnitudes."

I may here introduce a notice of the approximate estimations which have been hazarded respecting the number of stars in all parts of the heavens which may be visible to human eyes, aided by our present powerful space-penetrating telescopes. For Herschel's 20-feet reflector, which was used in the celebrated star-gaugings or sweeps, with a magnifying power of 180, Struve takes for the zones within 30° on either side of the Equator, 5800000 stars; and, for the whole heavens, 20374000 stars. With a still more powerful instrument, the 40-feet reflector, Sir William Herschel supposed that 18 millions of stars would be visible in the Milky Way alone. ([190])

Having considered the number of fixed stars, whether telescopic or visible to the naked eye, which have been entered in catalogues, together with the determination of their places, we now turn to their distribution and grouping on the celestial vault. We have seen that, from their small and exceedingly slow (apparent and real) change of place, due partly to precession and the unequal influence of the progressive movement of our solar system, and partly to their own proper motion, they may be regarded in the light of fixed marks in space, enabling the attentive observer to recognise all bodies moving amongst them, either at a more rapid rate or in a different direction, as planets and telescopic comets. In gazing on the vault of heaven, our first and leading interest is attracted by the bodies which by their multitude and mass fill space,—it is the fixed stars which claim and receive the homage of our admiration: but the orbits of the moving planetary bodies speak more to the investigating reason, to which they present complicated problems, whose study promotes and accelerates intellectual development in the domain of astronomy.

From the multitude of stars, large and small, which appear intermingled, as it were by accident, on the celestial vault, the rudest tribes of men (as several now carefully-examined languages of what are called savage nations testify) single out particular, and almost everywhere the same, groups, in which bright stars attract the eye, either by their proximity to each other, by peculiarities in their arrangement and relative position, or by a certain degree of isolation. Such groups awaken obscurely the idea of a relation of parts to each other; and, each being regarded as a whole, receive particular names, differing in different tribes, and most often taken from organic beings with which imagination peoples the silent regions of space. Thus there were early distinguished the Pleiades (called by some the brood of chickens), the seven stars of the Great Bear or Wain (the lesser Bear or Wain was remarked later, and only on account of the repetition of the form), Orion's Belt (Jacob's Staff), Cassiopeia, the constellations of the Swan, the Scorpion, the Southern Cross (on account of the striking change of direction before and after culmination), the Southern Crown, the Feet of the Centaur (as it were the Twins of the Southern Hemisphere), &c.

Where steppes, grassy prairies, or sandy deserts, present a wide horizon, the rising and setting of the constellations, varying with the seasons of the year, and associated thereby with the requirements of pastoral and agricultural life, become the subject of diligent attention, and are also gradually connected with symbolical combinations of ideas. Contemplative, not measuring, astronomy then begins to be more developed. Besides the diurnal movement common to all heavenly bodies from morning to evening, it is soon perceived that the sun has a movement of its own, much slower, and in the opposite direction. The stars which, when night comes on, are seen high in the evening sky, sink daily more and more towards the setting sun, until at last they are lost in his beams, and disappear in the twilight; on the other hand, the stars which shone in the morning sky before sunrise recede more and more from the Sun. In the constantly changing spectacle of the starry heavens, fresh and fresh constellations show themselves. With some degree of attention it is easily recognised that they were the same which had before become invisible in the West; and that, in the course of about half a year, those stars, which before were seen near the Sun, are now opposite to it, setting when it rises, and rising when it sets. From Hesiod to Eudoxus, and from Eudoxus to Aratus and Hipparchus, the literature of the Greeks is full of allusions to the disappearance of stars in the Sun's rays (their heliacal setting), and their becoming visible in the morning twilight (their heliacal rising). The accurate observation of these phenomena presented the first elements of chronology—elements which were simply expressed in numbers; while at the same time, mythology, varying in its imaginations with the gay or gloomy dispositions of the national mind, exercised without restraint its capricious sway in the fictions connected with the bright bodies of space.

The primitive Greek sphere (I here follow again, as in the history of the Physical Contemplation of the Universe, (191). the researches of my too early departed friend, the illustrious Letronne) became gradually filled with constellations, without their having been in the commencement referred in any way to the Ecliptic. Thus Homer and Hesiod distinguish different groups of stars, as well as single stars, by particular names: Homer notices the She Bear ("else called the Wain of Heaven, and which alone never descends to bathe in the ocean"), Bootes, and the Dog of Orion; and Hesiod names Sirius and Arcturus; both speak of the Pleiades, the Hyades, and Orion. ([192]). If Homer twice says that the Bear *alone* never plunges into the ocean, this merely implies that in his time the constellations of the Dragon, Cepheus, and the Little Bear, which also never set, had not yet been placed in the Greek Celestial Sphere. It by no means implies that the existence of the stars forming these three catasterisms was not known, but only that they had not yet been arranged in figures. A long and often misunderstood passage of Strabo (lib. i. p. 3, Casaub.) on Homer (Il. xviii. 485—489) proves rather than anything else that which is here important—viz., the *gradual* acceptance of figures or constellations in the Grecian Sphere. "It is unjustly," says Strabo, "that Homer is accused of ignorance, as if he knew only of one Bear instead of two. Perhaps the second was not yet constellated, and that it was only after the Phœnicians had marked out this constellation, and used it in navigation, that it came to the Greeks." All the scholiasts on Homer, Hygin, and Diogenes Laertius, ascribe the introduction to Thales. The Pseudo-Eratosthenes calls the Little Bear φοινικη (as it were the Phœnician Lodestar). One hundred years later (Ol. 71), Cleostratus of Tenedos enriched the Sphere with Sagittarius, τοξότης, and the Ram, κριός.

It is to this epoch, that of the tyranny of the Pisistratides, that we are to ascribe, according to Letronne, the introduction of the Zodiac in the ancient Greek Sphere. Eudemus of Rhodes, one of the most distinguished disciples of Aristotle, author of a "History of Astronomy," ascribes the introduction of the Zodiacal Zone (ἡ τοῦ ζωδιακοῦ διάζωσις, also *ζωίδιος κύκλος*) to Œnopides of Chios, a cotemporary of Anaxagoras. (193) The idea of referring the planets and fixed stars to the Sun's path, and the division of the Ecliptic into twelve equal parts (Dodecatomeria), are ancient Chaldean, and it is highly probable that they reached the Greeks from Chaldea itself, and not from the Valley of the Nile, and, at earliest, at the beginning of the 5th or in the 6th century before our Era. (194) The Greeks only selected from the constellations already marked in their primitive Sphere those which were nearest to the Ecliptic, and which could be employed as Signs of the Zodiac. If anything more than the idea and the number of divisions of a zodiac,—if the zodiac itself, with its signs,—had been borrowed by the Greeks from another nation, 11 signs would not have been thought sufficient originally; nor would the Scorpion have been applied to two divisions; nor would zodiacal figures have been formed,—some of which, as Taurus, Leo, Pisces, and Virgo, cover, with their outlines, 35° to 48°; while others, as Cancer, Aries, and Capricornus, occupy only 19° to 23°,—which deviate inconveniently to the North and South of the Ecliptic,—which sometimes are widely separated, and sometimes, like Taurus and Aries, Aquarius and Capricornus, are closely crowded and almost overlap. All these circumstances prove that earlier-formed catasterisms were made into zodiacal signs.

According to Letronne's conjecture, the sign Libra was introduced in the time of Hipparchus,—perhaps by himself. Eudoxus, Archimedes, Autolycus, and even Hipparchus, in the few remains of theirs which we possess (with the exception of one passage, probably falsified by a copyist), (195) never mention it. We first find a notice of the new sign in Geminus and Varro, hardly half a century before our Era; and as the Romans soon after this date, from Augustus to Antoninus, became vehemently attached to astrology, those constellations "which lay along the Sun's celestial path" grew into a heightened fanciful importance. To the first half of this period of the Roman Empire belong the Egyptian zodiacal figures of Dendera, Esne, the Propylon of Panopolis, and some mummy cases,—as was asserted by Visconti and Testa at a time when all the materials for the decision of the question had not yet been collected, and when wild hypotheses prevailed respecting the signification of those symbolical zodiacal signs, and their dependence on the precession of the equinoxes. From Adolph Holtzmann's acute researches, the high antiquity which, from passages in Menu's Institutes, Valmiki's Ramayana, and Amarasinha's Dictionary, August Wilhelm von Schlegel had attributed to zodiacs found in India, has become very doubtful. ([196])

The artificial grouping of stars in constellations which, in the course of centuries, has taken place in so accidental a manner,—the often inconvenient magnitude and uncertain outlines of these figures,—the confused nomenclature of separate stars in the constellations, with the exhaustion of several alphabets, as in the Ship Argo,—the incongruous mixture of mythical personages with the plain prose of physical instruments, chemical furnaces, and pendulum clocks, in the southern hemisphere,—have several times led to proposals for a new division of the celestial sphere, which should be entirely without imaginary figures. For the southern hemisphere, where only Scorpio, Sagittarius, Centaurus, Argo, and Eridanus, have ancient poetic possession, the enterprise would seem less hazardous. ([197])

The heaven of the fixed stars (orbis inerrans of Apuleius), and the improper expression "fixed stars" (astra fixa of Manilius), remind us, as I have already remarked in the Introduction to the portion of this volume which treats of Astrognosy, (198) of the combination and even confusion which has taken place between the two ideas of "being set or fastened in the sky," and of "absolute immobility or fixity." When Aristotle terms the non-wandering orbs (*ἀπλανῆ ἄστρα*) fastened (*ἐνδεδεμένα*), and when Ptolemy calls them attached (*προσπεφυκότες*), these expressions have a direct reference to Anaximenes' supposition of a crystal sphere. The apparent motion of all the fixed stars from East to West, while their distances from each other remained the same, had given rise to this hypothesis. "The fixed stars (*ἀπλανῆ ἄστρα*) belong to the upper or more remote region, in which they are fastened as if nailed to the crystal heaven; the planets (*ἄστρα πλανωμενα* or *πλανητά*), which have an opposite motion, belong to the lower or nearer region." (199) If, in Manilius, as early as the times of the first Cæsars, "stella fixa" is used instead of "infixa" or "affixa," we may still assume that the school of Rome kept only at first to the original meaning of being fastened; but that, as the word "fixus" also included the signification of "immobility," and might even be taken as synonymous with "immotus" and "immobilis," it might easily happen that popular opinion, or rather the usage of language, should gradually connect with "stella fixa" the idea of immobility, without remembering the sphere in which the stars had been supposed to be fastened: and thus Seneca might term the world of fixed stars "fixum et immobilem populum."

If, following Stobæus and the collector of the "Views of

Philosophers," we carry back the expression of "crystal heaven" to the early time of Anaximenes, we find, however, the idea which forms the groundwork of such an appellation first developed with precision by Empedocles. He regards the heaven of the fixed stars as a solid mass, formed from the æther which has been solidified into a crystalline substance by heat. (200) The Moon is regarded by him as a body which has been molten as by the action of fire, and subsequently consolidated like hail. The original idea of transparent solidified substances would not, according to the physics of the Ancients, (201) and their ideas of the solidification of fluids, have led directly to cold and ice; but the affinity of κρύσταλλος with κρύος and κρυσταινω, as well as comparison with the most transparent of all bodies, gave occasion to the more definite statements, that the vault of heaven consisted of ice or of glass. Thus we find in Lactantius "cœlum aërem glaciatum esse," and "vitreum cœlum." Empedocles was certainly not thinking of Phœnician glass, but of air which, by the action of the fiery æther, had been run together into a transparent solid body. In the comparison with ice (κρύσταλλος), the prevailing idea was that of transparency: the origin of ice by the action of cold was not regarded, all that was directly considered being the case of a fluid which had become solid and was transparent. If the poets used the word *crystal,* in prose (as is testified by the passage of Achilles Tatius, the commentator of Aratus, cited in Note 200,) the expression employed is only *crystalline,* or *similar to crystal* (κρυσταλλοειδης). So also πάγος (from πήγνυσθαι, to solidify) signifies a piece of ice, in which the solidification is the only thing considered.

Through the Fathers of the Church, who, in allusions to the subject, assume from seven to ten glass heavens successively placed over each other like the coats of an onion, this view of the crystal vault passed to the Middle Ages: it has even been preserved to recent times in some of the convents of the south of Europe, where, to my astonishment, a venerable dignitary of the Church, in reference to the fall of aerolites at Aigle which excited so much attention, expressed the opinion that what we called meteoric stones, and which were covered with a vitrified crust, were not parts of the fallen stone itself, but pieces of the crystal heaven which it had broken through in falling. Kepler first, two centuries and a half earlier, induced by the consideration of comets cutting through all the planetary orbits, had boasted (202) of having destroyed the 77 homocentric spheres of the celebrated Girolamo Fracastoro, as well as all the more ancient retrograding epicycles. How such great minds as Eudoxus, Menæchmus, Aristotle, and Apollonius of Perga, had conceived to themselves the possible mechanism and motion of spheres intercalated with each other, and carrying with them the planets,—or whether they regarded these spherical systems as ideal contemplations—fictions of the intellect—by the aid of which the difficult problems of the courses of the planets might be explained and approximately computed,—are questions which I have touched on elsewhere, (203) and which are not without importance in the history of astronomy, when that history attempts to distinguish periods of development.

Before we pass from the very ancient but artificial zodiacal grouping of the fixed stars (as imagined to be set in a solid sphere) to their natural or real grouping, and to such laws in respect to their relative distribution as have hitherto been recognised, we have still to consider some particular appearances presented by them to our sense of vision; viz. their rays, their apparent unreal diameters, and the diversities of colour of different stars. Of the apparent rays, which differ in number, position, and length, as seen by every individual, I have already spoken when treating of the subject of Jupiter's satellites. (204) Indistinct vision (la vue indistincte) arises from various organic causes, dependent on the spherical aberration of the eye, on diffraction at the margins of the pupils or at the eye-lashes, and on the irritability of the retina spreading more or less widely from a stimulated point. (205) I see very regularly, in stars from the 1st to the 3d magnitude, eight rays, at angles of 45°. As, according to Hassenfratz, these rays are caustics on the crystalline, formed by the intersection of the refracted rays, they move according as the spectator inclines his head to either side. (206) Some of my astronomical friends see three or at most four upward, and no downward rays. It has always appeared to me remarkable that the ancient Egyptians invariably give to stars five rays only (at every 72°); so much so, that, according to Horapollo, a star signifies in hieroglyphics the number 5. (207)

These rays disappear if the star is viewed through a small hole made in paper with a needle (I have often observed Canopus, as well as Sirius, in this manner). The rays appear in telescopic vision with high magnifying powers, when the stars present themselves either as luminous points of more intense light, or as extremely small discs. Although the less degree of scintillation between the tropics gives a certain impression of repose, yet the entire absence of rays, in viewing the heavens with the naked eye, would appear to me a privation. Illusion of the senses, and indistinctness of vision, may perhaps augment the magnificence of the shining canopy of heaven. Arago long ago proposed the question—Why is it that, notwithstanding the strong light of the fixed stars, we do not perceive them when rising above the horizon, whilst yet we see the extreme margin of the moon's disc under similar circumstances? (208)

Even the most perfect optical instruments, with the highest magnifying powers, give to the fixed stars false diameters (spurious discs, diamètres factices), which, according to Sir John Herschel's remark, (209) "with equal magnifying powers diminish as the aperture of the telescope increases." Occultations of stars by the Moon's disc show that immersion and emersion are sensibly instantaneous,—so much so, that no fraction of a second can be assigned for the time occupied in disappearance or reappearance. The frequent observation of stars in their immersion adhering to the disc of the moon, is a phenomenon of the inflection of light which has no connection with the question of the star's diameter. I have already noticed elsewhere, that Sir William Herschel, with a magnifying power of 6500, still found the diameter of α Lyræ 0″·36. The image of Arcturus was so lessened in a thick mist as to be even below 0″·2. It is remarkable that, from the illusion produced by irradiation, Kepler and Tycho Brahe, before the invention of telescopes, ascribed to Sirius a diameter, the one of 4′, the other of 2′ 20″. (210) The alternating light and dark rings which surround the factitious discs of stars, viewed with magnifying powers of two or three hundred, and which, when diaphragms of different shapes are applied, show prismatic colours, are the consequences at once of interference and of diffraction, as we learn from Arago's and Airy's observations. The smallest objects which can still be distinctly seen (telescopically) as luminous points (multiple stars such as ε Lyræ, and the 5th and 6th star discovered by Struve in 1826 and by Sir John Herschel in the trapezium, (211) formed by the quadruple star θ Orionis) may be employed to test the quantity of light and merits in other respects of optical instruments, whether refractors or reflectors.

A difference of colour in the proper light of the fixed stars, as well as in the reflected light of the planets, has been recognised from very early times; but the knowledge of this remarkable phenomenon has been wonderfully enlarged since the period of telescopic vision, and especially since double stars have become an object of lively interest and diligent observation. We do not here refer to the change of colour which, as has been already remarked, acccompanies scintillation even in the whitest heavenly bodies,—still less the transitory and most frequently reddish tinge which the light of stars receives in the vicinity of the horizon from the medium (*i. e.* the atmospheric strata) through which we view them; but we speak of the white or of the coloured light which radiates from stars as the result of peculiar luminous processes and the particular character of the surface of each. The Grecian astronomers knew only red stars; while, by the aid of the telescope, the moderns have discovered in the starry vault,—in the celestial fields which light traverses, as in the corollas of our flowering plants, and in the metallic oxides,—almost every gradation of prismatic colour between the two extremes of refrangibility, or between the violet and the red rays. Ptolemy, in his catalogue of the fixed stars, calls six stars ὑπόκιρροι, fiery red, (212) viz.—Arcturus, Aldebaran, Pollux, Antares, Betelgueze, and Sirius. Cleomedes even compares Antares with the red hue (213) of Mars, which is itself called sometimes πυρρὸς, and sometimes πυροειδὴς.

Of the six stars above enumerated, five have still, in our days, a red or reddish light: Pollux is still marked in our catalogues as reddish, whereas Castor is said to be greenish. (214) Sirius, on the other hand, offers the solitary example of an historically-proved alteration of colour, for it has at present a perfectly white light. Some great revolution of nature (215) must doubtless have taken place on the surface or in the photosphere of such a fixed star,—such a distant *sun*, as already Aristarchus of Samos would have called the fixed stars,—to disturb the process by which, through the absorption of other complementary rays (whether in the photosphere of the star itself, or in wandering cosmical clouds), the less refrangible red rays had once been the prevailing ones. Now that, from the modern advances in optics, this subject has become one of great and lively interest, it would be very desirable to be able to assign some fixed limits in point of time to the epoch of such an event in Nature as that of the disappearance of the red colour of Sirius. In the time of Tycho Brahe the light of Sirius must certainly have been already white; for when the new star which appeared in Cassiopeia in 1572, and which was at first of dazzling whiteness, was seen to assume, in March 1573, a red tinge, and, in January 1574, to become once more white,—the astonished observers who witnessed these changes compared the red star to Mars and Aldebaran, but not to Sirius. Perhaps Sédillot, or other philologists conversant with Arabian and Persian astronomy, may succeed in discovering in the intervals from El-Batani (Albategnius) and El-Fergani (Alfraganus) to Abdurrahman Sufi, and Ebn-Junis (from 880 to 1007), and from Ebn-Junis to Nassir-Eddin and Ulugh Beig (from 1007 to 1437) some evidence respecting the colour of Sirius at that time. El-Fergani (properly called Mohammed Ebn-Kethir El-Fergani), who, as early as the middle of the 10th century, observed at Rakka (Aracte) on the Euphrates, names as "red stars" ("stellæ ruffæ" in the old Latin version of 1590) Aldebaran, and, perplexingly enough, ([216]) the now yellow, or at the utmost reddish-yellow, Capella, but not Sirius. On the other hand, if we suppose that Sirius had then ceased to be a red star, it would seem strange that El-Fergani, who follows Ptolemy throughout, should not have pointed out the change of colour in a star of such note. Negative reasons are, however, seldom conclusive; and it should be remarked that, in the same passage, El-Fergani does not mention the colour of Betelgeuze (α Orionis), which is now, as in Ptolemy's time, a red star.

It has long been recognised, that among all the brightly-shining fixed stars in the heavens, Sirius occupies the first and most important place in chronological respects, and in its historical connection with the earliest development of human civilization in the Valley of the Nile. According to the most recent researches of Lepsius, ([217]) the Sothic period, and the heliacal rising of Sothis (Sirius),—on which subject Biot has furnished an excellent memoir,—remove the complete construction of the Egyptian calendar to the highly ancient epoch of almost 33 centuries before our Era, when not only the summer solstice, and consequently the commencement of the rising of the Nile, but also the heliacal rising of Sothis, fell upon the day of the first water-month (on the first Pachon). The most recent and hitherto unpublished researches on the etymology of Sothis and Sirius in the Coptic, the Zend, the Sanscrit, and the Greek, have been brought together by me in a note (218), which cannot be otherwise than welcome to those who, from interest in the history of astronomy, are led to recognise, in languages and their affinities, monuments of earlier knowledge.

At the present time, besides Sirius; Vega, Deneb, Regulus, and Spica, are decidedly white stars; and among the small double stars, Struve counts 300 in which both stars are white. (219) Procyon, Atair, Polaris, and especially β Ursæ Minoris, have a yellow or yellowish light. Of red or reddish large stars, we have already named Betelgeuze, Arcturus, Aldebaran, Antares and Pollux. Rümker finds γ Crucis to have a fine red colour; and my old friend Captain Bérard, who is an excellent observer, wrote from Madagascar in 1847, that he had for some years perceived α Crucis to be reddening. The star η Argûs, which has acquired celebrity from Sir John Herschel's observations, and of which I shall soon have occasion to speak in more detail, is changing the colour as well as the intensity of its light. In 1843, at Calcutta, Mr. Mackay found this star like Arcturus in colour, —therefore of a reddish yellow; (220) but in February 1850, Lieutenant Gilliss, in letters from Santiago de Chile, calls it "of a darker colour than Mars." Sir John Herschel, at the conclusion of his Cape observations, gives a list of 76 ruby-coloured small stars, from the 7th to the 9th magnitude. The appearance of some of them in the telescope is like drops of blood. The majority of "variable" stars are described as red or reddish. (221) I may name as exceptions—Algol in the head of Medusa, β Lyræ, and ε Aurigæ, which have a pure white light. Mira Ceti, whose periodic variation of light was the first recognised, (222) has a strongly reddish light; but the variability of Algol and β Lyræ shows that the red colour is not a necessary condition of variability of light; and we know, moreover, that there are several reddish stars which are not included among the variable stars. According to Struve, the faintest stars in which colours can still be distinguished are of the 9th and 10th magnitudes. We find the first mention of blue stars (223) in Mariotte's "Traité des Couleurs," in 1686. The star η Lyræ is bluish. A small cluster of 3½ minutes' diameter in the southern hemisphere consists, according to Dunlop, exclusively of small blue stars. Among the double stars there are many in which the principal star is white, and the companion blue; and some in which both the principal star and the companion have a blue light, (224) as δ Serp. and 59 Androm. Sometimes, as in the cluster of stars near κ of the Southern Cross, which was taken by Lacaille for a nebula, above a hundred small stars of different colours (red, green, blue, and bluish-green) are so crowded together, that they appear, in large telescopes, like gems of many colours ("like a superb piece of fancy jewellery)." (225)

The ancients thought they recognised a remarkable symmetrical arrangement in the position of certain stars of the 1st magnitude. Thus their attention was particularly directed to what they called the "four royal stars," which are opposite to each other on the sphere—Aldebaran and Antares, Regulus and Fomalhaut. This regular arrange ment, which I have noticed elsewhere,[226] is discussed at length by a Roman writer of the age of Constantine, Julius Firmicus Maternus.[227] The differences in right ascension of the "royal stars," "stellæ regales," are 11h. 57m. and 12h. 49m. The importance which was attached to this subject was probably founded on opinions derived from the East, which, under the Cæsars, made their way into the Roman empire, together with a great predilection for astrology. An obscure passage in the book of Job (ch. ix. v. 9), in which the "chambers of the south" are opposed to "the Leg," *i. e.* the North Star in the Great Bear (the celebrated Bull's Leg in the astronomical representations at Dendera, and in the Egyptian "Book of the Dead"), seems also intended to allude to the four quarters of the heavens, marked by four constellations.[228]

If a large and fine portion of the southern heavens,—viz. all stars beyond 53° of south declination,—remained concealed from the ancients, and even until the latter part of the Middle Ages, yet the knowledge of the southern celestial hemisphere had gradually become complete about one hundred years before the invention and employment of telescopes. In the time of Ptolemy, the Altar, the feet of the Centaur, the Southern Cross then included in the Centaur, or otherwise (according to Pliny) called Cæsaris Thronus in honour of Augustus, [229] and lastly Canopus (Canobus), which the scholiast to Germanicus [230] calls the Ptolemæon,—were all visible above the horizon of Alexandria. In the catalogue of the Almagest, Achernar, a star of the 1st magnitude, the last in the constellation of the River Eridanus (in Arabic, Achir-el-nahr), is also mentioned, although it was 9° below the horizon. Intelligence of the existence of this star must have been brought to Ptolemy from voyages to the southern part of the Red Sea, or between Očelis and the commercial entrepôt of Muziris ([231]) on the Malabar coast. No doubt Diego Cam in company with Martin Behaim, in 1484, on the West Coast of Africa, Bartholomew Diaz in 1487, and Vasco de Gama in 1497 on the voyage to India, passed far beyond the Equator, and into the Southern Ocean as far as 35° S. latitude; but the first particular notice of the large stars and nebulæ, the description of the Magellanic clouds and the "coal sacks," and even the fame of the "wonders of the heavens not seen in the Mediterranean," belong to the epoch of Vincent Yañez Pinzon, Amerigo Vespucci, and Andrea Corsali, between 1500 and 1515. Star-distances were measured in the southern heavens at the end of the 16th and the beginning of the 17th century. ([232])

Laws of relative density in the distribution of the fixed stars on the celestial vault began to be recognised when William Herschel, in 1785, conceived the happy thought of estimating the number of stars visible in the field of view, 15′ in diameter, of his 20-feet reflector, at different altitudes and in different directions. This laborious process of "gauging the heavens" has been already repeatedly referred to in the present work. The field of view embraced each time only $\frac{1}{833000}$th of the whole heavens; and, according to a remark of Struve's, 83 years would be required for the completion of such gaugings over the entire sphere. ([233]) In inquiries respecting the equal or unequal distribution of stars, their photometric magnitudes must be particularly taken into account. If we confine our attention to the bright stars of the first three or four classes of magnitude, we find them pretty uniformly distributed ([234]) on the whole;

but locally, in the southern hemisphere, from ε Orionis to α Crucis, rather crowded together in a superb zone in the direction of a great circle. The disagreement in the judgments pronounced by different travellers, as to the relative beauty of the northern and southern hemispheres, has often I believe, depended only on the circumstance, that some of he observers had visited the southern regions at a time when the finest constellations culminate in the day-time. From the gaugings of the two Herschels in the northern and southern celestial hemispheres, it follows that the fixed stars, from the 5th and 6th magnitudes down to the 10th and 15th magnitudes, (particularly, therefore, telescopic stars), increase regularly in density as the Milky Way (ὁ γαλαξιας κύκλος) is approached; and thus that there may be said to be poles of abundance or richness, and poles of scarcity or poverty, in respect to stars,—the latter being at right angles to the principal axis of the Milky Way. The density of stars is least at the poles of the galactic circle, and increases in all directions,—at first slowly, and then more and more rapidly as the galactic polar distance increases.

By an ingenious and careful consideration of the results of the star-gaugings which we possess, Struve finds that, on the average, there are, in the central parts of the Milky Way, 29·4 times (almost 30 times) as many stars as in the regions around the poles of the Milky Way; and in northern galactic polar distances of 0°, 30°, 60°, 75°, and 90°, the ratios of the numbers of stars in the field of view of 15 diameter are 4·15, 6·52, 17·68, 30·30, and 122·00. In the comparison of opposite zones, notwithstanding the great similarity in the law of increase in the number of stars, we again find an absolute preponderance (235) on the side of the richer and more beautiful southern heavens.

When, in the year 1843, I asked Captain Schwink to be so kind as to communicate to me the distribution, in right ascension, of the 12148 stars (1st to 7th magnitude inclusive), which, at Bessel's instance, he had entered in his "Mappa cœlestis," he found, in four groups—

Right	ascension,	50°—140°;	3147	stars
"	"	140°—230°;	2627	"
"	"	230°—320°;	3523	"
"	"	320°— 50°;	2851	"

These groups agree with the still more exact results of the "Etudes stellaires;" according to which, the maxima of stars from the 1st to the 9th magnitude fall in the right ascensions of 6h. 40m. and 18h. 40m., and the minima in those of 1h. 30m. and 13h. 30m. ([236])

In reference to conjectures respecting the structure of the Universe, and the position or depth of the sidereal strata, it is essential to distinguish, among the countless multitude of stars, those which are scattered sporadically, from those which we find crowded in detached independent groups. The latter are the "clusters of stars" which have been spoken of: they often contain many thousands of telescopic stars in recognisable relation to each other, and are seen by the naked eye as round or oval nebulæ, appearing like comets. These are the "nebulous stars" of Eratosthenes ([237]) and Ptolemy; the "nebulosæ" of the Alphonsine Tables of 1252, and those of Galileo, which (as it is said in the Nuncius sidereus) sicut areolæ sparsim per æthera subfulgent.

The clusters of stars, again, are either placed solitarily in the heavens, or else are closely and unequally crowded, as it were in strata, in the Milky Way and in the two Magellanic clouds. The most numerous, and, in respect to the annular configuration of the Milky Way, the most important assemblage of "globular clusters," is in a region of the southern heavens, (238) between the Corona australis, Sagittarius, the tail of the Scorpion, and the constellation of the Altar (R. A. 16h. 45m.—19h.) But all the clusters of stars which are in or near the Milky Way are not round or globular: there are several of irregular outline, less rich in stars, and with not very dense centres. In many round groups the individual stars are of equal, and in others of unequal, magnitudes. In some rare cases they show a fine reddish central star (239); (R. A. 2h. 10m., N. Decl. 56° 21′). How such world-islands, with their multiplicity of suns, can rotate free and undisturbed, is a difficult problem in dynamics. Clusters of stars and nebulæ, even though it be now very generally assumed respecting the latter that they also consist of very small but still more distant stars, yet appear to be subject to different laws in respect to their local distribution. The recognition of these laws will have a prominent influence in modifying conjectures respecting what has been adventurously termed the "structure of the heavens." It is also a very remarkable fact of observation, that, with the same aperture and magnifying power of the telescope, round nebulæ are more easily resolved into clusters of stars than oval ones. (240)

Of the clusters of stars which form, as it were, detached systems, I content myself with naming the following:—

The Pleiades: doubtless recognised from the earliest times by the rudest nations; the constellation of navigation, Pleias, ἀπὸ τοῦ πλέιν, according to the etymology of the old scholiast of Aratus, which is probably more correct than that of later writers, who derive the name from πλέος, abundance. The navigation of the Mediterranean lasted from May to the beginning of November,—from the early rising to the early setting of the Pleiades.

The Bee-hive in Cancer: according to Pliny, nubecula quam Præsepia vocant inter Asellos; a νεφέλιον of the Pseudo-Eratosthenes.

The cluster of stars in the hilt of the sword in Perseus, often mentioned by the Greek astronomers.

Coma Berenices: like the three former, visible to the naked eye.

Cluster of stars near Arcturus (No. 1663), telescopic; R. A. 13h. 34m. 12s., N. declination, 29° 14′; more than a thousand small stars of the 10th to the 12th magnitude.

Cluster of stars between η and ζ Herculis: in *very* fine nights visible to the naked eye; a magnificent object in the telescope (No. 1968), with singular ray-shaped outlines; R. A. 16h. 35m. 37s.; N. Decl. 36° 47′; first described by Halley in 1714.

Cluster of stars near ω Centauri: described as early as 1677 by Halley; appears to the naked eye as a round comet-like patch, shining almost like a star of the 4.5 magnitude; when seen in powerful telescopes it appears to be composed of a countless multitude of small stars of the 13th to the 15th magnitude, which are more densely crowded towards the centre; R. A. 13h. 16m. 38s., S. Declination 46° 35′; No. 3504 in Sir John Herschel's catalogue of the clusters of stars in the Southern Heavens, 15′ in diameter. (Cape Observ. pp. 21 and 105, Outl. of Astr. p. 595).

Cluster of stars near κ of the Southern Cross (No. 3435): composed of many-coloured stars of the 12th to the 16th magnitude, distributed over an area of $\frac{1}{48}$th of a square degree; a nebulous star according to Lacaille, but so completely resolved by Sir John Herschel that no nebulous appearance remained: the central star deep red. (Cape Observ. pp. 17 and 102, Pl. 1, fig. 2).

Cluster of stars 47 Toucani, Bode; No. 2322 of Sir John Herschel's catalogue, one of the most remarkable objects of the Southern heavens. I was myself deceived by it for some nights, taking it for a comet, when, on my first arrival in Peru, in 12° South latitude, I saw it rise high above the horizon. Its visibility to the naked eye is so much the greater because, although near the smaller Magellanic Cloud, it is in a place wholly devoid of stars, and has a diameter of 15′ to 20′. It is of a pale roseate colour in the inside, surrounded concentrically by a white border, and composed of small stars all about the same magnitude (14m. to 16m.), presenting all the characteristics of bodies of a globular form. ([241])

Cluster of stars in the girdle of Andromeda, near the star ν of that constellation. The resolution of this celebrated nebula into stars, above 1500 of which have been distinctly made out, is one of the most remarkable discoveries of this department of astronomy in our time. Its merit belongs to George Bond, ([142]) assistant at the Observatory of Cambridge in the United States (March 1848); and it also evidences the excellence and abundance of light of the refracting telescope of that Observatory (which has an object glass of 14 Parisian inches diameter), since even a reflecting telescope, in which the mirror has 18 inches diameter, does not shew the faintest trace by which the presence of a star can be divined. (243) The cluster of stars in Andromeda may perhaps have been known as a nebula of oval form as early as the end of the tenth century; but it is more certain that on the 15th of December, 1612, Simon Marius (Mayer of Guntzenhausen, the same who first remarked the change of colour in scintillation (244)), distinguished it as a new and wonderful starless cosmical body which had not been named by Tycho Brahe, and it was he who first gave a detailed description of it. Half a century later, Bouillaud, the author of the Astronomia philolaica, occupied himself with the same subject. This cluster of stars, which is $2\frac{1}{2}°$ long and above 1° broad, is particularly characterised by two remarkable very narrow black streaks, nearly parallel to each other and to the longer axis of the cluster, and, according to Bond's examination, traversing the whole like fissures. This arrangement reminds us strongly of the remarkable longitudinal fissure in an unresolved nebula of the Southern hemisphere, No. 3501, which has been described and figured by Sir John Herschel. (Cape Observ. pp. 20 and 105, Pl. IV. fig. 2.)

In this selection of remarkable clusters of stars, I have not included the great nebula in Orion's belt, notwithstanding the important discoveries for which we are indebted to the Earl of Rosse and his colossal telescope, as I prefer reserving it for the section on Nebulæ, although portions have thus been already resolved.

We find the greatest accumulation of clusters of stars (but by no means of nebulæ) in the Milky Way (245) (the Galaxy, the Celestial River (246) of the Arabians), which forms almost a great circle of the sphere, and is inclined to the equator at an angle of 63°. The poles of the Milky Way are situated in R. A. 14h. 47m., North Decl. 27°; and R. A. 0h. 47m., South Decl. 27°: therefore that which may be called the North pole is near Coma Berenices, and the South pole between Phœnix and Cetus. If all planetary relations of place are referred to the Ecliptic, *i. e.* to the great circle in which the plane of the sun's path cuts the sphere, we may with equal convenience refer many relations in space of the fixed stars, (for example their accumulation or grouping) to the approximate great circle of the Milky Way. In this sense, the latter is to the sidereal universe what the ecliptic is to the planetary world of our solar system. The Milky Way cuts the equator in the constellation of the Unicorn between Procyon and Sirius, R. A. 6h. 54m. (for 1800), and in the left hand of Antinous, R. A. 19h. 15m. Thus the Milky Way divides the celestial sphere into two rather unequal portions, whose areas are to each other in the proportion of about 8 to 9. The vernal point is situated in the smaller portion. The breadth of the Milky Way varies very much in different parts of its course. (247) Where it is narrowest, and at the same time brightest (between the prow of the Ship and the Cross, and nearest to the Southern Pole), its width is barely from 3° to 4°: at other points it is 16°, and in the divided part, between Ophiuchus and Antinous, (248) it is as much as 22°. William Herschel has remarked, that, judging by his star-gauging, the Milky Way is in many regions 6 or 7 degrees broader than the brightness visible to the naked eye. (249)

Huygens, who examined the Milky Way with his 23 feet refractor, had denied, as early as 1656, that its milky whiteness was to be attributed to unresolvable nebulæ. A more careful application of reflecting telescopes of the largest dimensions and greatest power of light, have subsequently proved with still more certainty, what Democritus and Manilius had already conjectured respecting the ancient path of Phaeton, viz. that the milky brightness was to be ascribed solely to the crowded strata of small stars, and not to the scantily interspersed nebulæ. The general white or shining appearance is the same in points where all can be perfectly resolved into stars, and even where these stars, thus viewed through the telescope, are seen to be projected on a black ground, entirely without any nebulous light. (250) It is in general a remarkable characteristic of the Milky Way, that globular clusters of stars, and nebulous patches of a regular oval shape, are equally rare in it, (251) whereas at a great distance from it both are congregated in large numbers; and in the Magellanic clouds we even find isolated stars, globular clusters in all states of condensation, and nebulæ both of definite oval and of wholly irregular form, intermingled. A remarkable exception to this rarity of globular clusters in the Milky Way occurs in a region of it which is situated between R. A. 16h. 45m. and 18h. 44m.; between the Altar, the Southern Crown, the head and body of Sagittarius, and the tail of the Scorpion. Between the stars ϵ and θ of the Scorpion, there is even one of those annular nebulæ which are so exceedingly rare in the southern celestial hemisphere. (252) In the field of view of powerful telescopes (and we must remember that, according to the estimations of Sir William Herschel, a 20-feet instrument penetrates space to 900, and a 40-feet instrument to 2800 distances of Sirius), the Milky Way appears in different parts as varied in its sidereal contents, as it seems irregular and indeterminate in its outlines and boundary when viewed by the naked eye. If in some parts of the Milky Way large spaces exhibit great uniformity, both in respect to light and to the apparent magnitude of the stars of which it consists, in other parts the brightest patches of closely-crowded luminous points are interrupted in a granular, and even in a reticular manner, by darker intervals ([253]) which are poor in stars: indeed, in some of these intervals, quite in the interior of the galaxy, not even the smallest star (18th or 20th magnitude) can be discovered. One can hardly refrain from thinking, that in such places we really see through the whole sidereal stratum of the Milky Way. When gauging with a field of view of the telescope of 15′ diameter, the change is almost immediate from fields containing 40 or 50 stars on an average, to others having between 400 and 500 stars. Often, stars of the higher orders of magnitude occur in the midst of the finest "star dust," while all the intermediate magnitudes are wanting. Perhaps those stars which we call of the lower orders of magnitude do not always appear to us such solely on account of their enormous distance: it is also possible that they may really have less volume and less development of light.

In order to represent to ourselves the greatest contrast, in respect to abundance or paucity of stars, we must take regions widely removed from each other. The maximum of accumulation and the greatest brilliancy are to be found between the prow of the Ship and Sagittarius; or, to speak more exactly, between the Altar, the tail of the Scorpion, the hand and bow of Sagittarius, and the right foot of Ophiuchus. "No region of the heavens is fuller of objects, beautiful and remarkable in themselves, and rendered still more so by their association and grouping." ([254]) Next in richness to this beautiful part of the southern celestial vault, is the pleasing and well-starred region in our northern heavens in Aquila and Cygnus, where the Milky Way divides into branches. As the Milky Way is most narrow below the foot of the Southern Cross, so, on the other hand, the region of minimum brightness (where the galaxy is comparatively desert) is in the vicinity of the Unicorn and of Perseus.

The magnificent effect of the Milky Way in the southern hemisphere is enhanced by the circumstance, that between the star η Argûs, which has become so celebrated on account of its variability, and α Crucis, it is intersected, in the parallels of 59° and 60° S. Latitude, at an angle of 20°, by the remarkable zone of very large and probably very near stars, to which the constellations of Orion, Canis Major, Scorpio, Centaurus, and Crux belong. A great circle, passing through ϵ Orionis and the foot of the Cross, indicates the direction of this remarkable zone. The (I might almost say) picturesque effect of the Milky Way is heightened in both hemispheres by its repeated divisions or branchings. For about two-fifths of its length it remains undivided. In the greatest bifurcation the branches divide, according to Sir John Herschel, at α Centauri, ([255]) not at β Centauri as our star-maps represent, nor at the Altar as was stated by Ptolemy ([256]) : they reunite in Cygnus.

In order to afford a general view of the course and direction of the Milky Way, together with its subordinate branches, I subjoin a very brief and compressed account of its parts, following their order of Right Ascension. Passing through γ and ϵ Cassiopeiæ, the Milky Way sends out to the southward, towards ϵ Persei, a branch, which loses itself near the Pleiades and Hyades. The main stream, which is here very faint, passes over the three remarkable stars called the Hœdi, in Auriga, between the feet of Gemini and the horns of Taurus,—where it intersects the Ecliptic nearly at the summer solstice,—and thence over the club of Orion, cutting the equinoctial (in 1800), at 6h. 54m. R. A., in the neck of Monoceros :—from this place it increases considerably in brightness. At the after-part of the Ship a branch detaches itself towards the south, proceeding as far as γ Argûs, where it breaks off suddenly. The main course continues to 33° South Declination, where, having opened out into a fan-like shape 20° wide, it breaks off; so that, in the line between γ and λ Argûs, there is a wide gap in the Milky Way. After this it resumes its course, at first with a similar expansion in breadth; but near the hind feet of the Centaur it narrows again, and before entering the constellation of the Cross it reaches its narrowest part, which is only 3° or 4° wide. Soon afterwards the shining Way spreads out into a bright and broad mass, which includes β Centauri as well as α and β Crucis, and in the middle of which the black pear-shaped coal-bag or coal-sack, which I have spoken of more particularly in the 7th section, is situated. It is in this remarkable region, a little below the coal-sack, that the Milky Way approaches nearest to the South Pole.

The principal division of the Milky Way, alluded to above, takes place at α Centauri: it is a bifurcation which, according to older views, continues to the constellation of Cygnus. Proceeding from α Centauri, a narrow branch goes northwards towards the constellation Lupus, where it loses itself: then a division shows itself at γ Normæ. The northern branch runs into irregular shapes until near the feet of Ophiuchus, where it entirely disappears; the southern branch now becomes the main stream, and passes through the Altar and the tail of the Scorpion to the bow of Sagittarius, where it cuts the Ecliptic in 276° longitude. Further on we recognise it still, but in an interrupted patchy form, passing through Aquila, Sagitta, and Vulpecula, to Cygnus. Here begins a very irregular district, where, between ϵ, α, and γ Cygni, there is a broad dark space, which Sir John Herschel (257) compares to the coal-sack in the Southern Cross, and which forms, as it were, a centre whence three partial streams diverge. One of these, which has most strength of light, may be pursued in, as it were, a retrograde course past β Cygni and s Aquilæ: it does not however unite with the branch before spoken of, which goes to the foot of Ophiuchus. There is still a considerable additional piece of the Milky Way, which extends from the head of Cepheus, and therefore in the vicinity of Cassiopeia, from which constellation we began our description, to Ursus Minor and the North Pole.

From the extraordinary improvement which, by the application of large telescopes, has gradually been made in the knowledge of the sidereal contents, and the differences in respect to concentration of light, in different parts of the Milky Way, views of merely optical projection have been replaced by what may rather be deemed views of physical character and formation. Thomas Wright of Durham, (258) Kant, Lambert, and at first also William Herschel, were inclined to regard the form of the Milky Way, and the apparent accumulation of stars in it, as consequences of the flattened form and unequal dimensions of the "world-island" (sidereal stratum) in which our solar system is included. The hypothesis of equal magnitude and equable distribution of fixed stars has recently been shaken on many sides. The bold and able investigator of the heavens, William Herschel, declared himself, in his last work, (259) decidedly in favour of the assumption of a ring or annulus of stars,—which assumption he had combated in a treatise in the year 1784. Recent observations have favoured the hypothesis of a system of detached concentric rings. The thickness of these rings appears to be very unequal, and the several strata whose united stronger or fainter light we receive, are doubtless situated at very different heights, *i. e.* very different distances from us: but the relative brightness of the several stars, which we estimate as being from the 10th to the 16th magnitude, cannot be regarded as such a measure of their relative distances, as could enable us to derive from thence a satisfactory numerical (260) determination of the radii of the respective spheres of distance.

In many parts of the Milky Way, the space-penetrating power of instruments is sufficient to resolve the star-clouds, and to enable us to see single luminous points projected on the dark starless regions of celestial space. In such case we really look through into free and open space. "It leads us," says Sir John Herschel, "irresistibly to the conclusion, that in these regions we see *fairly through* the starry stratum." (261) In other regions we see, as through openings and fissures, either distant world-islands, or out-branching parts of the annular system; in others, again, the Milky Way has hitherto remained "fathomless," even to the 40-feet telescope. (262) Investigations respecting differences in the intensity of light in the Milky Way, as well respecting the magnitudes of stars, and their regular increase in numbers from the poles of the galaxy to the galactic circle itself, (an increase which is particularly remarked for 30° on either side of the Milky Way in stars below the 11th magnitude, (263) and therefore in $\frac{16}{17}$ths of the whole number), have conducted those who have been engaged in the most recent researches in the southern heavens, to remarkable views and probable results in regard to the form of the galactic annular system, and to what has been boldly called the place of our Sun in the world-island to which that annular system belongs. The place assigned to the Sun is excentric, and conjectured to be where a subordinate stratum branches off from the principal ring, (264) in one of the comparatively desert regions, and nearer to the Southern Cross than to the opposite galactic node. (265) The depth to which our system is immersed in the star-stratum which forms the Milky Way (reckoned from the southern limit) is supposed to be equal to the distance, (or to the light-path) of stars of the 9th and 10th, but not of the 11th magnitude. (266) Where, from the peculiar nature of particular problems, measurements and immediate cognizance by the senses fail, we view, as it were by an imperfect twilight, the results which intellectual contemplation aspires to attain.

IV.

NEWLY-APPEARED AND VANISHED STARS.—VARIABLE STARS, WHICH HAVE MEASURED AND RECURRING PERIODS.—VARIATIONS OF THE INTENSITY OF LIGHT IN CELESTIAL BODIES OF WHICH THE PERIODICITY HAS NOT YET BEEN INVESTIGATED.

THE appearance of previously unseen stars in the celestial vault, especially the sudden appearance of strongly scintillating stars of the 1st magnitude, is an event in the regions of space of which the occurrence has ever excited the astonishment of men. This astonishment is so much the greater, as such an event in Nature as the sudden visibility of an object which, though previously unseen, we yet believe to have existed previously, is one of the rarest of all phænomena. In the course of the three centuries from 1500 to 1800, there have appeared to the inhabitants of the northern hemisphere 42 comets visible to the naked eye,—being, on an average, 14 in a century; while, during the same three hundred years, only 8 new stars have been observed. The rarity of the latter occurrence becomes still more striking when we embrace yet longer periods. From the important epoch in the history of astronomy of the completion of the Alphonsine Tables, to the time of William Herschel, or from 1252 to 1800, we reckon, of comets visible to the naked eye, about 63, and of new stars only 9; thus, for the period within which, in European civilised countries, we can count on a tolerably accurate enumeration, we find the proportion of new stars to comets, both being visible to the naked eye, as 1 to 7. We shall soon show, that if in the Chinese registers of Ma-tuan-lin, we carefully distinguish the observations of newly-appeared stars from those of tail-less comets,—and if we go back to a century and a half before the Christian era,—we find that, in the course of almost 2000 years, 20 or 22 of such phænomena are the utmost that can be adduced with any degree of certainty.

Before proceeding to general considerations, I prefer, by dwelling on a single example, and by the narration of an eye-witness, to attempt to convey to my readers a just idea of the vividness of the impression produced by the appearance of a new star. "When," says Tycho Brahe, "I was returning to the Danish Islands, after travelling in Germany, I remained awhile (ut aulicæ vitæ fastidium lenirem) with my uncle, Steno Bille, at the pleasantly-situated former convent of Herritzwadt, where I was in the habit of only quitting my chemical laboratory in the evening. On coming forth into the open air, and raising my eyes as usual to the well-known heavenly vault, I saw, with indescribable astonishment, near the zenith, in Cassiopeia, a radiant fixed star of a magnitude never before seen. In the excitement, I thought I could not trust my senses. In order to convince myself that it was no illusion, and to collect the testimony of others, I called my workman from the laboratory, and asked all the country people who were passing by, whether they saw the new suddenly-outshining bright star as I did. Subsequently

I learned that in Germany, waggoners, and 'other common people,' first called the attention of astronomers to this great celestial phænomenon, which (as in the case of comets appearing without having been predicted) renewed the usual scoffs at learned men."

"I found this new star," Tycho Brahe continues, "without any tail, not surrounded by any nebulous appearance, and perfectly similar in all respects to all the other fixed stars, but sparkling still more brightly than those of the 1st magnitude. It exceeded in brilliancy Sirius, α Lyræ, and Jupiter, and could only be paralleled by the brightness of Venus when she is nearest the Earth, (at which time only her fourth part is illuminated). When the atmosphere was clear, men gifted with keen sight could distinguish the new star in the day-time, and even at noon. At night, when the sky has been so far covered that all other stars were veiled, it has repeatedly been seen through clouds of moderate density (nubes non admodum densas). Distances from other neighbouring stars in Cassiopeia, which I measured with great care throughout the whole of the following year, convinced me of its perfect immobility. In December 1572, the light of the star began to diminish: it soon became equal to Jupiter; and in January 1573 it was less bright than that planet. Continued photometric estimations gave, in February and March, an equality with the stars of the 1st magnitude (stellarum affixarum primi honoris; for Tycho Brahe seems determined never to use the expression of Manilius, stellæ fixæ); for April and May, light equal to stars of the 2d; for July and August, of the 3d; and for October and November, of the 4th magnitude. About the month of November, the new star was no brighter than the eleventh star in the lower part of Cassiopeia's chair. From December 1573 to February 1574, it diminished successively to the 5th and 6th magnitudes. In the following month, after shining for seventeen months, the new star disappeared altogether, leaving no trace visible to the naked eye." (The telescope was invented thirty-seven years later.)

It appears, then, that the loss of light in this star was exceedingly gradual and regular, and not interrupted by periods of renewed or fresh increase of light, (as has been several times the case in our own days with η Argûs, which, indeed, is not to be called a new star). In the star in Cassiopeia, of which we have been speaking, there was alteration of colour as well as of light,—a circumstance which has since given occasion to many erroneous conclusions respecting the velocity of coloured rays in traversing space. When it first appeared, and as long as it equalled first Venus and then Jupiter in brightness, its light was, during two months, white; after which it passed through yellow into red. In the spring of 1573, Tycho Brahe compared it to Mars; he next found it *almost* comparable to the star in the right shoulder of Orion (Betelgeuze). Its colour resembled most nearly the red colour of Aldebaran. In the spring of 1573, particularly in the month of May, the whiteness returned (albedinem quandam sublividam induebat, qualis Saturni stellæ subesse videtur). In January 1574 it still continued to be of the 5th magnitude and white, but of a duller white, and with a degree of scintillation strikingly great in proportion to its feeble light, until its entire gradual disappearance in the month of March, 1574.

The detailed character of these statements (267) would of itself suffice to show how great a stimulus to the consideration of highly important questions must have been afforded, by the occurrence of such a phenomenon at a period so brilliant in the history of astronomy. The stimulus was the stronger, because, notwithstanding the above-described general rarity of the appearance of new stars, it happened that European astronomers witnessed phænomena of this kind three times within the short period of thirty-two years. The importance of star-catalogues, determining with certainty the novelty of such stars, was more and more recognised; their periodical character, *i. e.* their reappearance after the lapse of several centuries, was discussed; (268) and Tycho Brahe even boldly put forth a theory respecting the process of formation of stars from cosmical vapour or nebulosity, which had much analogy with that of the great William Herschel. He believed that the nebulous celestial matter, luminous in the course of its condensation, solidified into fixed stars:—"Cœli materiem tenuissimam, ubique nostro visui et planetarum circuitibus perviam, in unum globum condensatam, stellam effingere." He conceived this everywhere-diffused celestial matter to have already a certain degree of condensation in the Milky Way, where its dawning luminosity produced a mild silvery brightness,—and this he thought the reason why the new star, like those of 945 and 1264, shone forth on the edge of the Milky Way itself (quo factum est quod nova stella in ipso Galaxiæ margine constiterit); and it even seemed possible to recognise the place (the opening, hiatus) from whence the nebulous matter of the Milky Way had been taken. (269) All this reminds us of the transition of cosmical vapour into clusters of stars,—

of the concentration to a central nucleus,—and of the hypotheses respecting the gradual development of solid celestial bodies from a vaporous fluid,—which gained acceptance at the commencement of the present century; but which now, according to the ever-varying fluctuations of the world of thought, have become subject to fresh doubts.

We may, with more or less certainty, reckon among the new "temporary" stars the following, which I have arranged in the order of their first shining forth:—

a	134 B.C.	in Scorpio.
b	123 A.D.	in Ophiuchus.
c	173 —	in Centaurus.
d	369 ? —	
e	386 —	in Sagittarius.
f	389 —	in Aquila.
g	393 —	in Scorpio.
h	827 ? —	in Scorpio.
i	945 —	between Cepheus and Cassiopeia.
k	1012 —	in Aries.
l	1203 —	in Scorpio.
m	1230 —	in Ophiuchus.
n	1264 —	between Cepheus and Cassiopeia.
o	1572 —	in Cassiopeia.
p	1578 —	
q	1584 —	in Scorpio.
r	1600 —	in Cygnus.
s	1604 —	in Ophiuchus.
t	1609 —	
u	1670 —	in Vulpes.
v	1848 —	in Ophiuchus.

Elucidatory Notices of the above Temporary Stars.

a. Which first appeared between β and ρ Scorpii, in the month of July, 134 years before our Era, is recorded in the Chinese Notices of Ma-tuan-lin, for the knowledge of which we are indebted to the philological learning of Edouard Biot (Connaissance des Temps pour l'an 1846, p. 61). The "extraordinary" stars of "strange or foreign appearance" of these Chinese Notices,—called also "guest-stars" ("étoiles hôtes," "ke-sing," as it were foreigners of strange physiognomy), and from which the observers themselves had distinguished and separated comets with tails,—included, it is true, some tail-less comets, as well as non-moving new stars, properly so-called; but an important though not infallible criterion was implied by the assignment of motion in some cases (ke-sing of 1092, 1181, and 1458), and its non-assignment in others, as well as in the occasional addition of the remark—"the Ke-sing dissolved" (disappeared). We may also recal here the faint, never sparkling, always mild light of the heads of comets, whether with or without tails, whereas the Chinese "extraordinary stars" are compared, in respect to the intensity of their light, to Venus, which does not at all suit the character of comets, and more especially of tail-less comets. The star we are now speaking of (*a*, 134 B.C.), which appeared under the old dynasty of Han, may, as Sir John Herschel remarks, have been the new star of Hipparchus, which, according to Pliny's account, induced him to draw up his list of stars. Delambre twice calls this account "a fable," — "une historiette" (Hist. de l'Astr. anc. T. i. p. 290; and Hist.

de l'Astr. mod. T. i. p. 186). As, however, according to Ptolemy's express statement (Almag. vii. 2, p. 13, Halma), Hipparchus's star-list is connected with the year 128 B.C.; and Hipparchus, as I have already said elsewhere, observed in Rhodes, and perhaps also at Alexandria, between 162 and 127 B.C., there is at least nothing to contradict the conjecture: it is very conceivable that the great astronomer of Nicea might have observed much before the time when he may have been led to propose to himself the preparation of an actual catalogue. Pliny's expression—"suo ævo genita," refers to his whole life. When Tycho Brahe's star appeared, in 1572, the question was much debated whether it should be regarded as belonging to the class of new stars or to that of comets without tails. Tycho Brahe himself was of the first opinion (Progymn. p. 319—325). The words "ejusque *motu* ad dubitationem adductus" might, indeed, lead us to think of a faint or tail-less comet, but the rhetorical style of Pliny permits every degree of indefiniteness in expression.

b. Appeared between α Herculis and α Ophiuchi, in December, A.D. 123, according to the Chinese notice, extracted by Edouard Biot from Ma-tuan-lin. (A new star is also said to have appeared under Hadrian, in 130. A.D.)

c. A singular very large star. The notices of this and of the three following stars are also taken from Ma-tuan-lin. It appeared on the 10th of December, A.D. 173, between α and β Centauri, and disappeared at the end of eight months, having shown the five different colours one after another;—Edouard Biot says, in his translation, "successively" ("successivement"). Such an expression might almost lead us to infer a series of colours like those of the Tychonian Star before spoken of; but Sir John Herschel (I believe more correctly) regards it as a description of coloured scintillation (Outlines, p. 563), as Arago has interpreted an almost similar expression of Kepler's, relatively to the new star, in 1604, in Ophiuchus (Annuaire pour 1842, p. 347).

d. Shone from March to August, 369.

e. Between λ and ϕ in Sagittarius. In the Chinese Notices it is expressly remarked — "where the star remained without motion from April to July, 386."

f. A new star near α Aquilæ shone forth in the time of the Emperor Honorius in 389, with the brightness of Venus, as is related by Cuspinianus: three weeks afterwards it disappeared without leaving any trace. (270)

g. March, 393 in the tail of the Scorpion; from Ma-tuan-lin's notices.

h. The year 827 is doubtful; what is more certain is the epoch of the first half of the 9th century, in which, under the government of the Caliph Al-Mamun, the two celebrated Arabian Astronomers Haly, and Giafar Ben-Mohammed Albumazar, observed at Babylon a new star whose light is said "to have equalled that of the moon in her quarters!" This cosmical event also belongs to the constellation of Scorpio. The star disappeared after an interval of only four months.

i. The appearance of this star, which is said to have shone forth in the reign of the Emperor Otho the Great in the year 945, as well as that of the star of 1264, both rest solely on the testimony of the Bohemian astronomer Cyprianus Leovitius, who declares that he took the information from a manuscript chronicle, and who calls attention to the circumstance that both phenomena (in the years 945 and 1264) took place between the constellations of Cepheus and Cassiopeia, quite close to the Milky Way, and at the very place where the Tychonian star appeared in 1572. Tycho Brahe (Progymn. p. 331 and 709), defends the trustworthiness of Cyprianus Leovitius against Pontanus and Camerarius, who surmised a confusion with long-tailed comets.

k. According to the testimony of the monk of St. Galle, Hepidannus, (who died in the year 1088, and whose annals extend from 709 to 1044), a new star, of unusual magnitude and dazzling brightness (oculos verberans), was seen in the most southern part of the heavens in the sign of Aries: it appeared near the end of the month of May 1012, and contiuued to shine for three months. It varied in a wonderful manner, sometimes appearing larger, sometimes smaller, and sometimes not being seen at all. "Nova stella apparuit insolitæ magnitudinis, aspectu fulgurans, et oculos verberans non sine terrore. Quæ mirum in modum aliquando contractior, aliquando diffusior, etiam extinguebatur interdum. Visa est autem per tres menses in intimis finibus Austri, ultra omnia signa quæ videntur in cœlo," (see Hepidanni, Annales breves, in Duchesne, Historiæ Francorum Scriptores, T. iii. 1641, p. 477; compare also Schnurrer, Chronik der Seuchen, Th. I. S. 201. More recent historical criticism has, however, preferred to the manuscript used by Duchesne and Goldast, which places the phenomenon in 1012, another which gives a difference of dates, placing it six years earlier, or in 1006, (see Annales Sangallenses majores in Pertz, Monumenta Germaniæ historica Scriptorum, T. i. 1826, p. 81). The authorship of the supposed writings of Hepidannus has also been rendered doubtful by recent investigations. The strange phenomenon of variability has been called by Chladni the "conflagration and destruction of a fixed star." Hind, (Notices of the Astron. Soc. Vol. viii. 1848, p. 156) conjectures, that the star of Hepidannus may be identical with the star which Ma-tuan-lin marks as having been seen in China in February 1011, in Sagittarius, between σ and ϕ. But in such case Ma-tuan-lin must have been mistaken not only in the year, but also in the constellation in which the star appeared.

l. End of July 1203, in the tail of the Scorpion. According to the Chinese notice, "a new star of a blueish white light, without any luminous nebulosity, resembling Saturn (Edouard Biot, in the Connaissance des temps pour 1846, p. 68).

m. Another Chinese observation from Ma-tuan-lin, whose astronomical Notices, with the exact indication of the positions of the comets and fixed stars, reascend to 613 years B. C., or to the time of Thales and the Expedition of Colæus of Samos. The new star appeared in the middle of December, 1230, between Ophiuchus and the serpent. It "dissolved away" at the end of March 1231.

n. Is the star whose appearance in 1264 is mentioned by the Bohemian astronomer, Cyprianus Leovitius, (see the star previously referred to, *i*, 945). At the same time (July 1264) there appeared a great comet, whose tail extended over half the sky, and which therefore could not be confounded with the star described as having shone forth between Cepheus and Cassiopeia.

o. The star of Tycho Brahe, of the 11th of November 1572, in Cassiopeia's chair; R. A. 3° 26′; Decl. 63° 3′ (for 1800).

p. February 1578, from Ma-tuan-lin. The constellation in which the star appeared is not given; but the intensity and radiation of its light must have been extraordinary, since the Chinese notice has appended to it a note, saying "a star as great as the sun!"

q. 1st of July 1584, not far from π Scorpii; a Chinese observation.

r. The star 34 Cygni, according to Bayer. Wilhelm Janson, the distinguished geographer, who for some time observed with Tycho Brahe, first had his attention arrested by the new star in the breast of the Swan, (at the commencement of the neck), as an inscription upon his celestial globe testifies. Kepler being prevented, both by his journeys and by the want of instruments after Tycho Brahe's death, did not begin to observe it until two years later, and (which is the more surprising, as the star was of the 3rd magnitude) he even was not until then aware of its existence. He says: "Cum mense Majo anni 1902 primum litteris monerer de novo Cygni phænomeno . . ." (Kepler de Stella nova tertii honoris in Cygno 1606, appended to the work de stella nova in Serpent, p. 152, 154, 164, and 167). In Kepler's memoir it is never said (as it has often been in more modern writings) that the star in the Swan, on its first appearance, was of the 1st magnitude. Kepler even calls it parva Cygni stella, and everywhere describes it as of the 3rd magnitude. He determines its position in R. A. 300°46′; Decl. 36°52′: (therefore for 1800) R. A. 302°36′; Decl. +37°27′). The star decreased in brightness, especially after 1619, and disappeared in 1621. Dominique Cassini (see Jacques Cassini, Elémens d'Astr. p. 69) saw it again attain the 3rd magnitude in 1655, and then disappear. Hevelius observed it again in November 1665: at first very small, then larger, but without reattaining the 3rd magnitude. Between 1677 and 1682 it was already only of the 6th magnitude, and so it has remained. Sir John Herschel places it in the list of "variable" stars, but Argelander does not.

s. Next to the star in Cassiopeia, in 1572, the new star which has gained the greatest celebrity is that which appeared in Ophiuchus in 1604. (R. A. 259° 42′, and South Decl. 21° 15′ for 1800). With each of these two stars a great name is connected. The star in the right foot of Ophiuchus was first seen, not by Kepler himself but by his pupil, the Bohemian John Brunowski, on the 10th of October 1604; being then "brighter than any star of the first magnitude, larger than Jupiter and Saturn, but not so large as Venus." Herlicius claims to have observed it on the 27th of September. Its brightness was inferior to that of the Tychonian star of 1572, nor was it seen, like the latter, in the day-time; but its scintillation was much stronger, and especially excited the astonishment of all observers. As sparkling is always connected with dispersion of colour, much is said of its coloured and continually changing light. Arago (Annuaire pour 1834, p. 299-301; and Ann. pour 1842, p. 345-347), has already called attention to the fact, that Kepler's star did not change colour after long intervals like the Tychonian star, which was first white, then yellow, red, and again white. Kepler says decidedly, that his star, as soon as it had risen above terrestrial vapours, was white. If he speaks of the colours of the rainbow, it is in order to give a clear idea of the coloured scintillation,—"exemplo adamantis multanguli, qui Solis radios inter convertendum ad spectantium oculos variabili fulgore revibraret, colores Iridis (stella nova in Ophiucho) successive vibratu *continuo* reciprocabat." (De Nova Stella Serpent., p. 5 and 125.) In the beginning of January 1605, the star was still brighter than Antares, but not so bright as Arcturus. At the end of March of the same year it was described as of the 3rd magnitude. The proximity of the sun prevented all observations for four months. Between February and March 1606 it disappeared, without leaving any trace. The inaccurate observations of the "great changes of position of the new star" of Scipio Claramontius and the geographer Blaeu or Blaew, as Jacques Cassini has already remarked (Elém. d'Astron. p. 65), scarcely deserve to be mentioned, as they have been refuted by the more certain observations of Kepler. The Chinese notices of Ma-tuan-lin speak of a phenomenon which, in point of time and of position, has some resemblance to the appearance of the new star in Ophiuchus. On the 30th of September, 1604, there was seen in China, not far from π Scorpii, a reddish yellow (globe-large) star. It shone in the South West until November of the same year, when it became invisible. It appeared on the 14th of January, 1605, in the

South East, but "darkened" a little in March 1606. (Connaissance des temps pour 1846, p. 59). The locality, π Scorpii, might easily have been confounded with the foot of Ophiuchus, but the expressions South West and South East, the reappearance, and the circumstance of no mention being made of the final complete disappearance of the star, leave the identity doubtful.

t. Also from Ma-tuan-lin's notices: a star of considerable magnitude, seen in the South West; all more circumstantial details are wanting.

u. Discovered by the Carthusian Monk Anthelme, on the 20th of June, 1670, in the head of Vulpes (R. A. 294° 27′; Decl. 26° 47′), not far from β Cygni. When it first shone out it was not of the 1st but of the 3rd magnitude. It disappeared at the end of three months, but shewed itself on the 17th of March, 1671, being then of the 4th magnitude. Dominique Cassini observed it diligently in April 1671, and found its light very variable. The new star was expected to have returned to its original brightness at the end of about ten months, but it was sought in vain in February 1672, and did not appear until the 29th of March in that year, and then only of the 6th magnitude, and has never been seen since. (Jacques Cassini, Elémens d'Astronomie, p. 69-71.) These phenomena induced Dominique Cassini to seek for stars never before seen (by him!). He states that he found 14 such stars, of the 4th, 5th, and 6th magnitudes (8 in Cassiopeia, 2 in Eridanus, and 4 near the North Pole). From the absence of precisely assigned positions, and as, moreover, like those found by Maraldi between 1694 and 1709, they are in other respects more than doubtful, I do not include them in the present list. (Jacques Cassini, Elém. d'Astron. p. 73-77; Delambre, Hist. de l'Astr. mod. T. ii. p. 780.)

v. Since the appearance of the new star in Vulpes, 178 years had passed without any similar phenomenon having presented itself, although in this long interval the heavens had been most carefully examined by the combination of a more diligent use of telescopes, and comparisou with improved star-catalogues. On the 28th of April, 1848, in the private Observatory of Mr. Bishop (South Villa, Regent's Park), Mr. Hind made the important discovery of a new star of the 5th magnitude in Ophiuchus, of a reddish yellow colour: R. A. 16h. 50m. 59s.; South Decl. 12° 39′ 16″ for 1848. In the case of no other newly-appeared star have the novelty of the phenomenon and the invariability of position been more certainly and accurately shown. It is now (1850) barely of the 11th magnitude, and, according to Lichtenberg's diligent observation, is probably near its time of vanishing. (Notices of the Astr. Soc. Vol. viii. pp. 146 and 155-158.)

The above enumeration and description of new stars which have appeared and disappeared within the last 2000 years are perhaps somewhat more complete than any which have been given previously. It may justify some general considerations. We distinguish three kinds of phenomena: —new stars, which suddenly shine forth, and vanish again after a greater or less interval of time;—stars whose brightness is subject to an already determinable periodical variability;—and stars which, like η Argûs, show at once an extraordinarily increasing and an irregularly varying brightness. All these three phenomena are probably intimately allied. The new star in Cygnus (1600), which, after entirely disappearing, (to the unassisted eye, it must be remembered), reappeared and remained as a star of the 6th magnitude, leads us to recognise the affinity between the two first kinds of celestial phenomena. The celebrated Tychonian star of 1572 was believed, while its light still shone, to be identical with the new star of 945 and 1264. The period of 300 years surmised by Goodricke (the intervals between the epochs of the phenomena, which are perhaps not very certain, are 319 and 308 years), is reduced by Keill and Pigott to 150 years. Arago (271) has shewn how improbable it is that Tycho Brahe's star (1572) should belong to the class of periodically varying stars. Nothing as yet would appear to justify our regarding *all* newly appeared stars as variable in periods of long, and therefore unknown, duration. If, for example, we regard the self-luminosity of all the suns in the firmament as the results of electro-magnetic processes in their respective photospheres, we may (without assuming local and temporary condensations of the "celestial air," or the intervention of cosmical clouds) imagine this luminous process to take place in various manners, either once only or periodically, and either regularly or irregularly in respect to the time of recurrence. The electric luminous processes of our terrestrial globe, whether presenting themselves to us as thunderstorms in the atmosphere, or as polar effluxes, with much seemingly irregular variability, do yet often shew also a certain periodicity dependent on the seasons of the year and the hours of the day. We may even often trace this periodicity in the formation, for several successive days, and in an otherwise perfectly serene sky, of small clouds at the same part of the heavens, as is shewn by the frequently recurring failure in observations of the culmination of particular stars.

The circumstance that almost all have shone forth at first with great intensity of light as stars of the first magnitude, and even scintillating more brilliantly, and that they are not seen (by the naked eye at least) to increase gradually in brightness, appear to me peculiarities well deserving of regard. Kepler [272] attended so much to this as a criterion, that he confuted the vain pretension of Antonius Laurentinus Politianus, who claimed to have seen the star in Ophiuchus (1604) before it had been seen by Brunowski, by the fact of Laurentinus having said—"Apparuit nova stella parva, et postea de die in diem crescendo apparuit lumine non multo inferior Venere, superior Jove." Only three stars are known (and these may be viewed, therefore, as exceptional instances) which did not shine forth at first as stars of the first magnitude: viz. two of the 3rd magnitude, one in Cygnus in 1600, and one in Vulpes in 1670; and Hind's new star of the 5th magnitude in Ophiuchus in 1848.

It is much to be regretted, as we have already remarked, that in the long interval of 178 years which have elapsed since the invention of the telescope, only 2 new stars have been seen; whereas these phenomena have been sometimes so comparatively frequent, that at the close of the fourth century 4 took place in 24 years, in the thirteenth century 3 in 61 years, and at the end of the sixteenth and beginning of the seventeenth centuries (in the period of Kepler and Tycho Brahe), 6 were observed in 37 years. In all these numerical statements I take into account the Chinese observations of "extraordinary stars," the greater part of which are regarded by our most distinguished astronomers as worthy of confidence. If the question be asked why, among the new stars which have been seen in Europe, that of Kepler in Ophiucus may possibly be indicated in Ma-tuan-lin's notices, but that of Tycho Brahe in Cassiopeia (1572) certainly is not so, I can no more explain the reason of such a circumstance as an isolated fact, than I can explain, for example, why the great luminous phænomenon seen in China in February 1578 is not mentioned by European observers of that period. The difference of longitude (114°) could only explain invisibility in a few cases. Those who have occupied themselves with similar inquiries know that the circumstance of events, either in politics or in nature, either on the earth or in the skies, not being noticed, is not always a proof of their not having occurred; and if we compare together the three different Chinese lists of stars in Ma-tuan-lin, we shall also find that comets (*ex. gr.* those of 1385 and 1495) which are contained in the one list are wanting in the others.

Older astronomers, Tycho Brahe and Kepler, as well as modern ones, Sir John Herschel and Mr. Hind, have called attention to the circumstance, that by far the greater number (I find four-fifths) of all the new stars which have been described either in Europe or in China have appeared in or near the Milky Way. If, as is more than probable, the mild nebulous light of the annular sidereal strata of the galaxy proceeds solely from a simple aggregation of telescopic stars, Tycho Brahe's hypothesis of the formation of new fixed stars by a globular condensation of the celestial vapour falls to the ground. What may be effected by forces or powers of attraction in crowded sidereal strata or star-clusters, supposing them to rotate round central nuclei, cannot be here determined, and belongs rather to the mythical department of Astrognosy. Of the 21 new stars enumerated in the list above given, 5 (those of 134, 393, 827, 1203, and1584) appeared in the constellation Scorpius; 3 (those of 945, 1264, and 1572) in Cassiopeia and Cepheus; and 4 (those of 123, 1230, 1604, and 1848) in Ophiuchus. On one occasion, however, a new star (that of the Monk of St. Galle in 1012) appeared very far from the Milky Way, or in Aries. Kepler himself, who considered the star which Fabricius described as shining forth in the neck of the Whale in 1596, and as having disappeared from view in October of the same year, to be really a new star, yet gives its position as a reason to the contrary. (Kepler de Stella Nova Serp. p. 112.) Ought the comparative frequency of these phænomena in the same constellations to lead us to infer that, in certain directions in space, for example, in those in which we see the stars of Scorpius and Cassiopeia, the conditions of this kindling or beaming forth are peculiarly favoured by local conditions or relations? Are there situated in these directions rather than in any others such celestial bodies as are peculiarly adapted for explosive luminous processes of short duration?

The luminosity was briefest in the stars of the years 389, 827, and 1012. In the star corresponding to the first of these dates it lasted 3 weeks, in the second 4 weeks, and in the third 3 months. On the other hand, Tycho Brahe's star in Cassiopeia shone for 17 months, and Kepler's in Cygnus (1600) was fully 21 years before it disappeared. It reappeared in 1655, being then, as on its first appearance, of the 3rd magnitude, whence it declined to the 6th; but, according to Argelander's observations, it is not to be ranked in the class of periodically variable stars.

The careful consideration and enumeration of *vanished* stars, or stars which are supposed to have disappeared, are important in respect to the research for the great number of small planets which are probably belonging to our solar system; but notwithstanding the exactness of the modern registration of telescopic fixed stars, and of our modern star-maps, very great care is still required for the attainment of full certainty and conviction, that any particular star has actually disappeared from the heavens within any definite period. Errors of observation, of reduction, or of the press,(273) often disfigure the best catalogues. The disappearance of a celestial body from the place where it had certainly been seen before, may be occasioned either by its having moved from thence, or by the luminous process on its surface or in its photosphere being so far enfeebled, that the luminous undulations no longer sufficiently stimulate our visual organs. What we no longer see has not on that account ceased to exist. The idea of the "destruction" or the "burning out" of stars which are gradually becoming invisible, belongs to the Tychonian period. Pliny also, in the fine passage upon Hipparchus, asks: "Stellæ an obirent nascerenturve?" The continual apparent change in the Universe, such as the disappearance of what was before seen, is not annihilation, but only the transition of material substances into new forms, or into compositions dependent on new processes. Dark cosmical bodies may suddenly shine forth afresh by a renewed luminous process.

Since all is in motion in the celestial canopy, and all things are variable in space and in time, we are led by analogy to conjecture, that as the fixed stars have all not merely an apparent motion, but also a proper motion of their own,—so also their surfaces or luminous atmospheres may be generally subject to changes, which, in the case of the greater number of these cosmical bodies, may occur in exceedingly long, and therefore unmeasured, and perhaps indeterminable, periods; while, in the case of a few, they may take place without being periodical, as by a sudden revolution, and for a longer or shorter continuance. The latter class of phænomena, of which a remarkable example is presented in our own days by a large star in the Ship (η Argûs), will not be discussed in this place, where we are about to consider only stars variable within periods which have already been investigated and measured. It is important to distinguish from each other three great sidereal phænomena, of which the connection has not yet been recognised: viz. variable stars of known periodicity; the blazing forth of what are called new stars; and sudden changes of light in long-known fixed stars, which had previously always shewn a uniform intensity. I propose at present to dwell exclusively on the first-named form of variability, of which the earliest accurately observed example (1638) is furnished by Mira Ceti, a star in the neck of the Whale. David Fabricius, a minister of the church in East Friesland, and the father of the discoverer of the solar spots, had, it is true, already observed this star as of the 3rd magnitude, on the 13th of August, 1596, and had noticed its disappearance in October of the same year. But the alternately recurring change of light, or the periodical variability of the star, was not discovered until forty-two years later, by a Professor of Franeker, Johann Phocylides Holwarda. This discovery was followed in the same century by that of two other variable stars: β Persei (1669), described by Montanari, and χ Cygni (1687), described by Kirch.

The increased number of stars of this class which have been observed since the beginning of the present century, and the irregularities which have been remarked in their periods, have excited in the highest degree the interest which is taken in this very complicated group of phænomena. From the difficulty of the subject, and my earnest desire that in this work the *numerical elements*, as the most important fruit of all observation, should be given as they are afforded by the most recent investigation, and according to the actual state of our knowledge, I have requested the kind aid of the astronomer who, among our cotemporaries, has devoted himself with the greatest activity and the most brilliant success to the study of periodically varying stars. I laid before my kind friend Argelander, Director of the Astronomical Observatory at Bonn, in the fullest confidence, the doubts and questions to which my own inquiries had given occasion; and I am indebted solely to his manuscript communications for what follows, great part of which has not yet been otherwise published.

The greater number of variable stars are red or reddish, but by no means all. So, for example, besides β Persei (Algol in the head of Medusa), β Lyræ and ε Aurigæ have also white light. η Aquilæ is somewhat yellowish; and so, in a still less degree, is ζ Geminorum. The statement formerly made, that some variable stars, and particularly Mira Ceti, were redder while their brightness was diminishing than while it was increasing, appears unfounded. Whether in the double star α Herculis, in which Sir William Hershchel calls the large star red, and Struve calls it yellow and its companion dark-blue, this small companion which is estimated from the 5th to the 7th magnitude, be itself also variable, appears very problematical. Struve ([274]) himself says only "suspicor minorem esse variabilem." Variability is by no means attached to redness of colour. There are many red, and some very red, stars, as Arcturus and Aldebaran, in which, hitherto, no variation has ever been observed; and the existence of any variability in a star in Cepheus (No. 7582 of the Catalogue of the British Association),—which, on account of its extraordinary redness, was called by William Herschel, in 1782, the Garnet—is more than doubtful.

It is difficult to say exactly what ought to be regarded as the whole known number of periodically variable stars, because the periods which have already been deduced are of very unequal degrees of certainty. The two variable stars in Pegasus, as well α Hydræ, ε Aurigæ, and α Cassiopeiæ, have not the same certainty as Mira Ceti, Algol, and δ Cephei. In drawing up a table, therefore, the question arises, what degree of certainty is to be regarded as sufficient. As will be seen in the general table at the close of this investigation, Argelander reckons the number of satisfactorily determined periods at only 24. ([275])

We have seen that the phænomenon of variability belongs to some white stars as well as to red ones, and it is also found to exist in stars of very different magnitudes: for example, in one star of the 1st magnitude, α Orionis; in Mira Ceti, α Hydræ, α Cassiopeiæ, and β Pegasi, all of the 2nd magnitude; β Persei, 2·3 magnitude; and in η Aquilæ and β Lyræ, 3·4 magnitude. There are also, and in much greater number, variable stars of the 6th to the 9th magnitudes, as the Variabiles, Coronæ, Virginis, Cancri, and Aquarii. The maximum of the star χ Cygni undergoes great fluctuations.

That variable stars are very irregular in their periods had long been known; but that in the midst of this apparent irregularity their variations are yet subject to definite laws, has for the first time been made out by Argelander. He hopes to demonstrate the truth of his views in this respect in detail in an extensive treatise devoted expressly to the subject. He now considers that two perturbations in the period of χ Cygni, one of 100 and the other of 8·5 single periods, are more probable than one of 108. Whether such disturbances originate in alterations in the luminous process going on in the atmosphere of the star, or in the period of revolution of a planet revolving round the fixed star or sun χ Cygni, and affecting the form of its photosphere by attraction, remains indeed still uncertain. The greatest irregularities in the variation of lustre are certainly presented by the star "Variabilis Scuti" in Sobieski's Shield, as this star sometimes diminishes from 5·4m. down to 9m. and once, according to Pigott, disappeared entirely at the end of the last century. At other times its fluctuations have only been between 6·5m. and 6m. The maximum brightness observed in χ Cygni has varied between 6·7m. and 4m., and that of Mira, between 4m. and 2·1m. On the other hand, δ Cephei has shewn in the length of its periods an extraordinary degree of regularity, greater than in any other variable star, as has appeared by 87 minima observed between the 10th of October, 1840, and the 8th of January, 1848, and others still more recent. In ε Aurigæ the alteration of brightness, (276) as found by an indefatigable observer, Heis at Aix la Chapelle, is only from the 3·4m. to the 4·5 magnitude.

Mira Ceti shews great differences of maximum brightness: for example, on the 6th of November, 1779, it was only a little inferior to Aldebaran, and it has not infrequently been brighter than stars of the 2nd magnitude; whilst at other times it has not even attained the brightness of δ Ceti, which is of the 4th magnitude. Its mean brightness is equal to that of γ Ceti (3rd magnitude). If we represent the light of the faintest star visible to the naked eye by 0, and that of Aldebaran by 50, then Mira has fluctuated, in its maximum, between 20 and 47. Its probable brightness would be expressed by 30, and it is oftener below than above this limit: when it exceeds it, however, the excess is much greater in amount than is the defect when it falls below it. No decided period in these oscillations has yet been discovered, but there are indications of a period of 40, and of one of 160 years.

The periods of variation differ in different stars as much 1 : 250. The period of β Persei of 68 hours 49 minutes is unquestionably the shortest, supposing that of Polaris, of less than 2 days, not to be confirmed. Next to β Persei follow successively δ Cephei (5d. 8h. 49m.), η Aquilæ (7d. 4h. 14m.), and ζ Geminorum (10d. 3h. 35m.) The variable stars of which the period has the longest duration are: 30 Hydræ Hevelii, 495 days; χ Cygni, 406 days; Variabilis Aquarii, 388 days; Serpentis S. 367 days; and Mira Ceti, 332 days. In several variable stars it is certain that the light increases more rapidly than it decreases: this phenomenon shews itself in the most striking manner in δ Cephei. Other stars have equal times of increasing and decreasing light (*ex. gr.* β Lyræ). A difference in this respect is sometimes found in the same star. As a general rule, Mira Ceti (like δ Cephei) increases faster than it decreases; but the contrary has also been observed.

In regard to periods which are themselves subject to a periodical variation, we find such decidedly in Algol, Mira Ceti, and β Lyræ, and with much probability in χ Cygni. The decrease of the period of Algol is now undoubted. Goodricke did not find it, but Argelander has done so, having in 1842 been able to compare above 100 well-assured observations, of which the extremes are above 58 years apart, comprising 7600 periods. (Schumacher's Astr. Nachr. No 472 and 624.) The decrease of duration becomes more and more sensible. (277) For the periods of maximum in Mira (taking in the maximum of brightness observed by Fabricius in 1596), Argelander has given a formula (278) by which all the maxima can be so deduced that *the probable error* in a mean period of 331d. 8h. does not exceed 7 days, whereas on the assumption of a uniform period it would be 15 days.

The double maximum and minimum of β Lyræ, in each of its periods of almost 13 days, were already very correctly recognised in 1784 by the discoverer Goodricke, but have been placed still more beyond doubt by the most recent observations. (279) It is worthy of notice, that this star attains the same degree of brightness in both its maxima, but at its principal minimum it is half a magnitude less than at its secondary minimum. From the earliest discovery of the variability of β Lyræ its period was probably lengthening, but more and more slowly, until, between 1840 and 1844, the period ceased to increase, and has since decreased. We find something similar to the double maximum of β Lyræ in δ Cephei; it has so far an inclination to a second maximum that the decrease of light does not proceed uniformly, but, after having been at first rapid, comes after some time to a stand, or at least to a very inconsiderable degree of diminution; after which the decrease suddenly resumes a most rapid rate. It is as if the attainment of a second maximum was interfered with.

The question of whether there is, on the whole, more regularity in variable stars of very long than in those of very short periods, is one difficult to answer. The deviations from a uniform period can only be taken relatively, *i. e.* in parts of the period itself. In order to begin with long periods, χ Cygni, Mira Ceti, and 30 Hydræ, must be first considered. In χ Cygni, the deviations from the most probable period, on the assumption of a uniform variability (406·0634 days), is as great as 39·4 days. Even though a part of this may be ascribed to errors of observation, yet there will still certainly remain from 29 to 30 days, or $\frac{1}{14}$th of the whole period. In Mira Ceti, [280] in a period of 331·340 days, the deviations extend to 55·5 days, even if we leave out of the account the observations of David Fabricius. If, on account of errors of observation, we reduce the estimation to 40 days, we obtain a quotient of $\frac{1}{8}$th, or, as compared with χ Cygni, a deviation almost twice as great. In 30 Hydræ, which has a period of 495 days, the deviation is certainly still greater, perhaps amounting to $\frac{1}{5}$th. It is only within a few years, since 1840 and still later, that the variable stars with very short periods have been observed perseveringly and with due precision; so that, in regard to them, the question we are speaking of is still more difficult of solution. As far, however, as experience hitherto can enlighten us, the deviations would appear to be less considerable. In η Aquilæ (Period 7d. 4h.) they are only $\frac{1}{16}$ or $\frac{1}{17}$th of the whole period; in β Lyræ (Period 12d. 21h.) only $\frac{1}{27}$ or $\frac{1}{30}$th;

but as yet this investigation is still subject to many uncertainties in the comparison of long and short periods. Of β Lyræ, from 1700 to 1800 periods have been observed; of Mira Ceti, 279; of χ Cygni, only 145.

The question which has been asked, whether stars which have long shewn themselves variable in regular periods cease to be so, would appear to require to be answered in the negative. If among the persistently varying stars there are some which shew sometimes a very great and sometimes a very slight degree of variability (for example, variabilis Scuti), there would also appear to be others whose variability is at certain times so small, that, with our limited means, we cannot detect it. The star variabilis Coronæ bor. (No. 5236 in the British Association Catalogue), of which Pigott recognised the variability, and which he observed for some time, belongs to this class. In the winter 1795-1796, this star was quite invisible: subsequently it reappeared, and its alterations of light were observed by Koch. Harding and Westphal, in 1817, found its brightness almost constant; but, in 1824, Olbers was again able to observe its change. Afterwards the constancy of light returned, and from August 1843 to September 1845 was observed by Argelander. At the end of the month of September, 1845, a fresh decrease began to take place. In October, the star was no longer visible in the Comet-seeker: it reappeared in February 1846, and in the beginning of June it had again attained its usual magnitude (the 6th), which it has since retained, if we omit the consideration of small and not very well assured fluctuations. To this perplexing class of stars the one called variabilis Aquarii also belongs, as does perhaps Janson's and Kepler's star in Cygnus, which appeared in 1600, and which we have already noticed among "New stars."

Table of Variable Stars. By Fr. Argelander.

Number.	Name of the Star.	Duration of the Period.			Brightness at the Maximum.	Brightness at the Minimum.	Name of the Discoverer.	Date of Discovery.
		days.	hours.	min.	Magnitude.	Magnitude.		
1	o Ceti	331	20	0	4 to 2·1	0	Holwarda	1639
2	β Persei	2	20	49	2·3	4	Montanari	1669
3	χ Cygni	406	1	30	6·7 to 4	0	Gottfr. Kirch	1687
4	30 Hydræ Hev.	495	0	0	5 to 4	0	Maraldi	1704
5	Leonis R., 420 M.	312	18	0	5	0	Koch	1782
6	η Aquilæ	7	4	14	3·4	5·4	E. Pigott	1784
7	β Lyræ	12	21	45	3·4	4·5	Goodricke	1784
8	δ Cephei	5	8	49	4·3	5·4	Goodricke	1784
9	α Herculis	66	8	0	3	3·4	William Herschel	1795
10	Coronæ R.	323	0	0	6	0	E. Pigott	1795
11	Scuti R.	71	17	0	6·5 to 5·4	9 to 6	E. Pigott	1795
12	Virginis R.	145	21	0	7 to 6·7	0	Harding	1809
13	Aquarii R.	388	13	0	9 to 6·7	0	Harding	1810
14	Serpentis R.	359	0	0	6·7	0	Harding	1826
15	Serpentis S.	367	5	0	8 to 7·8	0	Harding	1828
16	Cancri R.	380	0	0	7	0	Schwerd	1829
17	α Cassiopeiæ	79	3	0	2	3·2	Birt	1831
18	α Orionis	196	0	0	1	1·2	John Herschel	1836
19	α Hydræ	55	0	0	2	2·3	John Herschel	1837
20	ϵ Aurigæ		?		3·4	4·5	Heis	1846
21	ζ Geminorum	10	3	35	4·3	5·4	Schmidt	1847
22	β Pegasi	40	23	0	2	2·3	Schmidt	1848
23	Pegasi R.	350	0	0	8	0	Hind	1848
24	Cancri S.		?		7·8	0	Hind	1848

Remarks: by Fr. Argelander.

Zero, in the column of minimum, denotes that the star is then fainter than the 10th magnitude. For the sake of indicating, in a convenient and simple manner, the smaller variable stars, which for the most part have neither names nor other designations, I have permitted myself to attach letters to them; and as the greater part of the Greek and small Latin alphabets have been already employed by Bayer, I have taken capital letters.

Besides the stars given in the table, there is an almost equal number which are surmised to be variable because different observers have assigned to them different magnitudes. But as such estimations were only occasional, and not made with great precision, and as different observers follow different principles in the estimation of magnitudes, it seems safer not to include such stars until a decided variation in them at different times shall have been found by the same observer. This is the case with all the stars given in the above table, and the fact of their change of light is well assured, even where no determination of its period has yet been possible. The periods assigned rest, for the most part, on my own investigations and examinations, both of older published observations, and of those made by myself and still unprinted which extend over more than ten years. The exceptions will be stated in the following notices.

In these notices the positions are for 1850, and are expressed in Right Ascension and Declination. The often-employed expression, *gradation*, signifies such a difference of brightness as can be securely recognised, either with the naked eye, or, in stars not visible to the naked eye, with a Fraunhofer's Comet-seeker of 24 Parisian inches focal length. For the brighter stars above the 6th magnitude, a gradation is about the 10th part of the difference between two successive orders of magnitude; for the smaller stars, the magnitudes in ordinary use are considerably closer together.

1. *o* Ceti, R. A. 32° 57′, Decl. −3° 40′; also called Mira, on account of its wonderful change of light, the phenomenon having been first observed in this star. The periodicity of the change was already recognised in the second half of the 17th century, and Bouillaud determined the duration of the period at 333 days; it was also found at the same time that this duration was sometimes longer and sometimes shorter, as well as that the light of the star, when at the greatest, was sometimes brighter and sometimes fainter. This has since been perfectly confirmed. Whether the star ever becomes quite invisible has not yet been decided; it has sometimes been seen of the 11th or 12th magnitude at the time of the minimum, and at other times it has not been possible to see it with 3 and 4 feet telescopes. Thus much is certain, that it is for a long time fainter than the 10th magnitude. There are, however, few existing observations of it at this stage; most observations commencing only when, being of the 6th magnitude, it begins to shew itself to the naked eye. From that moment the star increases in brightness, at first rapidly, then more slowly, and afterwards more rapidly. On the mean, the time occupied by the increase of light, from the 6th magnitude upwards, is 50 days, and by the decrease of light, down to the same degree of brightness,

69 days; so that the star is visible to the naked eye for an interval of about four months. This is, however, only the mean duration of the star's visibility, which has sometimes been augmented to five, and sometimes diminished to only three months. So, also, the relative duration of the increase and decrease of light is subject to great fluctuations, the former being sometimes slower than the latter: as was the case in 1840, when the star took 62 days to arrive at its greatest brightness, and in 49 days decreased from thence to invisibility to the naked eye. The shortest observed duration of the increase was 30 days, in 1679; the longest, 67 days, in 1709. The decrease lasted longest in 1839, when it extended over 91 days, and was shortest in 1660, when it was only 52 days. Sometimes, at the time of its greatest brightness, the light of the star scarcely undergoes any sensible change in the course of an entire month; at other times an alteration is distinctly perceptible at the end of a few days. Sometimes, after the star has decreased in brightness for some weeks, a suspension of change for several days ensues, or at least the decrease becomes scarcely sensible: this was the case in the years 1678 and 1847.

As already noticed, the maximum brightness is by no means always the same. If we represent the light of th faintest star visible to the naked eye by 0, and that of Aldebaran, a star of the first magnitude, by 50, then the observed maximum brightness of Mira has fluctuated between 20 and 47, *i. e.* between the brightness of stars of the 4th and of the 1st to the 2nd magnitudes: the mean brightness is 28, or that of the star γ Ceti. The duration of the period has been almost even more irregular:

in the mean it is 331 days 20 hours, but its fluctuations are as great as a month; for the shortest time which has been known to elapse from one maximum to the next was only 306, and the longest was 367 days. These irregularities become still more striking if we compare the epochs of the actually observed maxima of light with the results which would be obtained by calculating them upon the assumption of a uniform period. The differences between calculation and observation amount to 50 days; and these differences are found to be nearly the same and on the same side for several successive years. This circumstance clearly indicates that the luminous phenomena are affected by a perturbation of long period. More exact calculation has proved, however, that one perturbation does not suffice, and that we must assume several, which may indeed proceed from the same cause, one returning after 11, a second after 88, a third after 176, and a fourth after 264 single periods. According to these assumptions we may derive a formula of sines ([278]) with which the several maxima now shew a very near accordance, although there still remain deviations which cannot be explained by errors of observation.

2. β Persei, Algol; R. A. 44° 36′; Decl. +40° 22′. Although Geminiano Montanari first remarked the variability of this star in 1667, and although it was also observed by Maraldi, yet it was Goodricke who, in 1782, first made out the regularity of the variations. The reason of this may very probably be, that this star does not increase and decrease gradually, as do most of the other variable stars, but for 2 days and 13 hours shines constantly with the same brightness (2·3 m.), and only

shews a less degree of light for between 7 and 8 hours, in the course of which it descends to the 4th magnitude. The decrease and increase of brightness are not quite regular, but, proceeding more rapidly near the minimum, enable the moment of least brightness to be determined to within 10 or 15 minutes. It is remarkable that, after increasing in light for the space of an hour, it remains for about the same time at almost exactly the same degree of brightness, after which it again begins to increase sensibly. Hitherto the length of the period has been supposed to be perfectly uniform, and Wurm was able to represent all the observations well, by taking it at 2d. 21h. 48m. 58·5s. A more exact calculation, with an interval almost twice as great as that which Wurm had at his command, has, however, shewn that the period is becoming gradually shorter. In 1784 it was 2d. 20h. 48m. 59·4s., and in 1842 only 2d. 20h. 48m. 55·2s. The latest observations render it very probable, also, that this decrease of the period is taking place more rapidly than before, so that, for this star also, there will in time be derived a formula of sines for the perturbation of the period. The present shortening of the period might be explained by the assumption, that Algol either approaches us nearer every year by about 2000 geographical miles, or recedes from us that quantity less each year than the preceding; as in such case the light would reach us each year as much sooner as the diminution of the period requires, *i. e.* about 12 thousandth parts of a second. Should this be the true reason, there would naturally be deduced in time, a formula of sines.

3. χ Cygni, R. A. 269° 12′; Decl. + 32° 32′. This

star also shews nearly the same irregularities as Mira: the deviations of the observed maxima from the results calculated on the supposition of a uniform period are as much as 40 days, but are very greatly diminished by the introduction of a perturbation of 8½ single periods, and another of 100 such periods. At its maximum of brightness, this star reaches, on the mean, a faint 5m., or one gradation brighter than the star 17 Cygni. But here also the fluctuations are very considerable, and have been observed from 13 gradations below the mean to 10 above it. If the star never exceeded the weaker maximum, it would be altogether invisible to the naked eye, whereas, in 1847, it could be seen for fully 97 days without a telescope; the mean duration of its visibility is 52 days, of which 20 days in the mean are occupied by the increase, and 32 by the decrease.

4. 30 Hydræ Hevelii, R. A. 200° 23′; Decl. 22° 30′. Of this star, which from its position in the heavens can only be seen for a short time in each year, all that can yet be said is, that both its period and its maximum brightness are subject to great irregularities.

5. Leonis R = 420 Mayeri; R. A. 144° 52′, Decl. + 12° 7′. This star has often been confounded with the neighbouring stars 18 and 19 Leonis, and has on that account been very little observed; it has, however, been sufficiently so, to shew that the period is rather irregular. The maximum brightness also appears to fluctuate through some gradations.

6. η Aquilæ, also called η Antinoi; R. A. 296° 12′; Decl + 0° 37′. The period of this star is tolerably uniform, 7d. 4h. 53m. 53s.; but yet the observations

shew, that in longer intervals of time small fluctuations occur; not, however, exceeding about 20 seconds. The change of light even proceeds with so much regularity, that hitherto no deviations have been perceptible which may not be explained by errors of observation. At its minimum this star is a gradation fainter than ι Aquilæ; it then increases, at first slowly, then more rapidly, and then more slowly; and 2d. 9h. after the minimum it attains its greatest brightness, when it is almost three gradations brighter than β, but still 2 gradations fainter than δ Aquilæ. The decrease from the maximum is less regular, for when the star has declined to the brightness of β, which it reaches 1 day and 10 hours after the maximum, it alters more slowly than before or afterwards.

7. β Lyræ, R. A. 281° 8′, Decl. +33° 11′; a remarkable star, in having two maxima and two minima. At its lowest minimum it is $\frac{1}{3}$rd of a gradation fainter than ζ Lyræ; it then rises in 3d. 5h. to its first maximum, in which it continues to be $\frac{3}{4}$ths of a gradation fainter than γ Lyræ. It then sinks in 3d. 3h. to its secondary minimum, in which its brightness exceeds that of ζ by 5 gradations. After 3d. 2h. more, it reaches its second maximum, when it has again the same brightness as in the first, and then sinks again in 3d. 12h. to its lowest minimum; so that it passes through its whole variation of light in 12d. 21h. 46m. 40s. This duration, however, only holds good for the years 1840 to 1844: before that time the period was less; in 1784 by $2\frac{1}{2}$ hours, in 1817 and 1818 by more than an hour, and now there is evidently again a shortening of the period. No doubt, therefore, it will be possible, in the case of this star also,

to express the perturbation of the period by a formula of sines.

8. δ Cephei, R. A. 335° 54′, Decl. + 57° 39′. Is of all known stars the one which shews the greatest regularity in all respects. The period of 5d. 8h. 47m. 39·5s. represents all observations from 1784 to the present time, to within the limits of errors of observation, which errors may also suffice for the explanation of the small differences which shew themselves in the march of the variations of light. At its minimum the star is $\frac{3}{4}$th of a gradation brighter than ε Cephei, and at its maximum it is equal to ι of the same constellation; it takes 1d. 15h. to rise from the minimum to the maximum, and more than double that time, *i.e.* 3d. 18h. to return to the minimum; after which, however, it scarcely alters at all for eight hours, and only quite inconsiderably for an entire day.

9. α Herculis, R. A. 256° 57′, Decl. + 14° 34′. A very red double star, whose variation of light is irregular in every respect. Often it scarcely alters at all for months, at other times it is five gradations brighter at its maximum than at its minimum, and hence the period is also still very uncertain. The discoverer assumed it at 63 days; I began by taking it at 95, until a careful calculation of all my observations during seven years gave me the period assigned in the text. Heis thinks that he can represent the observations by a period of 184d. 9h., having two maxima and two minima.

10. Coronæ R., R. A. 235° 36′, Decl. + 28° 37′. This star is only occasionally variable; the assigned period was calculated by Koch from his own observations, which are unfortunately lost.

11. Scuti R., A. R. 279° 52′, Decl.—5° 51′. Sometimes the fluctuations of the light of this star are comprised within a few gradations, whilst at other times it sinks from the 5th to the 9th magnitude. It has been still too little observed to permit us to decide whether any determinate rule prevails in these alterations. The length of the period is also subject to considerable fluctuations.

12. Virginis R., R. A. 187° 43′, Decl. + 7° 49′. Its period and maximum brightness are tolerably regular, yet deviations occur which appear to me too large to be ascribed solely to errors of observation.

13. Aquarii R, R. A. 354° 11′, Decl. − 16° 6′.

14. Serpentis R, R. A. 235° 57′, Decl. + 15° 36′.

15. Serpentis S, R. A. 228° 40′, Decl. + 14° 52′.

16. Cancri R, R. A. 122° 6′, Decl. + 12° 9′.

Respecting these four stars, observations of which are exceedingly scanty, there is little more to be said than is given in the table.

17. *α* Cassiopeiæ, R. A. 8° 0′, Decl. + 55° 43′. This star is very difficult to observe; the difference between maximum and minimum only amounts to a few gradations, and is moreover as variable as is the length of the period. The very different results assigned for it are attributable to this circumstance. The result which I have given represents sufficiently well the observations from 1782 to 1849, and appears to me the most probable.

18. *α* Orionis, R. A. 86° 46′, Decl. + 7° 22′. The variation in the light of this star from the minimum to the maximum only amounts to four gradations; it increases in brightness during 91½ days, and decreases during 104½: its decrease from the 20th to the 70th day after the maxi-

mum is quite insensible. Sometimes its variation of light is still less, and scarcely noticeable. It is very red.

19. α Hydræ, R. A. 140° 3′, Decl. −8° 1′. Is of all variable stars the most difficult to observe, and the period is still quite unassured. Sir John Herschel gives it at 29 or 30 days.

20. ϵ Aurigæ, R. A. 72° 48′, Decl. +43° 36′. Either the changes of light in this star are very irregular, or in a period of several years there are several maxima and minima: this can only be determined after a lapse of many years.

21. ζ Geminorum, A. R. 103° 48′, Decl. +20° 47′. Hitherto this star has shewn an entirely regular course in its changes of light. At the minimum its brightness is half way between ν and v of the same constellation, and at the maximum not quite equal to λ; it occupies 4d. 21h. in increasing, and 5d. 6h. in decreasing.

22. β Pegasi, R. A. 344° 7′, Decl. +27° 16′. The period is already pretty well determined, but there is as yet nothing to be said about the regularity or otherwise of the variation of its light.

23. Pegasi R, R. A. 344° 47′, Decl. + 9° 43.

24. Cancri S, R. A. 128° 50′, Decl. +19° 34′.

There is as yet nothing to be said respecting these two stars.

FR. ARGELANDER.

Bonn, August 1850.

In the scientific investigation of important natural phenomena, whether in the telluric or in the sidereal sphere of the Cosmos, prudence commands us not to be too hasty in linking together phenomena whose immediate causes are still veiled in obscurity. For this reason we willingly distinguish between newly appeared stars which have again entirely disappeared (as the star in Cassiopeia in 1572); newly appeared stars which have not disappeared again (as the star in Cygnus, 1600); variable stars whose periods have been investigated (as Mira Ceti, Algol, &c.); and stars whose luminous intensity varies without our having as yet discovered any periodicity in the variation, (as η Argûs). It is not at all improbable, but it also by no means necessarily follows, that these four kinds of phenomena (281) arise from similar causes belonging to the photospheres of those distant suns, or to the nature of their surfaces.

As we began the description of the new stars with the most remarkable instance of this class of celestial events, *i. e.* the sudden appearance of the star of Tycho Brahe,—so, guided by the same reasons, we will begin the description of the alteration of the light of stars, in which the periodicity of the variation has not yet been investigated, by the still proceeding unperiodic fluctuations of luminous intensity in the star η Argûs. This star is situated in the great and magnificent constellation of the Ship, which is the "glory of the southern heavens." As early as 1677, Halley, on his return from his voyage to St. Helena, expressed many doubts respecting change of light in the stars of the Ship Argo, particularly on the shield of the prow and on the deck (ἀσπιδισκη and καταστρωμα), whose relative order of magnitude had been given by Ptolemy (282); but from the uncertainty of the star positions of the Ancients, the many variations in the manuscripts of the Almagest, and the uncertain estimations of luminous intensity, these doubts could not lead to any results.

In 1677 Halley had found η Argûs of the 4th magnitude; in 1751 Lacaille found it already of the 2d. Afterwards the star returned to its earlier fainter intensity, for Burchell, during his residence in Southern Africa in 1811—1815 found it of the 4th magnitude. From 1822 to 1826 Fallows and Brisbane saw it of the 2nd magnitude; and in February 1827, Burchell, who was then at St. Paul in Brazil, found it of the 1st magnitude, and quite equal to α Crucis. After a year it returned to the 2nd magnitude; it was found so by Burchell in the Brazilian town of Goyaz on the 29th February, 1828, and was so entered by Johnson and Taylor in their registers from 1829 to 1833. Sir John Herschel at the Cape of Good Hope also estimated it from 1834 to 1837 at between the 2nd and 1st magnitude.

But on the 16th of December, 1837, when the last named celebrated astronomer was preparing to make photometric measurements of the numberless telescopic stars of the 11th to the 16th magnitudes which fill the fine nebula around η Argûs, he was astonished at finding this often observed star increased to such an intensity of light, that it almost equalled the brightness of α Centauri, and surpassed that of all other stars of the first magnitude except Canopus and Sirius. It had attained the maximum of its brightness on that occasion on the 2nd of January, 1838. It soon became fainter than Arcturus, but still surpassed Aldebaran in the middle of April 1838. It went on decreasing until March 1843, always continuing, however, to be a star of the 1st magnitude, but we then find, particularly in April of the same year, that the light began to increase again to such a degree, that according to the observations of Mackay at Calcutta, and of Maclear at the Cape, η Argûs became brighter than Canopus, and even almost equal to Sirius. (283) It has retained this degree of brightness very nearly to the commencement of the present year. A distinguished observer, Lieutenant Gilliss, who has the command of the Astronomical Expedition which the Government of the United States has sent to the coast of Chili, writes from Santiago in February 1850 : "η Argûs with its yellowish red light, which is darker than that of Mars, now comes next to Canopus in brightness, and is brighter than the united light of α Centauri." (284) Since the appearance of the new star in Ophiuchus in 1604, no fixed star has brightened to such an intensity of light, and for a continuance of now already seven years. In the 173 years (from 1677 to 1850) during which we have accounts of the magnitude of this fine star, it has undergone eight or nine oscillations of increase and decrease. It was a fortunate circumstance, and one which has stimulated the persevering attention of astronomers to the phenomenon of a great but unperiodic variability in this star, that it should have manifested itself in the most striking manner during the memorable five years' expedition of Sir John Herschel to the Cape of Good Hope.

Similar variations of light which have not yet been recognised as periodical have been remarked in several other instances, both in isolated fixed stars and in double stars observed by Struve (Stellarum compos. Mensuræ microm. p. lxxi.—lxxiii.) The examples which it may suffice to cite here are founded on actual photometric estimations and measurements made at different times by the same astronomers, and not at all upon the alphabetical series in Bayer's Uranometry. Argelander, in the treatise "de fide Uranometriæ Bayerianæ," 1842, in p. 15, has shown very convincingly that Bayer did not follow the principle of always indicating the brightest stars by the first letters; but that, on the contrary, in the *same* star-magnitude he distributed the letters in the order of *position* in such manner as to pass usually from the head of the figure, in each constellation, to its feet. The alphabetical order of the letters employed in Bayer's Uranometry has long given prevalence to a belief in changes having taken place in the light of α Aquilæ, of Castor, and of Alphard.

Struve (1838) and Sir John Herschel saw Capella increase in light. Sir John Herschel now estimates Capella as much brighter than Vega, whereas he formerly always considered it fainter ([285]). Galle and Heis form the same judgment from a present comparison of Capella and Vega: Heis considers the latter star to be between five and six gradations, or more than half a magnitude, fainter than Capella.

The alterations in the light of some stars in the constellations of the Great and Little Bear, are deserving of particular attention. "The star η Ursæ majoris," says Sir John Herschel, "is now certainly the brightest of the seven bright stars in the Great Bear, whilst in 1837 the first rank belonged incontestably to ε." This remark occasioned me to make inquiries from Heis, who occupies himself with so much ardour, and so extensively, with the variability of the light of stars. He wrote to me in reply to the following effect:— "From the mean of the observations made by me at Aix-la-Chapelle from 1842 to 1850, I find the order of succession thus: 1. ε Ursæ maj., or Alioth; 2. α or Dubhe; 3. η or Benctnasch; 4. ζ or Mizar; 5. β; 6. γ; 7. δ. In respect to the differences of brightness between these seven stars, ε,

α and η are nearly equal to each other; so that, when the atmosphere is not quite clear, their order of succession may appear doubtful: ζ is decidedly fainter than ε, α, and η. The two stars β and γ, both sensibly fainter than ζ, are almost equal to each other. Lastly, δ, which in old maps is given as equal with β and γ, is more than an entire order of magnitude fainter than those stars. ε is certainly variable: although usually brighter than α, I have five times in three years seen it decidedly fainter than α. I also regard β Ursæ majoris as variable, but without being able to assign any determinate period. Sir John Herschel, in 1840 and 1841, found β Ursæ min. much brighter than Polaris; whereas, in May 1846, the contrary was observed by him. He surmises variability in β ([286]). Since 1843, I have usually found Polaris fainter than β Ursæ min.; but between October 1843 and July 1849 my registers show that, on fourteen occasions, Polaris was seen to exceed β in brightness. I have repeatedly had an opportunity of convincing myself that the last-named star is not always equally reddish: it is sometimes more or less yellow, and sometimes very decidedly red" ([287]). All laborious investigations of the relative brightness of stars will gain essentially in certainty, when successive arrangement according to mere estimation shall be finally superseded by methods of measurement founded on the progress of modern optical science ([288]), and astronomers and physicists ought not to doubt the possibility of attaining such an object.

From the probably great physical similarity of the luminous process in all self-luminous celestial bodies (in the central body of our own planetary system, and in the remoter suns or fixed stars), it has long been justly pointed out, ([289]) how important a bearing the periodical or non-periodical variation of light in stars may possibly have on climatology in general, —on the history of the terrestrial atmosphere, *i. e.* on the varying quantity of heat received in the course of ages by our planet from solar radiation,—and on the condition of organic life, and its forms of development, in different latitudes. The variable star, Mira Ceti, changes from the 2d to the 11th magnitude, and even to entire disappearance; and we have just seen that η Argûs has increased from the 4th to the 1st magnitude, and even to the brightness of Canopus, and almost to that of Sirius. If only a very small part of such alterations of luminous intensity and radiant heat, either in the ascending or descending scale, should have taken place in our Sun (and why should it be different from other suns?), they would have produced more powerful and even more fearful consequences to our planet, than are required for the explanation of all geological relations and ancient telluric revolutions. William Herschel and Laplace were the first who called attention to these considerations. If I thus notice them in this place, however, it is not because I would seek exclusively in them for the solution of the great problem of the alterations of temperature upon our globe. It may also have been that the primitive high temperature of the planet due to the manner of its formation and to its consolidation,—the radiation of heat through deep fissures or open clefts, and veins not yet filled with metallic ores,—more powerful electric currents,—and a very different distribution of land and sea,—*may*, in the earlier ages of our planet, have rendered the distribution of temperature independent of latitude, *i. e.* of position relatively to the Sun. Cosmical contemplation ought not to limit itself by too partial a view to astrognostic relations only.

V.

PROPER MOTION OF THE FIXED STARS.—PROBLEMATICAL EXISTENCE OF DARK BODIES.—PARALLAX.—MEASURED DISTANCE OF SOME FIXED STARS.—DOUBTS CONCERNING THE ASSUMPTION OF A CENTRAL BODY FOR THE WHOLE SIDEREAL HEAVENS.

Besides variations of luminous intensity, the heaven of the *fixed* Stars, in contradiction to its name, also undergoes variation from the perpetually progressive motion of the several stars. It has already been recalled how, without the general equilibrium of the sidereal system being disturbed thereby, no point in the entire heavens has remained fixed,—how, of the bright stars observed by the most ancient of the Greek astronomers, none has maintained its position in space unaltered. In two thousand years, the change of place, by the accumulated effects of annual proper motion, has amounted in Arcturus, μ Cassiopeiæ, and a double star in Cygnus to spaces corresponding to $2\frac{1}{2}$, $3\frac{1}{2}$, and 6 diameters of the moon. At the end of three thousand years, about 20 fixed stars will have altered their place 1° and upwards. (290) As the proper motions of fixed stars which have been measured vary from $\frac{1}{20}$th or ·05 of a second to 7·7 seconds, (differing, therefore, at least in the proportion of 1 : 154), it follows that the relative distances of the fixed stars, *inter se,* and the configuration of the constellations does not remain the same for long periods. The Southern Cross will not always shine in the heavens in the same form which that constellation now presents, as the four stars of which it is composed move with unequal velocities in different paths. How many thousand years may be required for the entire dissolution of the constellation is not to be calculated. In relations of space and time, there is no absolute great or small. If we would embrace in a general view the changes which take place in the heavens, modifying in the course of ages the "physionomic character" of the celestial canopy, or the aspect of the firmament as seen at a determinate point of the earth's surface, we must enumerate, as efficient causes of such alteration, (1) the precession of the equinoxes and the nutation of the earth's axis, by the joint influence of which new stars arise above the horizon, and others become invisible; (2) the periodic and non-periodic variations of luminous intensity in many fixed stars; (3) the shining forth of new stars, some few of which have remained; (4) the revolution of telescopic double stars round a common centre of gravity. Amongst these so-called fixed stars, which vary slowly and unequally in intensity of light and in position, 20 planets, and 20 satellites belonging to five of these planets, complete their more rapid course. Thus, besides the countless hosts of (also, without doubt, revolving) fixed stars, there are discovered up to the present time (October 1850), 40 planetary bodies. In the time of Copernicus, and of the great improver of the art of observation, Tycho Brahe, only 7 were known. We might also have named here as planetary bodies almost

200 calculated comets, of which 5 are of short periods of revolution, and interior, *i. e.* their paths are entirely comprised between those of the principal planets. During their mostly short appearance, they, or rather those amongst them which are visible to the naked eye, as well as the true planets, and those bodies which have suddenly shone forth as new stars of the first magnitude, animate, in the most attractive manner, the already rich picture of the sidereal heavens.

The knowledge of the proper motion of the fixed stars is wholly connected, historically, with the advances which have been made in the art of observing by the improvement of instruments and of methods. It first became possible to discover these motions when telescopes were combined with graduated instruments,—when astronomers were able progressively to advance from certainty in respect to a minute of arc (which Tycho Brahe first succeeded, by the most strenuous endeavours, in giving to his observations in the Island of Huen), to certainty in respect to seconds and parts of seconds,—and when it was possible to compare together results separated by a long series of years. Such a comparison was made by Halley, who employed in it the positions of Sirius, Arcturus, and Aldebaran, as entered by Ptolemy in his Hipparchian Catalogue, 1847 years before. He thought himself justified by this comparison (1717) in announcing the existence of a proper motion in the three above named fixed stars. ([291]) The great and deserved regard which, even long after Flamsteed's and Bradley's observations, was paid to the Right Ascensions contained in Römer's Triduum, incited Tobias Mayer (1756), Maskelyne (1770), and Piazzi (1800), to compare Römer's observations with later ones. ([292])

These comparisons led, as early as the middle of the last century, to the recognition of the proper motion of the fixed stars generally; but we are indebted for more exact and numerical determinations of this class of phenomena, first to the great work of William Herschel in 1783, founded on Flamsteed's observations ([293]), and since in a far higher degree to Bessel's and Argelander's comparison of Bradley's Star Positions for 1755 with later catalogues.

The discovery of the proper motion of the fixed stars, is of so much the higher importance to physical astronomy, since it has led to the recognition of the movement of our own solar system through star-filled space, and even to the exact knowledge of the direction of this movement. This is a fact of which we could never have become aware, if the progressive proper motion of the fixed stars had been so small as altogether to escape our measurement. The zealous endeavour to investigate the quantity and direction of this movement, together with the parallax of the fixed stars and their distance, by stimulating the improvement of arc-graduation and micrometric apparatus combined with optical instruments, has eminently contributed to the advance of observing astronomy to the point to which, (especially since 1830), it has been raised by the judicious employment of large meridian-circles, refractors, and heliometers.

The quantity of proper motion which has been measured in different stars varies, as I have remarked in the beginning of this section, from the 20th part of a second to almost 8 seconds. The brighter stars have in many cases a less motion than stars of the 5th, 6th, and 7th magnitudes. ([294]) The 7 stars which have shewn unusually great proper motion, are, Arcturus (1st magnitude) which has an annual proper motion of 2″·25; *α* Centauri (1st m.), 3″·58 [295]; *μ* Cassiopeiæ (6th m.), 3″·74; the double star *δ* in Eridanus (5·4 m.) 4″·08; the double star 61 Cygni (5·6 m.), 5″·123, the motion being recognised by Bessel in 1812 by comparison with Bradley's observations; a star on the borders of the constellations Canis Venaticus [296] and Ursus Major, No. 1830 of Groombridge's catalogue of circumpolar stars (7th m.), according to Argelander 6″·974; *ε* Indi, 7″·74 according to D'Arrest [297]; 2151 Puppis (6th m.) 7″·871. The arithmetical mean [298] of the several proper motions of fixed stars, taken from all the zones into which Mädler has divided the celestial sphere, would hardly exceed 0″·102.

An important investigation into the variability of the proper motions of Procyon and Sirius, had in 1844 (a short time before the commencement of his painful and fatal illness), impressed the mind of the greatest astronomer of our time, Bessel, with the conviction, "that stars, whose variable motions become sensible when examined with the most perfect instruments, are parts of systems which are limited to spaces small in comparison with the great distances of the fixed stars from each other." This belief in the existence of double stars, of which one member of the pair is supposed to be non-luminous, was so strong in Bessel's mind (as his long correspondence with myself testified), as to add greatly to the general interest excited by whatever promises to enlarge our knowledge of the physical constitution of the sidereal heavens. "The attracting body," said he, "must be situated either very near the star which shews the observed change of place, or very near the sun. But since nothing in the motions of our planetary system betrays the presence of an attracting body of considerable mass at a very small distance from the sun, we are conducted back to the supposition of the existence of such a body at a *very small distance from a star*, as the only valid explanation of an alteration in the proper motion of the latter becoming visible in the course of century." ([299]) In a letter to myself, in July 1844, (I had sportively expressed some uneasiness at the idea of such a ghost-world of dark stars), he said, "I do, indeed, continue in the belief, that Procyon and Sirius are both true double stars, each consisting of one visible and one invisible star. There is no *à priori* reason for regarding luminosity as an essential property of bodies. The countless host of visible stars clearly proves nothing against the possible existence of an equally countless host of invisible stars. The physical difficulty of a variation in the proper motion, is satisfactorily met by the hypothesis of dark stars. The simple supposition cannot be blamed, that an alteration of velocity only takes place in obedience to a force, and that forces act according to the Newtonian laws."

A year after Bessel's death, Fuss, at Struve's instance, renewed the investigation of the anomalies of Procyon and Sirius, partly by new observations with Ertel's Meridian Telescope at Pulkova, and partly by reductions and comparison with earlier observations. Struve and Fuss ([300]) consider the result to be against Bessel's opinion. On the other hand, a laborious inquiry, just completed by Peters at Königsberg, and a similar one by Schubert, the calculator employed on the North American Nautical Almanac, support Bessel.

The belief in the existence of non-luminous stars was already prevalent in Grecian antiquity, and especially in the early times of Christianity. It was assumed that "among the fiery stars which are nourished by vapours, there move other earthy bodies which remain invisible to us." ([301]) The entire extinction of new stars, particularly of those in Cassiopeia and Ophiuchus, so carefully observed by Tycho Brahe and Kepler, appeared to afford a firmer support to this notion. As it was then supposed that the first-named of these two stars had already shone forth twice before, at intervals of about 300 years, the idea of annihilation or complete dissolution was not likely to find acceptance. The illustrious author of the "Mécanique Céleste" founds his persuasion of the existence of non-luminous masses in the Universe on the same phenomena of 1572 and 1604. "Ces astres devenus invisibles après avoir surpassé l'éclat de Jupiter même, n'ont point changé de place durant leur apparition." (Only the luminous process in them has ceased.) "Il existe donc dans l'espace celeste des corps opaques aussi considerables et peut-être en aussi grands nombres que les étoiles". ([302]) So also Mädler, in his "Untersuchungen über die Fixstern-Systeme" ([303]) says, "A dark body might be a central body; it might, like our sun, be only surrounded in its immediate vicinity by dark bodies such as are our planets. The movements of Procyon and Sirius pointed out by Bessel constrain (?) the assumption that there are cases in which luminous bodies are satellites to dark masses." I have already noticed that some adherents of the emanation-theory of light supposed such masses to be light-radiating, though at the same time invisible from being of such enormous dimensions that the rays of light sent forth (luminous molecules) are so held back by the force of attraction, that they cannot pass beyond a certain limit. ([304]) If, as may well be assumed, there are dark invisible bodies in space in which the process of light-producing undulations does not take place, they must either not fall within the circumference of our planetary and cometary system, or they must be of very small mass, since their presence does not manifest itself by any perceptible perturbations.

The investigation of the motion of the fixed stars in amount and direction (meaning thereby both their true proper motion, and the merely apparent motion due to the change in the observer's place caused by the earth's motion in her orbit),—the determination of the distance of the fixed stars from the Sun by investigations of their parallax,—and conjectures as to the part of space towards which our planetary system is moving;—are three problems in Astronomy which, in respect to the means of observation which have been successfully employed in their partial solution, are nearly allied to each other. Every improvement, either of instruments or of methods, applied to the advancement of one of these difficult and complicated inquiries, has been productive of benefit to the others. I prefer commencing with the parallaxes, and with the determination of the distances of some of the fixed stars, in order to complete the account of the present state of our knowledge in reference to single fixed stars.

As early as the beginning of the 17th century, Galileo put forward the idea of "measuring the, doubtless very unequal, distances of the fixed stars from the solar system"; and even with great acuteness, proposed the means of finding the parallax, not by the determination of the distance of a star from the zenith or the pole, but "by the careful comparison of one star with another very near to it." Although expressed in very general terms, this is the micrometric method subsequently employed by William Herschel (1781), Struve and Bessel. "Perchè io non credo," said Galileo ([305]) in his third discourse (Giornata terza), "che tutte le stelle siano sparse in una sferica superficie *egualmente distanti da un centro;* ma stimo, che le loro lontananze da noi siano talmente varie, che alcune ve ne possano esser 2 e 3 volte più remote di alcune altre; talchè quando si trovasse col Telescopio *qualche picciolissima stella vicinissima ad alcuna delle maggiori,* e che però quella fusse altissima, *potrebbe accadere, che qualche sensibile mutazione succedesse tra di loro.*" The promulgation of the Copernican system carried with it the grounds for requiring the numerical assignment by measurement of the change of direction, which the half-yearly change of place of the Earth, in her orbit round the Sun, must produce in the apparent position of the fixed stars. But as the angular determinations of Tycho Brahe, so happily employed by Kepler, (although, as I have already said, they might be considered certain to one minute of arc), still did not shew any such change arising from parallax, the Copernicans long satisfied themselves by replying to such requirements, that the diameter of the Earth's orbit, ($41\frac{1}{3}$ German, $165\frac{1}{3}$ English millions of geographical miles), was too small in proportion to the exceedingly great distance of the fixed stars.

The hope of being able to discover by observation the existence of parallax, must therefore have been seen to be dependent on the improvement of optical and measuring instruments, and on the possibility of determining very small angles with certainty. So long as such certainty was only equal to one minute, the non-detection of parallax only proved that the fixed stars must be more distant than 3438 semi-diameters of the Earth's orbit. ([306]) Certainty to a second in the observations of the great Astronomer, James Bradley, raised this lower limit to 206265 semi-diameters; and in the brilliant epoch of the Fraunhofer instruments, it was raised, by the direct measurement of nearly the tenth part of a second of arc, to 2062648 semi-diameters of the Earth's orbit. The efforts, and ingeniously devised Zenith apparatus, of Newton's great cotemporary, Robert Hooke, in 1669, did not conduct to the desired aim. Picard, Horrebow who worked out Römer's rescued observations, and Flamsteed thought they had found parallaxes of several seconds, because they confounded the proper motions of the Stars with the effects of parallax. On the other hand, the sagacious John Michell (Phil. Trans. 1767, Vol. lvii. pp. 234-264), was of opinion that the parallaxes of the nearest fixed stars must be less than 0″·02, and therefore "could only be recognised by a magnifying power of 12000." From the very prevalent idea that the superior brightness of a star must always indicate its greater proximity, stars of the first magnitude, Vega, Aldebaran, Sirius, and Procyon, were first studied, and were the subjects of the unsuccessful observations of Calandrelli, and of the meritorious Piazzi. (1805) To these observations, we must add those which were published (1815) in Dublin by Brinkley, and which, ten years later, were refuted by Pond, and especially by Airy. A sure and satisfactory knowledge of parallaxes, founded on micrometric measurements, only commenced between the years 1832 and 1838.

Although Peters, [307] in his important work on the distances of fixed stars (1846), gives the number of cases of parallax already discovered at 33, I will content myself with citing nine, which deserve, though in very unequal degrees, the greatest amount of confidence, giving them nearly in the order of time of their determinations.

The first place belongs to the Star 61 Cygni, which Bessel has rendered so celebrated. As early as 1812, the Königsberg astronomer determined the large proper motion of this double star (below the sixth magnitude); but it was only in 1838, that he ascertained its parallax by the employment of the heliometer. My friends Arago and Mathieu made a series of numerous observations, from August 1812 to November 1813, for ascertaining the parallax of 61 Cygni by measuring its Zenith distance. They arrived at the very just conjecture, that the parallax of the Star must be less than half a second.[308] As late as 1815 and 1816, Bessel, as he himself expresses it, "had not arrived at any admissible result." [309] Observations from August 1837 to October 1838, in which he availed himself of the large heliometer established in 1829, first led him to infer a parallax of 0″·3483, corresponding to a distance of 592200 semi-diameters of the Earth's orbit, and to a passage of light of 9¼ years. Peters, in 1842, confirmed this result, by finding 0″·3490; subsequently, however, Bessel's result was converted by a temperature correction into 0″·3744. [310]

The parallax of the finest double Star in the Southern Heavens, *α* Centauri, has been determined by observations at the Cape of Good Hope, by Henderson in 1832, and by

Maclear in 1839, at $0''\cdot9128$. ([311]) This would make it the nearest of all the fixed Stars whose parallaxes have yet been measured, and three times nearer than 61 Cygni.

The parallax of *a* Lyræ, has long been the subject of Struve's observations. The earlier observations (1836) gave ([312]) between $0''\cdot07$ and $0''\cdot18$; later ones gave $0''\cdot2613$, and a distance of 771400 semi-diameters of the Earth's orbit, with a light passage of 12 years; ([313]) but Peters has found the distance of this bright Star still greater, since he gives its parallax at only $0''\cdot103$. This result contrasts with another Star of the first magnitude (*a* Centauri), and with a Star of the sixth magnitude (61 Cygni).

The parallax of Polaris was determined by Peters, by many comparisons made in the years 1818—1838, at $0''\cdot106$, and the more satisfactorily as the same comparisons give the aberration $20''\cdot455$. ([314])

The parallax of Arcturus is, according to Peters, $0''\cdot127$ (Rumker's earlier observations with the Hamburgh Meridian Circle had given it much larger). The parallax of another star of the 1st magnitude, Capella, is still less, being, according to Peters, $0''\cdot046$.

The Star 1830 of Groombridge's Catalogue, which, according to Argelander, has shown the greatest proper motion of any star yet observed, has a parallax of $0''\cdot226$, as inferred from 48 very exactly observed Zenith distances by Peters in 1842 and 1843. Faye had believed it to be 5 times greater, viz., $1''\cdot08$, or more considerable than the parallax of *a* Centauri. ([315])

The following table contains the parallaxes of the nine stars which deserve the greatest amount of confidence, with the names of the observers, and the probable errors of the determinations.

Fixed Stars.	Parallaxes.	Probable Errors.	Names of Observers.
α Centauri	0″·913	0″.070	Henderson & Maclear.
61 Cygni...............	0″.3744	0″·020	Bessel.
Sirius	0″·230	......	Henderson.
1830 Groombridge ...	0″·226	0″·141	Peters.
ι Ursæ maj............	0″·133	0″·106	Peters.
Arcturus	0″·127	0″·073	Peters.
α Lyræ	0″·207	0″·038	Peters.
Polaris	0″·106	0″·012	Peters.
Capella	0″·046	0″·200	Peters.

The results hitherto obtained by no means show generally that the brightest stars are also the nearest. Although the parallax of *α* Centauri is indeed the largest hitherto known, yet, on the other hand, *α* Lyræ, Arcturus, and especially Capella, have parallaxes from 3 to 8 times less than a star of the 6th magnitude in Cygnus. It is also to be remarked that the two stars which, next to 2151 Puppis and ε Indi, show the most rapid proper motion, *i. e.,* the Star in Cygnus which has just been named (having an annual motion of 5″·123), and No. 1830 of Groombridge, called in France Argelander's Star (annual motion 6″·974), are, the one 3, and the other 4 times as far from the Sun as *a* Centauri, which has a proper motion of 3″·58. Volume, mass, intensity of light, proper motion ([316]), and distance from our solar system, are certainly in very various and complicated relations to each other. Although, therefore, it may be generally probable that the brightest stars are the nearest, yet there may be individual cases of very remote small stars whose photospheres and surfaces may, from the nature of their physical constitution, support a very intense luminous process. Stars, which on account of their brightness we reckon as belonging to the 1st magnitude, may thus be really more distant from us than stars which we call of the 4th, 5th, or 6th magnitudes. If we descend from the consideration of the great sidereal stratum, of which our solar system is a part, to the subordinate particular system of our planetary world, and step by step, still lower, to the systems of Jupiter and Saturn with their respective satellites, we see central bodies surrounded by masses in which the succession of magnitudes and of intensities of reflected light does not appear to depend at all on distance. The immediate connection subsisting between our direct knowledge, still so slight, of the parallaxes of stars, and our knowledge of the entire structural form of the universe, gives a peculiar interest and charm to considerations which relate to the distance of the fixed stars.

Human ingenuity has devised for this class of investigations a method quite different from those usually employed; it is founded on the velocity of light, and deserves to be briefly noticed in this place. Savary, of whom the physical sciences have been too early deprived, has shown how, in double stars, the aberration of light may be used for determining the parallax. If the plane of the orbit, which the secondary star describes round the central body, is not perpendicular to the line of sight from the earth to the double star, but, on the contrary, nearly coincides with it, then the course of the secondary star will appear to be in a right line, and the points on the half of its orbit which is turned towards the earth will all be nearer the observer, than the corresponding points of the other half which is turned from the earth. Such a division into two halves produces, not a really, but to the observer an apparently, unequal velocity according as the smaller star is approaching or receding from him. If, then, the semi-diameter of the orbit is so large that light requires several days or weeks to traverse it, then the time of the semi-revolution on the farther side will be greater than on the side turned towards the observer. The sum of the two unequal numbers which express the duration of the two semi-revolutions, is still equal to the true period of entire revolution, since the inequalities occasioned by the cause referred to mutually destroy each other. In Savary's ingenious method, by converting days and parts of days into a standard of length (light traverses 14356 millions of geographical miles in 24 hours), it is possible to deduce from these ratios of duration the absolute magnitude of the semi-diameter of the orbit, and by the simple determination of the angle under which the semi-diameter presents itself to the observer, the *distance* of the central body and its parallax. ([317])

As the determination of the parallaxes informs us concerning the distances of a small number of fixed stars and the position in space to be assigned to them, so the knowledge of the measure and direction of their proper motion (*i. e.* of the changes experienced by the relative positions of self-luminous bodies) conducts us to two problems dependent on each other; viz., the motion of our solar system, ([318]) and the situation of the centre of gravity of the whole heaven of the fixed stars. What can as yet only be reduced in so very incomplete a manner to numerical relations, must for that very reason be ill adapted for the clear manifestation of casual connection. Of the two last named problems, the first only has received a solution, in particular by Argelander's excellent investigation, which can be viewed as in some degree of a satisfactory definiteness; the second, in which so many opposing and mutually compensating forces are concerned, has been treated with great ingenuity by Mädler; but, according to that astronomer's own avowal, ([319]) the attempted solution is deficient in "all the evidences of a complete and scientifically adequate demonstration."

After carefully separating and deducting all that belongs to the precession of the equinoxes, the nutation of the earth's axis, the aberration of light, and the parallactic change occasioned by the earth's revolution round the Sun, the remaining annual motion of the fixed stars still includes both the effects of the *movement of translation of the entire solar system in space*, and those of the true proper motion of the fixed stars themselves. In Bradley's admirable investigation of nutation in his great work in 1748, we find the first expressed anticipation of the translation of the solar system, and also an indication of the method of observation most desirable to be pursued for its discovery. "If," says he, ([320]) "it should be found that our planetary system changes its situation in absolute space, there may thence arise, in course of time, an apparent variation in the angular distance of the fixed stars. Now, as in such case the position of the stars nearest to us would be more affected than that of the more distant ones, the position of these two classes of stars would appear altered relatively to each other, although in themselves they might all have remained unmoved. If, on the other hand, our solar system is in repose, and some stars actually move, then their apparent positions will also be altered; and this the more as the motions are more rapid, the stars in a favourable position, and the distance from the earth less. The alteration in their relative positions may be dependent on so great a number of causes that, perhaps, many centuries may be required before the laws can be discovered."

After Bradley, sometimes the mere possibility, and sometimes the greater or less probability of the movement in space of the solar system, were discussed in the writings of Tobias Mayer, Lambert, and Lalande; but William Herschel had first the merit of supporting the opinion by actual observation (1783, 1805, and 1806). He found, what many later and more exact investigations have confirmed and determined within narrower limits of uncertainty, that our solar system is moving towards a point near the constellation of Hercules in R.A. 260° 44′, and North Declination 26° 16′ (reduced to 1800). Argelander, by a comparison of 319 Stars, and taking into account Lundahl's investigations, found for the situation of this point, for 1800; R.A. 257° 54′·1; Decl. + 28° 49′·2; and for 1850; R.A. 258° 23′·5; Decl. + 28° 45′·6; and Otto Struve (from 392 Stars) found it for 1800, R.A. 261° 26′·9, Decl. + 37°

35′·5, and for 1850, R.A. 261° 52′·6 and Dec. 37° 33′·0. According to Gauss, [321] the place sought for is situated within a quadrangle whose angular points are in

R.A.	258° 40′	and Decl.	+ 30° 40′
„	258° 42′	„	30° 57′
„	259° 13′	„	31° 9′
„	260° 4′	„	30° 32′

It still remained to examine what result would be obtained by employing stars of the Southern Hemisphere, which never rise above the horizon in Europe. Galloway has devoted himself with great diligence to this research. He has compared very recent determinations (1830) by Johnson at St. Helena, and by Henderson at the Cape of Good Hope, with determinations of older date, (1750 and 1757) of Bradley and Lacaille. The result [322] has been, for 1790, R.A. 260° 0′, Decl. + 34° 23′, and therefore for 1800 R.A. 260° 5′, Decl. + 34° 22′; and for 1850, 260° 33′ and + 34° 20′. This agreement with the results obtained from Northern Stars is extremely satisfactory.

If, then, we may consider the direction of the progressive movement of our solar system to be determined within moderate limits, the questions very naturally arise,—Is the world of the fixed stars distributed into groups, each consisting only of neighbouring partial systems?—or must we imagine a general relation, *i.e.* that all self-luminous celestial bodies (suns) revolve around a common *centre of gravity, either occupied by a mass of matter, or void, i.e.* not so occupied? We are here entering on the domain of mere conjecture, to which a scientific form may indeed be given, but which, from the insufficiency of the data at our command, either as the results of observation or of analogy, are not capable of leading to such evidence as other parts of Astronomy enjoy.

One reason which especially opposes a thorough mathematical treatment of problems so difficult of solution, consists in our ignorance of the proper motion of a countless host of very small stars (10th to 14th magnitude), which appear scattered amongst brighter ones, and most abundantly in what is so important a part of our sidereal stratum, the rings of the Milky Way. The consideration of our planetary sphere, in which we ascend from the small partial systems of Jupiter, Saturn, and Uranus with their respective satellites, to the general solar system, easily led to the belief that the fixed stars might be imagined to be in an analogous manner divided into many single groups, which, though separated by wide intervals, might yet (in the higher relation of such groups to each other) be all subjected to the preponderating attracting force of a great central body, which might be regarded, as it were, as the one central *Sun* of the Universe. ([323]) But the series of consequences here alluded to as having been based on the analogy of our solar system, is opposed by the facts of observation as known to us up to the present time. In the "Multiple Stars," two or more self-luminous heavenly bodies or suns do not revolve around each other, but around a centre of gravity situated far outside of them. It is true that in our planetary system, something similar takes place, inasmuch as the planets revolve, not around the centre of the body of the solar orb itself, but around the centre of gravity of all the masses of the system. This common centre of gravity falls, according to the relative position of the larger planets, Jupiter and Saturn, sometimes within the corporeal circumference of the Sun, and sometimes (and this is the more frequent case) on the outside of that circumference. [324] Thus the centre of gravity, which in the double stars is void, is in the solar system sometimes void, and sometimes occupied by matter. All that has been said respecting the possibility of the assumption of a dark central body in the centre of gravity of the double stars, or of planets originally dark but faintly illuminated by foreign light revolving around them, belongs to the wide domain of mythical hypothesis.

It is a graver consideration, and one more deserving of a thorough examination, that, if we assume a movement of revolution, both for our own entire solar system, and for all the proper motions of the fixed stars situated at such widely different distances from us, the *centrum* of this revolving motion must be 90° from the point [325] towards which our solar system is moving. In reference to the combination of ideas which is here introduced, the situation of the stars, which have, on the one hand, a very considerable, or, on the other hand, a very slight proper motion, becomes of great moment. Argelander has cautiously, and with his own peculiar sagacity, tested the degree of probability with which, in our own sidereal stratum, a general centrum of attraction might be sought for in the sidereal constellation of Perseus. [326] Mädler, rejecting the hypothesis of a central body occupying the place of the general centre of gravity, and being itself of preponderating mass, seeks the centre of gravity in the group of the Pleiades, and in the middle of the group, in or near [327] the bright star η Tauri (Alcyone). This work is not the place for examining the degree of probability, on the one hand, or, on the other, the insufficiency of the foundation, [328] of this last supposition. With the distinguished and active director of the Observatory at Dorpat, rests the merit of having in his laborious investigation examined the position and proper motion of upwards of 800 fixed stars, and of having at the same time given activity to researches, which, if they do not conduct to a satisfactory resolution of the great problem itself, are yet suited to throw light on kindred subjects in physical astronomy.

VI.

MULTIPLE, OR DOUBLE STARS.—THEIR NUMBER AND DISTANCES APART.—PERIOD OF REVOLUTION OF TWO SUNS ROUND A COMMON CENTRE OF GRAVITY.

IF, in considerations on the subject of the fixed stars, we descend from conjectural, higher and more general relations, to such as are more special, we find ourselves on ground firmer and better adapted for direct observation. In *multiple stars,* to which class *binary* or *double stars* belong, several self-luminous cosmical bodies (Suns) are connected with each other by mutual attraction, and this attraction necessarily calls forth motion in re-entering curved lines. Previous to the recognition, by actual observation, of the revolutions of double stars, (329) our knowledge of the existence of motion in re-entering curved lines was limited entirely to our own planetary solar system. On this apparent analogy hasty inferences were based, which led aside from the true path. As the name of double-star was applied in all cases where proximity prevented separation by the unassisted eye (as in Castor, α Lyrae, β Orionis, and α Centauri), the term very naturally came to include two classes of multiple stars; those whose proximity might be occasioned solely by their accidental position in relation to the observer, while they might really be situated at very different distances, and might belong to altogether different sidereal strata,—and those which, being actually and truly near to each other, and being connected by mutual dependence or reciprocal attraction, form a particular system of their own. It is now the custom to call the first class *optically*, and the second *physically*, double stars. Very great distance and slowness of elliptic motion, may possibly cause several of the latter class to be confounded with the former. To cite here a well-known object, the small star Alcor, (which received much attention from Arabian astronomers, because visible to the naked eye in very clear atmosphere and to persons whose visual organs are very perfect,) forms, *in the widest sense of the term*, such an optical combination as has been spoken of, with ζ in the tail of the Great Bear. I have already noticed in Sections II. and III. the difficulty of separating with the unassisted eye adjacent stars of very unequal intensity of light,—the influence generally of such inequality of light,—the rays which appear to issue from stars,—and the organic defects which produce indistinctness of vision. (330)

Galileo, without making double stars a particular subject of his telescope observations, (for which, indeed, the magnifying powers employed by him would have been quite inadequate), yet in a celebrated passage of the Giornata terza of his Discourses, pointed out by Arago, mentions the use which astronomers might make of optically double stars (quando si trovasse nel telescopio qualche picciolissima stella, vicinissima ad alcuna delle maggiori), for discovering parallax in the fixed stars. (331) Until the middle of the last century, star-catalogues scarcely contained notices of as many as 20 double stars, exclusive of such as are more than 32″ apart; now, a hundred years later (thanks principally to the great labours of the two Herschels and Struve), there have been discovered in both hemispheres about 6000. Among the earliest described double stars, [332] are ζ Ursæ maj. (7th Sept. 1700, by Gottfried Kirch), α Centauri (1709, by Feuillée), γ Virginis (1718), α Geminorum (1719), 61 Cygni (1753, the distances and angles of direction were observed in this and the two preceding cases by Bradley), p Ophiuchi, and ζ Cancri. The number of double stars enumerated gradually augmented, from Flamsteed who employed a micrometer, to the Star Catalogue of Tobias Mayer, which appeared in 1756. Two men, sagacious in conjecture and apt in combination of thought, Lambert ("Photometria," 1760; and "Cosmological Letters on the Arrangement of the Structure of the Universe," 1761), and John Michell (1767), although they did not themselves observe double stars, were the first who promulgated just views respecting the relations of attraction of stars in partial binary systems. Lambert, like Kepler, ventured to suppose the distant suns (fixed stars), to be, like our own sun, surrounded by dark bodies, as planets and comets, but respecting fixed stars in near proximity to each other, (although he otherwise seems inclined to entertain the supposition also of dark central bodies), his belief was, [333] that they performed within a moderate time a revolution around their common centre of gravity. Michell, [334] who had no knowledge of Kant's and Lambert's ideas, was the first who, with much sagacity, applied the calculus of probabilities to close groups of stars, especially to multiple stars, binary and quaternary. He showed the probabilities to be 500,000 to 1 against the juxtaposition of the six principal stars in the Pleiades being accidental, and thence inferred that their grouping must rather be supposed to be founded on some peculiar relation existing between them. He felt so certain of the existence of luminous stars which move round each other, that he proposed to apply these partial star-systems to the ingenious solution of some astronomical problems. ([335])

The Manheim astronomer, Christian Mayer, has the great merit of having first (1778) made the double stars a special object of research by the sure path of actual observation. The name which he unfortunately selected of "fixed-star satellites," and the relations which he thought he recognised between stars $2\frac{1}{2}^\circ$ and $2^\circ\ 55'$ distant from Arcturus, exposed him to the bitter attacks of his cotemporaries, and among the number to the censure of the great and acute mathematician, Nicolaus Fuss. That dark bodies should become visible by reflected light at such enormous distances was indeed improbable. The results of observations carefully planned and executed were unfortunately disregarded, because the proposed systematic explanation of the phenomena was rejected; and yet, in a paper written in his own defence against Maximilian Hell, Director of the Imperial Astronomical Observatory at Vienna, Mayer had expressly said, "that the small stars which are so near large ones may be either planets dark in themselves, but illuminated by reflected light, *or,* that both bodies, *i. e.,* the principal star and its companion, may *both* be self-luminous suns revolving round each other." Long after Mayer's death, that which is important in his works has been gratefully and publicly acknowledged by Struve and Mädler. In his two Memoirs, entitled, "Vertheidigung neuer Beobachtungen von Fixstern-trabanten (1778), and Diss. de novis in Cœlo sidereo Phænomenis (1779)," 80 multiple stars observed by him are described, among which 67 are less than 32″ apart. The greater number were new discoveries of his own made with the excellent eight-feet telescope of the Manheim Mural quadrant; "some are still amongst the most difficult objects, and which can only be shown by powerful instruments; as ρ and 71 Herculis, ε Lyræ, and ω Piscium." Mayer, indeed (as, however, was still done long after his time), only measured distances in Right Ascension and Declination by his meridian instrument; and from his own observations, and those of earlier astronomers, showed changes of position, from the numerical values of which he erroneously did not deduct what (in particular cases) belonged to the proper motions of the stars ([336]).

These slight but memorable beginnings were followed by William Herschel's colossal work on multiple stars. It embraces a period of more than 25 years; for although the first table of Herschel's double stars was published 4 years after Mayer's Memoir on the same subject, yet Herschel's observations go back to 1779, or even, if we include his investigations on the trapezium in the great nebula in Orion, to 1776. Almost all that we now know relative to the several classes of double stars has its origin in Sir William Herschel's work. He not only gave in the catalogues of 1782, 1783, and 1804, the positions and angular distances apart of 846 double stars ([337]), the majority of which were discovered exclusively by himself; but what is much more important than the increase of number, he exercised his acute sagacity and true spirit of observation on all that relates to the paths, supposed periods of revolution, luminous intensity, contrast of colours, and classification according to the degree of distance apart, of the double stars. Imaginative, and yet always advancing with caution, he expressed himself, in the year 1794, when distinguishing between optically and physically double stars, in a brief and preliminary manner respecting the nature of the relation subsisting between the larger star and its smaller companion. Nine years afterwards, he first developed the entire connection and mutual dependence of the phenomena, in the 93rd volume of the Philosophical Transactions. The idea of partial star-systems, in which two or more suns revolve around a common centre of gravity, was now firmly established. The powerful dominion of attracting forces, which, in our solar system, extends to Neptune, at a mean solar distance 30 times greater than that of the Earth (or 2488 millions of geographical miles), and even constrained the great comet of 1680 to return when at a distance equal to 28 distances of Neptune, or 70,800 millions of geographical miles,—also, reveals itself in the motion of the double star 61 Cygni, which, in correspondence with a parallax of 0″·3744, is 18,240 distances of Neptune, or 550,900 semi-diameters of the Earth's orbit, or 11,394,000 German or 45,576,000 English millions of geographical miles from our sun. If, however, the causes and the general connection of the phenomena were very distinctly recognised by William Herschel, yet in the first ten years of the 19th century, the angles of position derived from his own observations, and from older star-catalogues employed without sufficient care, belonged to epochs too close together, to admit of the periods of revolution or the elements of the orbits being derived with due certainty from the several numerical values. Sir

John Herschel himself notices the very uncertain assignments of the periods of α Geminorum (334 years instead of according to Mädler, 520), [338]; of γ Virginius (708 years instead of 169); and of γ Leonis (1424 of Struve's great catalogue), a superb pair of stars, golden yellow and reddish-green (1200 years).

After William Herschel, the foundations of this important branch of astronomy were laid in a more thorough and special manner by Struve (Senior), 1813—1842, and Sir John Herschel, 1819—1838, with admirable activity and by the aid of highly improved instruments (more particularly in micrometric apparatus). Struve published his first Dorpat Table of double stars (796 in number) in 1820. This was followed in 1824 by a second, containing 3112 double stars down to the 9th magnitude at distances apart less than 32″, only about one-sixth of which had been previously seen. For the execution of this work, 120000 fixed stars had been examined in the great Fraunhofer refractor. Struve's third Table was published in 1837, and forms the important work entitled, "Stellarum Compositarum Mensuræ micrometricæ." [339] It contains, (several insecurely observed objects being carefully excluded,) 2787 multiple stars.

During Sir John Herschel's four years' residence at Feldhausen, at the Cape of Good Hope, a residence which constitutes an epoch in respect to the more exact topographical knowledge of the southern heavens, his perseverance enriched the department of astronomy which we are now considering by upwards of 2100 double stars, which, with a few exceptions, had never been observed before. [340] All these African observations were made with a twenty-feet reflector; they are reduced to 1830, and are arranged in 6 Catalogues, which contain 3346 double stars, and were presented by Sir John Herschel to the Royal Astronomical Society of London, for the 6th and 9th parts of their valuable memoirs. ([341]) In the European portion of these catalogues, there are included 380 double stars which were observed in 1825 by the above-named celebrated astronomer, conjointly with Sir James South.

We see by this historical account, how, in the course of half a century, science has gradually arrived at an extensive and accurate knowledge of partial, and more particularly of binary, star systems existing in space. The number of double stars (including those both optically and physically double) may now be estimated with some degree of security at 6000, including those observed by Bessel with the fine Fraunhofer heliometer, by Argelander ([342]) at Abo (1827—1835), by Encke and Galle at Berlin (1836 and 1839), by Preuss and Otto Struve at Pulkova (since the Catalogue of 1837), by Mädler at Dorpat, and by Mitchell at Cincinnati in Ohio with a 17 feet Munich Refractor. In how many of these cases the stars seen in close proximity in the telescope are really connected with each other by immediate relations of attraction, forming particular systems and revolving in closed orbits,—*i. e.* how many are what are called physically double stars,—is an important question, but one difficult to answer. More and more revolving companions are gradually being discovered. Extraordinary slowness of motion, or the circumstance of the direction of the plane of the orbit, as it presents itself to our eyes, being such that the position of the moving star is unfavourable for observation, may long cause *physically* double stars to be included by us among *optically* double stars in which the proximity is only apparent. But a distinctly recognised measurable motion, such as we have been speaking of, is not the only criterion; Argelander and Bessel have shown, in a considerable number of multiple stars, a perfectly equal proper motion in space (*i. e.* a *common* progressive movement, such as that of our own solar system, including, together with the Sun, all its planets and satellites), which testifies in favour of the principal stars and their companions being respectively connected with each other by a true and actual relation, forming separate partial systems. Mädler has made the interesting remark that,—whereas in 1836, among 2640 catalogued double stars, there were only 58 in which a difference of relative position had been observed with certainty, and 105 in which such a difference could be regarded as indicated with a greater or less degree of probability,—the proportion of physical to optical double stars is now so changed in favour of the first, that among 6000 multiple stars there are, according to a Table published in 1849, six hundred and fifty ([343]) in which an alteration of relative position can be demonstrated. The earlier ratio gave 1 in 16, the latter one already gives 1 in 9, for the proportion of cases in which the motions of the principal star and its companion show these celestial bodies to be physically double.

The relative distribution of binary star-systems, not only in the celestial spaces generally, but even simply on the apparent heavenly vault, has as yet been but little examined numerically. In the Northern Hemisphere, double stars are most frequent in the *direction* of certain constellations (Andromeda, Boötes, the Great Bear, the Lynx, and Orion).

In the Southern Hemisphere, we have from Sir John Herschel, the unexpected result that, "in the extra-tropical parts, the number of multiple stars is *much less* than in the corresponding parts of the Northern Hemisphere." And yet these fair southern regions were examined with an excellent 20-feet reflector, which separated stars of the 8th magnitude in distances of only three-fourths of a second apart, under the most favourable atmospheric conditions, and by a most practised observer. ([344])

An exceedingly remarkable peculiarity of multiple stars, consists in the occurrence among them of contrasted colours. Struve, in his great work published in 1837, gave the following results in respect to colours, derived from 600 of the brightest double stars. ([345]) In 375 cases, the colour of the principal star and the companion was the same, and equally intense. In 101, the colour was the same, but a difference of intensity was perceived. The cases of double or multiple stars having entirely different colours, were 120 in number, or one-fifth of the whole; whereas uniformity of colour between the principal stars and their companions, extended to four-fifths of the entire carefully examined mass. In almost half the 600 cases, both the principal star and the companion are white. Among those in which the colours are different, combinations of yellow and blue (as in ι Cancri), and of reddish-yellow and green (as in the ternary star γ Andromedæ), ([346]) are very frequent.

It was Arago who in 1825 first called attention to the circumstance, that in most, or at least in very many cases, the diversity of colour in binary systems appeared to have reference to *complementary* colours (*i. e.* to the subjective relation between colours, the union of which forms white). ([347])

It is a well-known optical phenomenon, that a faint white light appears green, when a strong (intense) red light is brought near to it; and that white light becomes blue, when the surrounding stronger light is yellowish. Arago, however, cautiously and justly remarked, that, although the green or the blue colour of the companion may sometimes be the result of contrast with the brighter star, yet that the actual existence of green or of blue stars is by no means to be denied. ([348]) He gives instances in which a bright white star (1527 Leonis, 1768 Can. ven.) is accompanied by a small blue star; cites a double star (δ Serp.), in which both the principal star and its companion are blue; ([349]) and proposes a mode of examining whether the contrasted colour is merely subjective, by covering the principal star in the telescope, when the distance permits, by a wire, or by a diaphragm. Usually it is the smallest star only which is blue; it is otherwise, however, in the double star 23 Orionis (696 of Struve's catalogue, p. lxxx), in which the principal star is bluish, and the companion pure white. If, in the multiple stars, the different coloured suns are often surrounded by planets invisible to us, such planets must be variously illuminated, having their white and blue, or their red and green days. ([350])

As we have already seen ([351]) in a preceding section, that the periodical variability is not necessarily associated with a red or reddish colour, so also neither is colour in general, nor a contrasted diversity of colour in the principal star and its companion in particular, a characteristic of double stars. Circumstances, which we find to be frequent, are not therefore general and necessary conditions of the phenomena, whether of the periodical variation of the light of stars, or of the revolution of sidereal bodies in partial systems round a common centre of gravity. A careful examination of the brighter double stars (colour is still determinable in stars of the 9th magnitude), teaches us that, besides pure white, all the colours of the solar spectrum are to be found in double stars; but that the principal star, when not white, generally approximates to the red extreme, namely, that of the least refrangible rays, and the companion to the violet extreme, or that of the most refrangible rays. The reddish stars are twice as frequent as the blue and bluish, and the white are about twice and a half as numerous as the red and reddish. It is also to be remarked, that usually a great difference of colour is combined with a considerable difference in the intensity of the light. In two pairs of stars, which, from their great brightness, can be easily measured in the daytime with powerful telescopes,—ζ Boötis and γ Leonis,—the first-named pair consists of two white stars of the 3rd and 4th magnitudes, and the latter of a principal star of the 2m., and a companion of the 3·5m. This last-named star (γ Leonis) is said to be the finest double star of the Northern Hemisphere, but α Centauri ([352]) and α Crucis, of the Southern Heavens, surpass all other double stars in brilliancy. As in ζ Boötis, so also in α Centauri and γ Virginis, we remark the rare combination of two large stars having but little inequality of light.

Respecting variability of brightness in multiple stars, and especially respecting variability in the companion, unanimity and certainty do not yet prevail. We have already spoken more than once ([353]) of the somewhat irregular variability of the brightness of the principal star of a yellowish-red colour, in α Herculis. Also the variation of brightness, observed by

Struve (1831-1833), in the nearly equally bright yellowish stars (3rd magnitude) of the double star γ Virginis and Anon. 2718, may perhaps indicate a very slow rotation around the axes of those two suns. ([354]) Whether any actual change of colour has ever taken place in double stars (γ Leonis and γ Delphini ?), whether white light ever becomes coloured in them,—as we know that inversely in Sirius, which is a single star, coloured light has become white,—is still undecided; ([355]) when the differences in question only have reference to faint shades of colour, organic individuality in the observers, and when refractors are not employed, the often reddening influence of the metallic speculum in telescopes, are to be taken into account.

Among the multiple stars, or systems, I may cite:—ternary; ξ Libræ, ζ Cancri, 12 Lyncis, 11 Monoceritis:—quaternary; 102 and 2681 of Struve's catalogue, α Andromedæ and ϵ Lyræ:—and a six-fold combination in θ Orionis, the celebrated trapezium in the great nebula in Orion, probably forming a single physical system united by laws of mutual attraction, since the five smaller stars (6·3m.; 7m.; 8m.; 11·3m.; and 12m.) follow the proper motion of the principal star (4·7m). As yet, however, no change in their relative positions has been observed. ([356]) In two ternary multiple stars, ξ Libræ and ζ Cancri, the movement of revolution of both companions has been recognised with great certainty; ζ Cancri consists of three stars differing but little in brightness, being all of the 3rd magnitude, and the nearer companion appears to have a ten times quicker motion than the more distant one.

The number of double stars, in which it has been possible to compute the elements of the orbits, is given at present as from 14 to 16. [357] Of these ζ Herculis, since its first discovery, has already twice completed its circuit of revolution; and in so doing has presented (in 1802 and 1831) the phenomenon of the apparent occultation of one fixed star by another. We are indebted for the earliest calculations of the orbits of double stars to the industry of Savary (in the case of ξ Ursæ majoris), Encke (70 Ophiuchi), and Sir John Herschel; and they have been since followed by Bessel, Struve, Mädler, Hind, Smyth, and Captain Jacob. Savary's and Encke's methods require four complete observations sufficiently distant from each other. The shortest periods of revolution yet known are of 30, 42, 58, and 77 years, intermediate, therefore, between those of the planets Saturn and Uranus; the longest periods yet determined with any degree of certainty exceed 500 years, or are about three times as long as that of Le Verrier's planet Neptune. According to the investigations hitherto made, the excentricity of the orbits of double stars appears to be extremely considerable, resembling that of comets; in the case of σ Coronæ it is 0·62, in that of α Centauri 0·95. The least excentric internal comet, that of Faye, has an excentricity of 0·55, or less than that of the orbits of the two double stars just named; excentricities much smaller are presented, according to Mädler's and Hind's calculations, by η Coronæ and Castor, being 0·29 in the former, and 0·22 or 0·24 in the latter. In these double stars, therefore, the suns describe ellipses, which approximate closely to those of two of the smaller planets of our solar system, as the orbit of Pallas has an excentricity of 0·24, and that of Juno 0·25.

If with Encke we regard the brighter of the two stars in a binary system as being in repose, and accordingly refer to it the motions of its companion, we find, from the observations hitherto made, that the companion describes round the principal star a conic section in the focus of which the latter is placed; or an ellipse in which the radius vector of the revolving body passes over equal areas in equal times. Exact measurements of angles of position and of distances, adapted for determinations of orbits, have already shewn, in the case of a considerable number of double stars, that the companion moves round the principal star considered as a body at rest, in obedience to the same gravitating forces which prevail in our solar system. This well-established conviction, gained within scarcely a quarter of a century, marks one of the great epochs in the history of the development of the higher cosmical knowledge. Celestial bodies, to which the name of fixed stars (assigned by ancient usage) is still given, although they are neither affixed to the heavenly vault nor motionless, have been seen to occult each other. The knowledge of the existence of partial systems, the several parts of which have motions referable to and dependent on each other, extends our views the more widely as those motions are again subordinated to more general ones.

The table on the next page contains the Elements of the orbits of six double stars, the determinations of which appear entitled to principal confidence.

Elements of the Orbits of Double Stars.

Name.	Semi Major Axis.	Eccentricity.	Period of Revolution in Years.	Computer.
1. ξ Ursæ Maj. ...	3″·857	0·4164	58·262	Savary, in 1830.
„	3″·278	0·3777	60·720	John Herschel, Table of 1849.
„	2″·295	0·4037	61·300	Mädler, 1847.
2. p Ophiuchi	4″·328	0·4300	73·862	Encke, 1832.
3. ζ Herculis	1″·208	0·4320	30·22	Mädler, 1847.
4. Castor	8″·086	0·7582	252·66	John Herschel, Table of 1849.
„	5″·692	0·2194	519·77	Mädler, 1847.
„	6″·300	0·2405	632·27	Hind, 1849.
5. γ Virginis	3″·580	0·8795	182·12	John Herschel, Table of 1849.
„	3″·863	0·8806	169·44	Mädler, 1847.
6. α Centauri	15″·500	0·9500	77·00	Captain Jacob, 1848.

NOTES.

(1) p. 4.—Kosmos, Bd. i. S. 56—59 and 141 (English edition, Vol. i. p. 50—53 and 126).

(2) p. 6.—Kosmos, Bd. i. S. 6—8; Bd. ii. S. 10—12 and 92 (English edition, Vol. i. p. 6—7; Vol. ii. p. 9—11 and 89).

(3) p. 6.—Kosmos, Bd. ii. S. 26—31 and 44—49 (English edition, Vol. ii. p. 24—30 and 43—48).

(4) p. 7.—Kosmos, Bd. i. S. 383—386; Bd. ii. S. 141—144 (English edition, Vol. i. p. 354—357; Vol. ii. p. 107).

(5) p. 7.—M. von Olfers, On the Remains of Animals of Gigantic Size belonging to the Ancient World, in connection with Legends of Eastern Asia, in the Abh. der Berl. Akad. 1839, S. 51. On the opinion of Empedocles respecting the cause of the destruction of the more ancient forms of animal life, vide Hegel's Geschichte der Philosophie, Bd. ii. S. 344.

(6) p. 7.—Respecting the world-tree, Ygdrasil, and the raging fountain, Hvergelmir, see Jacob Grimm's Deutsche Mythologie, 1844, S. 530 and 756; and Mallet's Northern Antiquities, 1847, p. 410, 489, and 492.

(7) p. 9.—Kosmos, Bd. i. S. 30—33 and 62—70 (English edition, p. 30—33 and 56—64).

(8) p. 10.—Kosmos, Bd. ii. S. 484 (English edition, p. 285 and xciv.)

(9) p. 10.—In the introductory Contemplations in the first volume of Cosmos (p. 33), it should not have been said generally and without exception that "the discovery of laws, and their progressive generalisation, are the objects of the experimental sciences:" a more limited sense should have been given by the introduction of the words "in many groups of phænomena." The manner in which I expressed myself in the second volume respecting the

relation subsisting between the achievements of Newton and Kepler, must, I think, show without doubt that I do not confound together the discovery of natural laws, and the interpretation, *i. e.* the explanation, of phænomena. I say of Kepler (p. 310)—"The rich supply of exact observations which were furnished by Tycho Brahe, laid the foundation of the discovery of those unchanging laws of the planetary movements which prepared for Kepler imperishable fame, and which, when *interpreted* by Newton, and shown by him to be *theoretically necessary*, were transferred to the bright domain of thought, and became the *intelligent recognition of Nature*;"—of Newton (p. 351)—"We terminate with the figure of the Earth as then recognised from theoretical considerations. Newton attained to the explanation of the system of the Universe, because he succeeded in discovering the Force of whose operation the Keplerian laws are the necessary consequences." See on this subject the excellent remarks "On Laws and Causes," contained in Sir John Herschel's Address at the Fifteenth Meeting of the British Association, held at Cambridge, 1845, p. xlii.; and the Edinburgh Review, Vol. lxxxvii. 1848, p. 180—183.

(⁰) p. 11.—In the remarkable passage in which Aristotle (Metaph. xii. 8, p. 1074, Bekker) speaks of the "fragments of an early knowledge once discovered and subsequently lost," there occurs a passage of much import, indicating freedom from the Deification of natural forces or powers, personified under the forms of various divinities resembling human beings: he says—"Much has been added mythically for the sake of persuading the multitude, as well as for the support of the laws and other useful objects."

([11]) p. 11.—The important difference between these directions, τρόποι, in Natural Philosophy, is clearly indicated in Aristot. Phys. Auscult. i. 4, p. 187, Bekker. Comp. Brandis, in the Rhein. Museum für Philologie, Jahr. iii. S. 105.

([12]) p. 12.—Kosmos, Bd. i. S. 139 and 405, Note 59; Bd. ii. S. 348 and 501, Note 27 (English edition, Vol. i. p. 124, and Note 89; Vol. ii. p. 308, and Note 467). A remarkable passage of Simplicius (p. 491) opposes in the clearest manner the centripetal force to the centrifugal force: it speaks of "the heavenly bodies not falling where the centrifugal force preponderate over the proper falling force—that which draws them downwards." On the same account, in Plutarch de Facie in Orbe Lunæ, p. 923, the moon is compared, in respect to its not falling towards the Earth, to "the stone in the sling." Respecting the proper signification of the περιχώρησις of Anaxagoras, vide Schaubach, in Anaxag. Clazom. Fragm. 1827, p. 107—109.

(13) p. 12.—Schaubach, in Anaxag. Clazom. Fragm. p. 151—156 and 185—189. Plants were also supposed to be animated by the νοῦς, or mind (Aristot. de Plant. i. 1, p. 1815, Bekk.)

(14) p. 13.—On this part of the mathematical physics of Plato, compare Böckh de Platonico Syst. cœlestium globorum, 1810 et 1811; Martin, Etudes sur le Timée, T. ii. p. 234—242; and Brandis, in the Geschichte der Griechisch-Römischen Philosophie, Th. ii. Abth. i. 1844, S. 375.

(15) p. 13.—Kosmos, Bd. ii. S. 520, Note 4 (English edition, Vol. ii. Note 544). Compare Gruppe über die Fragmente des Archytas, 1840, S. 33.

(16) p. 13.—Aristot. Polit. vii. 4, p. 1326; and Metaph. xii. 7, p. 1072, 10, Bekk., and xii. 10, p. 1074, 5. The pseudo-Aristotelian book, De Mundo, which Osann ascribes to Chrysippus (Kosmos, Bd. ii. S. 14 and 106), contains also (cap. 6, p. 307) a very eloquent passage on the "Orderer and Upholder of the Universe."

(17) p. 13.—The passages which prove this are collected in Ritter's Gesch. der Philosophie, Th. iii. S. 185—191.

(18) p. 14.—Compare Aristot. de Anima, ii. p. 419. The analogy with sound is most clearly expressed in this passage; but in other parts of his writings Aristotle modified his theory of vision in various ways. Thus he says, in De Insomniis, cap. ii. p. 459, Bekker—"It is evident that vision is active as well as passive,—that the sight not only suffers, or receives as a passive recipient, something from the air (the medium of vision), but that it also acts upon the medium." He alleges as proof that, "under particular circumstances, a new and very pure metallic mirror, being looked upon by a woman, has its surface dimmed by clouded spots difficult to efface." (Compare therewith Martin, Etudes sur le Timée de Platon, T. ii. p. 159—163.)

(19) p. 14.—Aristot. de Partibus Anim., Lib. iv. cap. 5, p. 681, lin. 12, Bekker.

(20) p. 14.—Aristot. Hist. Anim., Lib. ix. cap. 1, p. 588, lin. 10—24, Bekker. "If in the animal kingdom some of the representatives of the four elements,—those, for instance, corresponding to the element of the purest fire,—are wanting upon our Earth, these intermediate steps may perhaps be present in the moon." (Biese, Die Phil. des Aristoteles, Bd. ii. S. 186). The Stagirite sought in another celestial body absent links in the chain: we find such missing intermediate gradations among ancient terrestrial forms of plants and animals which have perished.

(21) p. 14.—Aristot. Metaph. lib. xiii. cap. 3, p. 1090, lin. 20, Bekker.

(22) p. 15.—The ἀντιπερίστασις of Aristotle especially plays a great part

in all explanations of meteorological processes, as in the works—De generatione et interitu, Lib. ii. cap. 3, p. 330; Meteorologicis, Lib. i. cap. 12, and Lib. iii. cap. 3, p. 372; and in the Problems (Lib. xiv. cap. 3, Lib. viii. No. 9, p. 888, and Lib. xiv. No. 3, p. 909), which are at least drawn up according to Aristotelian principles. In the ancient hypothesis of polarity, *κατ' ἀντιπερίστασιν*, similar conditions attract each other, and dissimilar conditions (+ and −) repel each other (compare Ideler, Meteorol. veterum Græc. et Rom. 1832, p. 10). "Opposite conditions, instead of neutralising tension by their combination, on the contrary increase it. The *ψυχρὸν* heightens the *θερμόν*; so also, inversely, in the formation of hail, while the cloud sinks into warmer strata of air, the surrounding warmth makes the cold body still colder." Aristotle explains by his antiperistatic process, by polarity of heat, what modern physical science explains by conduction, radiation, evaporation, and change of capacity for heat. See ingenious considerations by Paul Erman, in the Abhandl. der Berliner Akademie auf das J. 1825, S. 128.

(23) p. 15.—"All variation in natural bodies, all terrestrial phænomena, are called forth by the motion of the celestial sphere."—Aristot. Meteor. i. 2, p. 339; and De gener. et corrupt. ii. 10, p. 336.

(24) p. 15.—Aristot. de Cœlo, Lib. i. cap. 9, p. 279; Lib. ii. cap. 3, p. 286; Lib. ii. cap. 13, p. 292, Bekker. (Compare Biese, Bd. i. S. 352—357.)

(25) p. 15.—Aristot. phys. Auscult. Lib. ii. cap. 8, p. 199; De Anima, Lib. iii. cap. 12, p. 434; De Animal. generat. Lib. v. cap. 1, p. 778, Bekker.

(26) p. 16.—Aristot. Meteor. xii. 8, p. 1074; of which passage a remarkable elucidation is contained in the Commentary of Alexander Aphrodisiensis. The heavenly bodies are not soul-less matter, they are rather to be regarded as acting and living beings (Aristot. de Cœlo, Lib. ii. cap. 12, p. 292). They are the divinest of phenomena, *τὰ θειότερα τῶν φανερῶν* (Aristot. de Cœlo, Lib. i. cap. 9, p. 278; and Lib. ii. cap. 1, p. 284). In the little pseudo-Aristotelian writing, De Mundo, in which a religious tone (respecting the preserving omnipotence of God, cap. 6, p. 400) is often seen to prevail, the upper æther is also termed divine (cap. 2, p. 392). What Kepler, in the Mysterium cosmographicum (cap. 20, p. 71), fancifully terms "moving spirits"—"animæ motrices"—is the confused idea of a force (virtus) which has its principal seat in the sun (anima mundi), diminishes by distance according to the laws of light, and impels the planets in their elliptic paths. Comp. Apelt, Epochen der Gesch. der Menscheit (Epochs in the History of Mankind), Bd. i. S. 274.

([27]) p. 16.—Kosmos, Bd. ii. S. 280—291 (English edition, Vol. ii. p. 243—254).

([28]) p. 17.—See the ingenious and learned account of the writings of the philosopher of Nola, in the work entitled—Jordano Bruno, par Christian Bartholmèss, T. ii. 1847, p. 129, 149, and 201.

([29]) p. 17.—He was burnt at Rome on the 17th of February, 1600, according to the sentence—"ut quam clementissime et citra sanguinis effusionem puniretur." Bruno was a prisoner six years under the leads at Venice, and two years in the inquisition at Rome. Undaunted and unbroken in spirit when the sentence of death was announced to him, he replied—"Majori forsitan cum timore sententiam in me fertis quam ego accipiam." When a fugitive from Italy (in 1580), he taught in Geneva, Lyons, Toulouse, Paris, Oxford, Marburg, Wittenberg (which he called the Athens of Germany), Prague, Helmstedt, where in 1589 he completed the scientific education of Duke Henry Julius, of Brunswick-Wolfenbüttel (Bartholmèss, T. i. p. 167—178), and from 1592 in Padua.

([30]) p. 18.—Bartholmèss, T. ii. pp. 219, 232, and 370. Bruno collected with care the several observations respecting the great cosmical event (1572) of the sudden shining forth of a new star in Cassiopeia. The relations of his natural philosophy to that of two of his Calabrian countrymen—Bernardino Telesio and Thomas Campanella, and to the platonising Cardinal Nicolaus Krebs of Cusa (vide Kosmos, Bd. ii. S. 503; English edition, Vol. ii. p. 109),—have been much examined in modern times.

([31]) p. 18.—"Si duo lapides in aliquo loco mundi collocarentur propinqui invicem, extra orbem virtutis tertii cognati corporis; illi lapides ad similitudinem duorum magneticorum corporum coirent loco intermedio, quilibet accedens ad alterum tanto intervallo, quanta est alterius *moles* in comparatione. Si Luna et Terra non retinerentur vi animali (!) aut alia aliqua æquipollente, quælibet in suo circuitu, Terra adscenderet ad Lunam quinquagesima quarta parte intervalli, Luna descenderet ad Terram quinquaginta tribus circiter partibus intervalli; ibi jungerentur, posito tamen quod substantia utriusque sit unius et ejusdem densitatis." Kepler, Astronomia nova seu Physica cœlestis de Motibus Stellæ Martis, 1609, Introd. fol. v. On the older views of gravitation, see Kosmos, Bd. ii. S. 348, 501, and 502 (English edition, Vol. ii. pp. 308, cvii. and cviii.

([32]) p. 18.—"Si Terra cessaret attrahere ad se aquas suas, aquæ marinæ omnes elevarentur et in corpus Lunæ influerent. Orbis virtutis tractoriæ, quæ est in Luna, porrigitur usque ad terras, et prolectat aquas quacunque in verticem loci incidit sub zonam torridam, quippe in occursum suum quacunque in verticem loci incidit, insensibiliter in maribus inclusis, sensibiliter ibi ubi sunt latissimi alvei oceani propinqui, aquisque spaciosa reciprocationis libertas" (Kepler, l. c.) "Undas a Luna trahi ut ferrum a magnete......" Kepleri Harmonices Mundi libri quinque, 1619, lib. iv. cap. 7, p. 162. This same work, which contains so much that is admirable, and even the basis of the important "third law" (according to which the squares of the periods of revolution of two planets are to each other as the cubes of the mean distances), is disfigured by the wildest fancies: respiration, nutrition, and vital heat of the Earth as an animal; on a soul possessed by this animal; its memory (memoria animæ Terræ); and even its imaginative powers (animæ Telluris imaginatio). Kepler was so much attached to these reveries that he even had a serious dispute with the mystic author of the Macrocosmos—Robert Fludd, of Oxford,—(said to have had a share in the invention of the thermometer)—respecting the right of priority in these views of the Earth as a living creature (Harm. Mundi, p. 252). The attraction of mass is often confounded in Kepler's writings with magnetic attraction. "Corpus Solis esse magneticum. Virtutem, quæ planetas movet, residere in corpore Solis," (Stella Martis, Pars iii. cap. 32 and 34). He gives to every planet a magnetic axis, which is always directed to the same quarter of the heavens (Apelt, Joh. Keppler's astron. Weltansicht, 1849, S. 73).

(33) p. 19.—Comp. Kosmos, Bd. ii. S. 364 and 512, Note 55 (English edition, Vol. ii. p. 323, and Note 495).

(34) p. 19.—La Vie de M. Des-Cartes (par Baillet), 1691, P. i. p. 197; and Œuvres de Descartes publiées par Victor Cousin, T. i. 1824, p. 101.

(35) p. 20.—Lettres de Descartes au P. Mersenne du 19 Nov. 1633 et du 5 Janvier 1634 (Baillet, P. i. p. 244—247).

(36) p. 20.—The Latin translation is entitled, Mundus, sive Dissertatio de Lumine ut et de aliis Sensuum Objectis primariis. See R. Descartes, Opuscula posthuma physica et mathematica, Amst. 1704.

(37) p. 21.—"Lunam aquis carere et aëre: marium similitudinem in Luna nullam reperio. Nam regiones planas quæ montosis multo obscuriores sunt, quasque vulgo pro maribus haberi video et oceanorum nominibus insigniri, in his ipsis, longiore telescopio inspectis, cavitates exiguas inesse comperio rotundas, umbris intus cadentibus; quod maris superficiei convenire nequit tum ipsi campi illi latiores non prorsus æquabilem superficiem præferunt, cum diligentius eas intuemur. Quodcirca maria esse non possunt, sed materia constare debent minus candicante, quam quæ est partibus asperioribus, in

quibus rursus quædam viridiori lumine cæteras præcellunt" (Hugeni Cosmotheoros, ed. alt. 1699, Lib. ii. p. 114). Huygens supposes, however, that there is much storm and rain in Jupiter, for "ventorum flatus ex illa nubium Jovialium mutabili facie cognoscitur" (Lib. i. p. 69). The reveries of Huygens respecting the inhabitants of the distant planets, which were not worthy of a severe mathematician, have been renewed unfortunately by Immanuel Kant in his excellent work, Allgemeine Naturgeschichte und Theorie des Himmels, 1755 (S. 173—192).

(38) p. 21.—Laplace, (des Oscillations de l'Atmosphère, du Flux solaire et lunaire,) in the Mécanique céleste, Livre iv.; and in the Exposition du Syst. du Monde, 1824, p. 291—296.

(39) p. 21.—"Adjicere jam licet de spiritu quodam subtilissimo corpora crassa pervadente et in iisdem latente, cujus vi et actionibus particulæ corporum ad *minimas distantias* se mutuo *attrahunt* et contiguæ factæ cohærent" (Newton, Principia Phil. nat. ed. Le Seur et Jacquier, 1760; Schol. gén. T. iii. p. 676). Compare also Newton, Opticks (ed. 1718), Query 31, p. 305, 353, 367, and 372. (Laplace, Syst. du Monde, p. 384; Kosmos, Bd. i. S. 56 and 74 (English edit. Vol. i. pp. 50 and x. Note 22).

(40) p. 22.—"Hactenus phænomena cœlorum et maris nostri per vim gravitatis exposui, sed causam gravitatis nondum assignavi. Oritur utique hæc vis a causa aliqua, quæ penetrat ad usque centra solis et planetarum, sine virtutis diminutione; quæque agit non pro quantitate superficierum particularum, in quas agit (ut solent causæ mechanicæ), sed pro quantitate materiæ solidæ.—Rationem harum gravitatis proprietatum ex phænomenis nondum potui deducere et hypotheses non fingo. Satis est quod gravitas revera existat et agat secundum leges a nobis expositas" (Newton, Principia Phil. Nat. p. 676). "To tell us that every species of things is endowed with an occult specifick quality, by which it acts and produces manifest effects, is to tell us nothing; but to derive two or three general principles of motion from phænomena, and afterwards to tell us how the properties and actions of all corporeal things follow from those manifest principles, would be a very great step in philosophy, though the causes of those principles were not yet discovered, and therefore I scruple not to propose the principles of motion, and leave their causes to be found out" (Newton, Opticks, p. 377). In an earlier place (Query 31, p. 351) it is said—"Bodies act one upon another by the attraction of gravity, magnetism, and electricity; and it is not improbable that there may be more attractive powers than these. How these attractions may be performed, I do not here consider. What I call

attraction, may be performed by *impulse*, or by some other means unknown to me. I use that word here to signify any force by which bodies tend towards one another, whatsoever be the cause."

([41]) p. 22.—"I suppose the rarer æther within bodies, and the denser without them." Operum Newtoni, Tomus iv. (ed. 1782, Sam. Horsley), p. 386; with application to the explanation of diffraction or bending of light discovered by Grimaldi. At the conclusion of Newton's letter to Robert Boyle, written in February 1678, p. 394, he says, "I shall set down one conjecture more which came into my mind: it is about the cause of gravity." Newton's correspondence with Oldenburg, in December 1675, also shows that he was not, at that period, disinclined to the hypothesis of an æther. According to it the impulse of material light would put the æther in vibration; the vibrations of the æther, which is akin to a nervous fluid, not by themselves producing light. See, respecting the controversy with Hook, Horsley, T. iv. p. 378—380.

([42]) p. 22.—Brewster, Life of Sir Isaac Newton, p. 303—305.

([43]) p. 23.—The precautionary explanation, "not to take gravity for an essential property of matter," given by Newton in the "Second Advertisement," contrasts with the forces of attraction and repulsion which he attributes to all molecules, in order to explain, in a manner accordant with the theory of emission, the phænomena of refraction and reflection of rays of light from mirror surfaces "before actual contact." (Newton, Opticks, Book ii. Prop. 8, p. 241; and Brewster's Life of Newton, p. 301.) According to Kant (Die metaphysischen Anfangsgründe der Naturwissenschaft, 1800, S. 28), the existence of matter, without these forces of attraction and repulsion, cannot be imagined. According to him, therefore, as according to the earlier Goodwin Knight (Phil. Trans. 1748, p. 264), all physical phænomena are to be traced back to the conflict of these two fundamental forces. In the atomic systems, which are diametrically opposed to Kant's dynamic views, and according to an assumption which was widely diffused, especially through the influence of Lavoisier, the attractive force is attributed to the ultimate particles or molecules of which all bodies consist, and the repulsive force to the atmospheres of caloric which surround the molecules. In this hypothesis, which regards the so-called caloric as matter in a constant state of expansion, there are assumed two different kinds of matter; *i. e.* two different elementary substances, as in the myth of two kinds of æther. (Newton, Opt. Query 28, p. 399.) One then asks, What is it which again expands this caloric matter? Considerations on the density of the molecules in comparison with the density of their aggregates (the entire body), lead, in following atomic hypotheses, to the result, that the distance of the molecules from each other is much greater than their diameters.

([44]) p. 24.—Kosmos, Bd. i. S. 98—102 (English edit. Vol. i. p. 85—89).

([45]) p. 24.—Id. Bd. i. S. 39 and 50—56 (English. edit. Vol. i. p. 40 and 42—50).

([46]) p. 24.—Wilhelm von Humboldt, Gesammelte Werke, Bd. i. S. 23.

([47]) p. 26.—Kosmos, Bd. i. S. 80 and 81 (English edition, Vol. i. p. 68 and 69).

([48]) p. 27.—Id. S. 51 (English edition, p. 44).

([49]) p. 27.—Halley, in the Phil. Trans. for 1717, Vol. xxx. p. 736.

([50]) p. 28.—Pseudo-Plut. de plac. Philos. ii. 15—16; Stob. Eclog. phys. p. 582; Plato, in Tim. p. 40.

([51]) p. 28.—Macrob. Somn. Scip. i. 9—10; "stellæ inerrantes," in Cicero de Nat. Deorum, iii. 20.

([52]) p. 28.—The principal passage in which the technical expression, *ἐνδεδεμένα ἄστρα*, occurs, is Aristot. de Cœlo, ii. 8, p. 289, lin. 34; p. 290, lin. 19, Bekker. This alteration of the nomenclature had previously arrested my attention when engaged in examinations respecting Ptolemy's optics, and his experiments on the refraction of rays. Professor Franz, of whose philological learning I have often been glad to avail myself, remarks that Ptolemy (Syntax. vii. 1) also says of the fixed stars—*ὥσπερ προσπεφυκότες*, as if fastened to the sky. Ptolemy blames the expression *σφαίρα ἀπλανὴς* (orbis inerrans), remarking that, "inasmuch as the stars always preserve their distances from each other, we may justly term them *ἀπλανεῖς*; but inasmuch as the whole sphere to which they are attached is in motion, the name *απλανὴς* seems but little suited thereto."

([53]) p. 28.—Cicero de Nat. Deor. i. 13; Plin. ii. 6 and 24; Manilius, ii. 35.

([54]) p. 30.—Kosmos, Bd. i. S. 91 (English edition, Vol. i. p. 78). Compare Encke's excellent considerations on the Arrangement of the Sidereal System, 1844, S. 7.

([55]) p. 31.—Kosmos, Bd. i. S. 162 (English edition, Vol. i. p. 145).

([56]) p. 31.—Aristot. de Cœlo, i. 7, p. 276, Bekker.

([57]) p. 31.—Sir John Herschel, Outlines of Astronomy, 1849, § 803, p. 541.

([58]) p. 32.—Bessel, in Schumacher's Jahrbuch für 1839, S. 50.

([59]) p. 32.—Ehrenberg, in the Abhandl. der Berl. Akad. 1838, S. 59; in his "Infusionsthieren," S. 170.

([60]) p. 33.—Aristotle, at that early period, argued against Leucippus and Democrites that there can be no unoccupied space—no void in the Universe (Phys. Auscult. iv. 6 to 10, p. 213—217, Bekker).

([61]) p. 33.—"Âkâ'sa, according to Wilson's Sanscrit Dictionary, is 'the subtle and ethereal fluid supposed to fill and pervade the Universe, and to be the peculiar vehicle of light and sound.' The word âkâ'sa (shining) comes from the root kâ's, to shine, combined with the preposition â. The five elements collectively are called pantschatâ or pantschatra; and a dead man is, singularly enough, called one who has attained the five elements (prâpta-pantschatra), *i. e.* one who has been dissolved into the five elements. So in the text of the Amarakoscha, Amarasinha's Dictionary" (Bopp). Colebrook's excellent Memoir on the Sânkhya-Philosophy treats of the five elements (Transactions of the Asiatic Society, Vol. i. Lond. 1827, p. 31). Strabo (xv. § 59, p. 713, Cas.) notices, from Megasthenes, the fifth all-fashioning element of the Indians, without, however, naming it.

([62]) p. 33.—Empedocles (v. 216) terms the æther *παμφανόων*, bright-beaming, therefore self-luminous.

([63]) p. 33.—Plato, Cratyl. 410, B, where *ἀειθεὴρ* is found. Aristot. de Cœlo, i. 3, p. 270, Bekk., in opposition to Anaxagoras—*αιθέρα προσωνόμασαν τὸν ἀνωτάτω τόπον, ἀπὸ τοῦ θεῖν ἀει τὸν ὀΐδιον χρόνον θεμενοι τῆν επωνυμιαν αὐτῶ. Αναξαγὸρας δὲ κατακέχρηται τῶ ὑνὸματι τούτω όυ καλῶς ὀνομάζει γαρ αιθέρα αντι πυρος.* In Aristot. Meteor. i. 3, p. 339, lin. 21—34, Bekk., it is said more in detail—"The so-called æther has an ancient appellation, which Anaxagoras appears to identify with fire; for the upper region, he says, is full of fire, and that upper region he looked upon as æther: and herein he was also right, for the bodies which move eternally in their courses appear to have been regarded by the ancients as having in their nature something divine, and therefore were called æther, as a substance to which there is nothing comparable on earth. Those, however, who regard surrounding space, and not merely the bodies which move in it, as fire, and all between the Earth and the stars as air, would surely give up their childish dream if they would accurately consider the results of the latest researches of mathematicians." (The same etymology of the word, from rapid revolution, is repeated by the author of the book De Mundo, cap. 2, p. 392, Bekk.) Professor Franz has justly remarked, "that the play upon words of bodies engaged in an 'eternal course' (σῶμα ἀει θέον) and 'divine' (θεῖον), alluded to in the Meteorologica, is strikingly indicative of Greek fancy, and gives an additional evidence of the far from happy treatment of etymologies by the ancients." Professor Buschmann calls attention to a Sanscrit word, âschtra, for æther, atmosphere, which resembles much in appearance the Greek αιθηρ, and had been compared with it by Vans Kennedy, in his "Researches into the Origin and Affinity of the principal Languages of Asia and Europe," 1828, p. 279. There may be assigned to this word, also, a root (as, asch), to which the Indians attached the idea of "shining."

(64) p. 34.—Aristot. de Cœlo, iv. 1 and 3—4, p. 308 and 311—312, Bekk. If Aristotle refused to the æther the name of a fifth element—which, indeed, Ritter and Martin deny (vide Ritter, Geschichte der Philosophie, Th. iii. S. 259; and Martin, Etudes sur le Timée de Platon, T. ii. p. 150)—it was only because the æther, as a state of matter, appeared to him to want a counterpart (compare Biese, Philosophie des Aristoteles, Bd. ii. S. 66). With the Pythagoreans, æther as a fifth element was represented by the fifth of the regularly-formed bodies, the dodecahedron, composed of twelve pentagons (Martin, T. ii. p. 245—250).

(65) p. 34.—See on this subject the passages collected by Biese, Bd. ii. S. 93.

(66) p. 35.—Kosmos, Bd. i. S. 159 and 416, Note 88 (English edition, Vol. i. p. 143, Note 118).

(67) p. 35.—Compare the fine passage on the rays of the sun in Sir John Herschel's Outlines of Astronomy, p. 237:—By the vivifying action of the sun's rays vegetables are enabled to draw support from inorganic matter, and become, in their turn, the support of animals and of man, and the sources of those *great deposits of dynamical efficiency which are laid up for human use in our coal strata*. By them the waters of the sea are made to circulate in vapour through the air, and irrigate the land, producing springs and rivers. By them are produced all disturbances of the chemical equilibrium of the elements of nature, which, by a series of compositions and decompositions, give rise to new products, and originate a transfer of materials." . . . . .

(68) p. 35.—Phil. Trans. for 1795, Vol. lxxxv. p. 318; John Herschel, Outlines of Astronomy, p. 238; Kosmos, Bd. i. S. 195 and 436, Note 33 (English edition, Vol. i. p. 177 and Note 163).

(69) p. 36.—Bessel, in Schumacher's Astr. Nachr. Bd. xiii. 1836, No. 300, S. 201.

(70) p. 36.—Bessel, in the same, S. 186—192 and 229.

(71) p. 36.—Fourier, Théorie analytique de la Chaleur, 1822, p. ix. (Annales de Chimie et de Physique, T. iii. 1816, p. 350; T. iv. 1817, p. 128; T. vi. 1817, p. 259; T. xiii. 1820, p. 418.) Numerical estimations of the loss which the heat of the stars (chaleur stellaire) suffers in passing through space, by absorption in the ether, are attempted by Poisson, in his Théorie mathématique de la Chaleur, § 196, p. 436; § 200, p. 447; and § 228, p. 521.

(72) p. 36.—On the warming power of the stars, see Aristot. Meteor. i. 3, p. 340, lin. 28; and Seneca, on the height of the strata of the atmosphere which have the minimum of heat, in Nat. Quæst. ii. 10—"superiora enim aëris calorem vicinorum siderum sentiunt. . . . ."

(73) p. 36.—Plut. de plac. Philos. ii. 13.

(74) p. 37.—Arago sur la température du Pole et des espaces célestes, in the Annuaire du Bureau des Long. pour 1825, p. 189, and pour 1834, p. 192; Saigey, Physique du Globe, 1832, p. 60—78. From discussions on the refraction of rays, Svanberg finds, for the temperature of space, −50°.3 Cent., or −58°.5 F. (Berzelius, Jahresbericht für 1830, S. 54); Arago makes it, from polar observations, −56°.7 Cent. (−70° F.); Peclet, −60° Cent. (−76° F.); Saigey, by the diminution of heat in the atmosphere from 367 of my determinations in the Andes and in Mexico, −65° Cent. (−85° F.), and by thermometric observations on Mont Blanc and in Gay-Lussac's aerostatic voyage, −77° Cent. (−106°.6 F.); Sir John Herschel (Edinburgh Review, Vol. lxxxvii. 1848, p. 223) makes it −132° F. That Poisson, (the mean temperature of Melville Island, lat. 74° 47′, being already −18°.7 Cent. or —1°.7 F.), could deduce for the temperature of space, from purely theoretical grounds—[according to which space would be warmer than the extreme limit of the atmosphere (§ 227, p. 520)]—a temperature no lower than −13° or + 8°.6 F., —while, on the other hand, Pouillet (Comptes rendus de l'Acad. des Sc. T. vii. 1838, p. 25-65) makes it −142° C. (223°.6 F),—must excite our astonishment, and diminish our confidence in the methods of inquiry hitherto pursued in these interesting speculations.

(75) p. 38.—Poisson, Théorie mathém. de la Chaleur, p. 438. According to him, the consolidation of the terrestrial strata began from the centre, and proceeded gradually from thence to the surface (§ 193, p. 429). Compare also Kosmos, Bd. i. S. 184 (English edition, Vol. i. p. 166).

(76) p. 38.—Kosmos, Bd. i. S. 86 and 149 (English edition, Vol. i. p. 74 and 133).

(77) p. 39.—"Were there no atmosphere, a thermometer, freely exposed (at sunset) to the heating influence of the earth's radiation, and the cooling

power of its own into space, would indicate a medium temperature between that of the celestial spaces (−132° F.) and that of the earth's surface below it (82° F. at the equator, −3°.5 F. in the Polar Sea). Under the equator, then, it would stand, on the average, at −25° F., and in the Polar Sea at −68° F. The presence of the atmosphere tends to prevent the thermometer so exposed from attaining these extreme low temperatures—first, by imparting heat by conduction; secondly, by impeding radiation outwards" (Sir John Herschel, in the Edinburgh Review, Vol. lxxxvii. 1848, p. 223). "Si la chaleur des espaces planétaires n'existoit point, notre atmosphère éprouverait un refroidissement, dont on ne peut fixer la limite. Probablement, la vie des plantes et des animaux seroit impossible à la surface du globe, ou réleguée dans une étroite zone de cette surface" (Saigey, Physique du Globe, p. 77).

(78) p. 39.—Traité de la Comète de 1743, avec une Addition sur la Force de la Lumière et sa Propagation dans l'Ether, et sur la Distance des Etoiles fixes, par Loys de Cheseaux (1744). On the transparency of space, see Olbers, in Bode's Jahrbuch für 1826, S. 110—121; Struve, Etudes d'Astr. stellaire, 1847, p. 83—93, and Note 95. Compare also Sir John Herschel, Outlines of Astr. § 798; and Kosmos, Bd. i. S. 158 (English edit. vol. i. p. 142).

(79) p. 40.—Halley on the Infinity of the Sphere of Fixed Stars, in the Phil. Trans. Vol. xxxi. for the year 1720, p. 22—26.

(80) p. 40.—Kosmos, Bd. i. S. 92 (English Edition, Vol. i. p. 80).

(81) p. 40.—"Throughout by far the larger portion of the extent of the Milky Way in both hemispheres, the *general blackness* of the ground of the heavens on which its stars are projected," &c....... "In those regions where that zone is clearly resolved into stars well separated, and seen projected *on a black ground*, and where we look out beyond them into space"......(Sir John Herschel, Outlines of Astronomy, p. 537 and 539).

(82) p. 40.—Kosmos, Bd. i. S. 89, 113, and 393, Note 23 (English edition, p. 77, 99, and Note 53); Laplace, Essai philosophique sur les Probabilités, 1825, p. 133; Arago, in the Annuaire du Bureau des Long. pour 1832, p. 188, pour 1836, p. 216; John Herschel, Outlines of Astronomy, § 577.

(83) p. 40.—The vibratory motion of the effluxes at the head of some comets—such as was observed in the comet of 1744, and by Bessel in Halley's comet between the 12th and 22d October, 1835 (Schumacher, Astron. Nachr. No. 300—302, S. 185—232)—"may, indeed, in particular individuals of this class of bodies, influence the translatory motion and the rotation, and even lead us to infer polar forces (S. 201 and 229) different from the ordinary attracting power of the Sun;" but the acceleration of the three and a half yearly period

of revolution of Encke's comet, which has already manifested itself with such great regularity for sixty-three years, cannot well be conceived to be dependent on a sum of accidental effluxes. Compare, respecting this cosmically important subject, Bessel, in Schumacher's Astr. Nachr. No. 289, S. 6, and No. 310, S. 345—350, with Encke's Memoir on the Hypothesis of a Resisting Medium, in Schum. No. 305, S. 265—274.

(84) p. 41.—Olbers, in Schum. Astr. Nachr. No. 268, S. 58.

(85) p. 41.—Outlines of Astronomy, § 556 and 597.

(86) p. 41.—"En assimilant la matière très rare qui remplit les espaces célestes quant à ses propriétés réfringentes aux gas terrestres, la densité de cette matière ne saurait dépasser une certaine limite dont les observations des étoiles changeantes, *p. e.* celles d'Algol ou de β de Persée, peuvent assigner la valeur (Arago, Annuaire pour 1842, p. 336—345).

(87) p. 41.—Wollaston, in the Phil. Trans. for 1822, p. 89; Sir John Herschel, Outl. of Astr. § 34 and 36.

(88) p. 42.—Newton, Princ. mathem. T. iii. (1760), p. 671:—"Vapores, qui ex sole et stellis fixis et *caudis cometarum* oriuntur, incidere *possunt* in atmosphæras planetarum."………

(89) p. 42.—Kosmos, Bd. i. S. 129 and 141 (English edition, Vol. i. p. 114 and 126).

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(90) p. 43.—Kosmos, Bd. ii. S. 355—373 and 507—515 (English edition, Vol. ii. p. 314—330, Note 482—503).

(91) p. 43.—Delambre, Hist. de l'Astronomie moderne, T. ii. p. 255, 269, and 272. Morin says himself, in his Scientia Longitudinum, published in 1634—"Applicatio tubi optici ad alhidadam pro stellis fixis prompte et accurate mensurandis a me excogitata est." Picard used no telescope with his mural quadrant up to 1667; and Hevelius, when Halley visited him in 1679, at Dantzic, and admired the exactness of his measurements of altitude (Baily, Catal. of Stars, p. 38), observed through improved apertures for unassisted vision.

(92) p. 44.—The unfortunate Gascoigne, whose merits were long unacknowledged, met his death, when hardly 23 years of age, at the battle of Marston Moor, between Cromwell and the King's troops (see Derham, in the Phil. Trans. Vol. xxx. for 1717—1719, p. 603—610). To him belong inventions or adaptations which were long attributed to Picard and Anzout, and which gave to "Observing Astronomy,"—which has for its chief object

the determination of place in the heavens,—an extension and success never before attained.

([93]) p. 44.—Kosmos, Bd. ii. S. 209 (English edition, Vol. ii. p. 175).

([94]) p. 45.—The passage in which Strabo (Lib. iii. p. 138, Casaub.) seeks to refute the views of Posidonius, runs, according to the manuscript, as follows:—"The image of the sun, both at sunrise and sunset, is enlarged over the sea, because there the vapours ascend most abundantly from the humid element; for the eye, when it sees through vapours, as when it looks through tubes, receives the images refracted and enlarged: and the same thing happens when it sees the sun or moon set behind a thin dry cloud, in which case they also appear of a red colour." This passage has, quite lately, been supposed to be corrupt (Kramer, in Strabonis Geogr. 1844, Vol. i. p. 211); and it has been proposed to read in lieu of δι αυλῶν, δι υάλων (through glass globes) (Schneider, Eclog. phys. Vol. ii. p. 273). The magnifying power of hollow glass globes filled with water (Seneca, i. 6) was, indeed, known to the ancients, as well as the effects of burning glasses, or "burning crystals" (Aristoph. Nub. v. 765), and of Nero's emerald (Plin. xxxvii. 5); but certainly such globes could not serve for astronomical measuring instruments (compare Kosmos, Bd. ii. S. 464, Note 44; English edition, Vol. ii. Note 384). Altitudes of the Sun, taken through thin light clouds, or through volcanic vapours, show no trace of the influence of refraction (Humboldt, Recueil d'Observ. astr. Vol. i. p 123). Colonel Baeyer has been unable to find any angular alteration of the heliotrope light when streaks of mist were passing, or even with vapours purposely called forth,—thus confirming Arago's experiments. Peters, in Pulkova, in comparing groups of star-altitudes measured when the sky was clear with others observed through light clouds, finds no difference amounting to 0″.017 (see his Recherches sur la Parallaxe des Etoiles, 1848, p. 80 and 140—143; Struve, Études stellaires p. 98). On the employment of tubes in Arabian instruments, see Jourdain sur l'Observatoire de Meragah, p. 27; and A. Sédillot, Mém. sur les Instruments astronomiques des Arabes, 1841, p. 198. Arabian astronomers have also the merit of having first introduced large gnomons with small circular openings. In the colossal sextants of Abu Mohammed al-Chokandi, the limb, graduated to 5 minutes, received the image of the Sun itself. "A midi les rayons du Soleil passaient par une ouverture pratiquée dans la voûte de l'Observatoire qui couvrait l'instrument, suivaient le tuyau, et formaient sur la concavité du sextant une image circulaire, dont le centre donnait, sur l'arc gradué, le complément de la hauteur du Soleil. Cet instrument ne diffère de notre Mural qu'en ce qu'il était garni d'un simple tuyau au lieu d'une lunette" Sédillot, p. 37, 202, and 205. Pierced Sight-vanes (Diopters, Pinnulæ,) were employed by the Greeks and Arabians for the determination of the diameter of the Moon in such manner, that the circular opening in the moveable object-diopter was larger than that of the eye-diopter, which did not move; and the former was moved until the disc of the Moon seen through the eye-aperture filled up the object-aperture (Delambre, Hist. de l'Astr. du moyen Age, p. 201; Sédillot, p. 198). The sight-vanes, with round or longitudinal openings of Archimedes, who made use of the direction of the shadows of two small cylinders attached to the same alidade, appear to be an arrangement first introduced by Hipparchus (Bailly, Hist. de l'Astr. mod. 2de édit. 1785, T. i. p. 480). Compare also Theon Alexandrin. Bas. 1538, p. 257 and 262; Les Hypotyp. de Proclus Diadochus, ed. Halma, 1820, p. 107 and 110; and Ptolem. Almag. ed. Halma, T. i. Par. 1813, p. lvii.

([95]) p. 45.—According to Arago. See Moigno, Répert. d'Optique moderne, 1847, p. 153.

([96]) p. 46.—Respecting the comportment of the dark streaks of the Sun's image in the Daguerreotype, see the Comptes rendus des Séances de l'Académie des Sciences, T. xiv. 1842, p. 902—904; and T. xvi. 1843, p. 402—407.

([97]) p. 47.—Kosmos, Bd. ii. S. 370 (English edition, Vol. ii. p. 329).

([98]) p. 47.—For the important distinction of proper and reflected light I may adduce, as an example, Arago's investigation of the light of comets. By the employment of chromatic polarisation, discovered by him in 1811, the production of the complementary colours, red and green, showed that the light of Halley's comet (1835) contained reflected solar light. I was myself present at his earlier attempts to compare, by means of the equal or unequal intensities of the images in the polariscope, the proper light of Capella with the light of the bright comet which emerged suddenly from amidst the rays of the Sun in the beginning of July 1819. Annuaire du Bureau des Long. pour 1836, p. 232; Kosmos, Bd. i. S. 111 and 392 (English edition, p. 97 and p. xix. Note 51); and Bessel, in Schumacher's Jahrbuch für 1837, S. 169.

([99]) p. 47.—Lettre de M. Arago à M. Alexandre de Humboldt, 1840, p. 37:—"A l'aide d'un polariscope de mon invention, je reconnus (avant 1820), que la lumière de tous les corps terrestres incandescents, *solides* ou *liquides*, est de la lumière naturelle, tant qu'elle émane du corps sous des incidences perpendiculaires. La lumière, au contraire, qui sort de la surface incandescente sous un angle aigu, offre des marques manifestes de polarisation.

Je ne m'arrête pas à te rappeler içi comment je déduisis de ce fait la conséquence curieuse que la lumière ne s'engendre pas seulement à la surface des corps: qu'une portion nait *dans leur substance même*, cette substance fût-elle du platine. J'ai seulement besoin de dire qu'en répétant la même série d'épreuves, et avec les mêmes instruments, sur la lumière que lance une substance *gazeuse* enflammée, on ne lui trouve, sous quelque *inclinaison que ce soit*, aucun des caractères de la *lumière polarisée;* que la lumière des gaz, prise à la sortie de la surface enflammée, est de la lumière naturelle, ce qui n'empêche pas qu'elle ne se polarise ensuite complètement si on la soumet à des réflexions ou à des réfractions convenables. De là une méthode très simple pour découvrir à 40 millions de lieues de distance la nature du Soleil. La lumière provenant *du bord de cet astre*, la lumière emanée de la matière solaire *sous un angle aigu*, et nous arrivant sans avoir éprouvé en route des réflexions ou des réfractions sensibles, offre-t-elle des traces de polarisation, le Soleil est un corps *solide* ou *liquide*. S'il n'y a, au contraire, aucun indice de polarisation dans la lumière du bord, la *partie incandescente* du Soleil *est gazeuse*. C'est par cet enchaînement méthodique d'observations qu'on peut arriver à des notions exactes sur la constitution physique du Soleil." (On the envelopes of the Sun, see Arago, in the Annuaire pour 1846, p. 464.) I give all the detailed optical explanations which I borrow from the writings of my friend (whether manuscript or printed) in his own words, in order to avoid mistakes to which the fluctuations of scientific terminology might give rise in either retranslating into French or in translating into the several other languages in which Cosmos appears.

([100]) p. 47.—Sur l'effet d'une lame de tourmaline taillée parallèlement aux arrêtes du prisme servant, lorsqu'elle est convenablement située, à éliminer en totalité les rayons réfléchis par la surface de la mer et mêlés à la lumière provenant de l'écueil: vide Arago, Instructions de la Bonite, in the Annuaire pour 1836, p. 339—343.

([101]) p. 47.—De la possibilité de déterminer les pouvoirs réfringents des corps d'après leur composition chimique (applied to the proportions of oxygen and nitrogen in atmospheric air; to the quantity of hydrogen contained in ammonia and in water; to carbonic acid, alcohol, and the diamond), see Biot et Arago, Mémoire sur les Affinités des Corps pour la Lumière, March 1806; also, Mémoires mathém. et phys. de l'Institut, T. vii. p. 327—346; and my Mémoire sur les Réfractions astronomiques dans la Zone torride, in the Recueil d'Observ. astron. Vol. i. p. 115 and 122.

([102]) p. 47.—Expériences de M. Arago sur la puissance réfractive des corps diaphanes (de l'air sec et de l'air humide) par le déplacement des franges, in Moigno, Répertoire d'Optique mod. 1847, p. 159—162.

([103]) p. 48.—In order to refute the statement of Aratus, that in the Pleiades there are only six stars visible, Hipparchus says, (Ad Arati Phæn. i. p. 190, in Uranologio Petavii) "A star has escaped Aratus; for if, in a clear and moonless light, one gazes steadfastly and keenly upon the constellation of the Pleiades, there appear in it seven stars: it seems, therefore, surprising that Attalus, in his description of the Pleiades, allows the oversight of Aratus to pass unnoticed, as if his statement had been correct." In the Catasterisms (xxiii.) attributed to Eratosthenes, Merope is termed "the invisible," *πανaφανής*. On a conjectured connection between the name of the veiled daughter of Atlas with geographical myths in the Meropis of Theopompus, as well as with the great Saturnian continent of Plutarch, and the Atlantis, see my Examen. crit. de l'Hist. de la Géographie, T. i. p. 170. Compare also Ideler, Untersuchungen über den Ursprung und die Bedeutung der Sternnamen, 1809, S. 145; and in reference to the determination of astronomical place, see Mädler, Untersuch. über die Fixstern-Systeme, Th. ii. 1848, S. 36 und 166, as well as Baily, in the Mem. of the Astr. Soc. Vol. xiii. p. 33.

([104]) p. 48.—Ideler, Sternnamen, S. 19 und 25. "On observe," says Arago, "qu'une lumière forte fait disparaître une lumière faible placée dans le voisinage. Quelle peut en être la cause? Il est possible physiologiquement que l'ébranlement communiqué à la rétine par la lumière forte s'étend au delà des points que la lumière forte a frappés, et que cet ébranlement secondaire absorbe et neutralise en quelque sorte l'ébranlement provenant de la seconde et faible lumière. Mais sans entrer dans ces causes physiologiques, il y a une cause directe qu'on peut indiquer pour la disparition de la faible lumière: c'est que les rayons provenant de la grande n'ont pas seulement formé une image nette sur la rétine, mais se sont dispersés aussi sur toutes les parties de cet organe à cause des imperfections de transparence de la cornée. Les rayons du corps plus brillant, a, en traversant la cornée se comportent comme en traversant un corps légèrement dépoli. Une partie de ces rayons réfractés regulièrement forme l'image même de *a*, l'autre partie *dispersée* éclaire la totalité de la rétine. C'est donc sur ce fond lumineux que se projette l'image de l'objet voisin *b*. Cette dernière image doit donc ou disparaître ou être affaiblie. De jour deux causes contribuent à l'affaiblissement des étoiles: l'une de ces causes, c'est l'image distincte de cette portion de l'atmosphère, comprise dans la direction de l'étoile (de la portion aérienne placée entre l'œil et l'étoile), et sur laquelle l'image de l'étoile vient de se peindre; l'autre cause, c'est la lumière diffuse provenant de la dispersion que les défauts de la cornée impriment aux rayons émanants de tous les points de l'atmosphère visible. *De nuit* les couches atmosphèriques interposées entre l'œil et l'étoile vers laquelle on vise, n'agissent pas; chaque étoile du firmament forme une image plus nette, mais une partie de leur lumière se trouve dispersée à cause du manque de diaphanité de la cornée. Le même raisonnement s'applique à une deuxième, troisième . . . . millième étoile. La rétine se trouve donc éclairée en totalité par une lumière diffuse proportionelle au nombre de ces étoiles et à leur éclat. On conçoit par là que cette somme de lumière diffuse affaiblisse ou fasse entièrement disparaître l'image de l'étoile vers laquelle on dirige la vue" (Arago, Manuscript, 1847).

(105) p. 50.—Arago, in the Annuaire for 1842, p. 284, and in the Comptes rendus, T. xv. 1842, p. 750; Schum. Astr. Nachr. No. 702. Dr. Galle writes to me—"With reference to your conjectures on the visibility of Jupiter's satellites, I have made some estimations of their magnitude, and, contrary to my own expectation, have found that they are not of the 5th, but only of the 7th, or at the utmost of the 6th magnitude. It was only the brightest of the satellites, the third, which showed itself at all equal to a neighbouring star of the 6th magnitude, which I could only recognise with the naked eye at some little distance from Jupiter: so that, making allowance for the brightness of Jupiter, this satellite might, perhaps, be estimated at from the 5th to the 6th magnitude if it stood alone. The fourth satellite was at its greatest elongation, but I could only estimate it at the 7th magnitude. The rays of Jupiter would not prevent this satellite from being visible if it were itself brighter. After comparisons of Aldebaran with the neighbouring clearly-recognisable double star, ϑ Tauri (with 5½ minutes of distance), I estimate, for an ordinary eye, the radiation from Jupiter at from 5 to 6 minutes at least." These estimations agree with those of Arago; the latter even believes that the false rays may amount in some persons to double the quantity. The mean distances of the four satellites from the centre of the planet are, as is well known, 1′ 51″, 2′ 57″, 4′ 42″, and 8′ 16″. "Si nous supposons que l'image de Jupiter, dans certains yeux exceptionnels, s'épanouisse seulement par des rayons d'une ou deux minutes d'amplitude, il ne semblera pas impossible que les satellites soient de tems en tems aperçus sans avoir besoin de recourir à l'artifice de l'amplification. Pour vérifier cette conjecture, j'ai fait construire une petite lunette dans laquelle l'objectif et l'oculaire ont à peu près le même foyer, et qui dès lors *ne grossit point*. Cette lunette ne détruit pas entièrement les rayons divergents, mais elle en

reduit considérablement la longueur. Cela a suffi pour qu'un satellite convenablement écarté de la planète soit devenu visible. Le fait a été constaté par tous les jeunes astronomes de l'Observatoire" (Arago, in the Comptes rendus, T. xv. p. 751). I may instance, as a remarkable example of the keen sight and great sensibility of the retina in particular individuals who see Jupiter's satellites with the naked eye, a deceased master tailor of the name of Schön, in Breslau, respecting whom the learned and active Director of the Observatory of that place, Herr von Boguslawski, has given me interesting communications. "After being assured by repeated trials, since 1820, that in clear moonless nights Schön, with the naked eye, could assign correctly the position of Jupiter's satellites, even of more than one at a time, —on speaking to him of the rays and tails of light which seemed to prevent others from doing the same, he expressed his astonishment at it; and from the animated discussion which arose between him and the bystanders respecting the difficulty of seeing the satellites with the naked eye, I could not but infer that the planets and the fixed stars always appeared to him as luminous points, free from rays. He saw the third satellite best, and he could also see the first at its widest elongation; but he never saw the second or fourth. When the atmosphere was not quite favourable, the satellites appeared to him only as faint streaks of light. Small fixed stars, perhaps on account of their scintillating and less tranquil light, were never confounded by him with the satellites. Some years before his death, Schön complained to me that his eyes, as they grew older, could no longer reach Jupiter's satellites, and that now, even when the atmosphere was quite clear, their place was only marked to him by faint streaks." The above account agrees perfectly with what has long been known respecting the relative brightness of Jupiter's satellites; for, in individuals whose organs have so high a degree of perfection and sensibility, probably brightness and the quality of light are more influential than distance from the central planet. Schön never saw the second and fourth satellites: the second is the smallest of all; the fourth is, indeed, next to the third, the largest, and also the most distant, but periodically it is dark in colour, and at ordinary times it has the faintest light of any of the satellites. Of the third and first, which have been seen best and most often with the unassisted eye, the third is the largest of all, usually the brightest, and of a very decided yellow colour; but the first sometimes exceeds in the intensity of its bright yellow light the brightness of the third, which is much larger (Mädler, Astron. 1846, S. 231—234 und 439). How, by relations of refraction in the visual organ itself, distant luminous points may appear as lines or streaks of light, has been shown by Sturm and Airy in the Comptes rendus, T. xx. p. 764—766.

(106) p. 50.—"L'image *épanouie* d'une étoile de 7ème grandeur n'ébranle pas suffisamment la rétine : elle n'y fait pas naître une sensation appréciable de lumière. Si l'image *n'etait point épanouie* (par des rayons divergents), la sensation aurait plus de force et l'étoile se verrait. La première classe d'étoiles invisibles à l'œil nu ne serait plus alors la 7ème : pour la trouver, il faudrait peut-être descendre alors jusqu'à la 12ème. Considerons un groupe d'étoiles de 7ème grandeur tellement rapprochées les unes des autres que les intervalles échappent nécessairement à l'œil. *Si la vision avait de la netteté*,—si l'image de chaque étoile était tres petite et bien terminée, l'observateur apercevrait un champ de lumière dont chaque point aurait l'*éclat concentré* d'une étoile de 7ème grandeur. L'*éclat concentré* d'une étoile de 7ème grandeur suffit à la vision à l'œil nu. Le groupe serait donc visible à l'œil nu. Dilatons maintenant sur la rétine l'image de chaque étoile du groupe; remplacons chaque point de l'ancienne image générale par un petit cercle : ces cercles empiéteront les uns sur les autres, et les divers points de la rétine se trouveront éclairés par de la lumière venant simultanément de plusieurs étoiles. Pour peu qu'on y réfléchisse, il restera évident qu'excepté sur les bords de l'image générale l'aire lumineuse ainsi éclairée a précisément, à cause de la superposition des cercles, la même intensité que dans le cas où chaque étoile n'éclaire qu'un seul point au fond de l'œil ; mais si chacun de ces points reçoit une lumière égale en intensité à la lumière concentrée d'une étoile de 7e grandeur, il est clair que l'épanouissement des images individuelles des étoiles contigües ne doit pas empêcher la visibilité de l'ensemble. Les instruments télescopiques ont, quoiqu'à un beaucoup moindre degré, le défaut de donner aussi aux étoiles un *diamètre sensible et factice*. Avec ces instruments, comme à l'œil nu, on doit donc apercevoir des groupes, composés d'étoiles inférieures en intensité à celles que les mêmes lunettes ou télescopes feraient apercevoir isolément" (Arago, in the Annuaire du Bureau des Longitudes pour l'an 1842, p. 284).

(107) p. 50.—Sir William Herschel, in the Phil. Trans. for 1803, Vol. xciii. p. 225 ; and for 1805, Vol. xcv. p. 184. Compare Arago, in the Annuaire pour 1842, p. 360—374.

(108) p. 53.—Humboldt, Relation hist. du Voyage aux Régions équinox. T. i. p. 92—97 ; and Bouguer, Traité d'Optique, p. 360 and 365. Compare also Captain Beechey, in the Manual for Scientific Enquiry for the use of the Royal Navy, 1849, p. 71.

([109]) p. 53.—The passage of Aristotle referred to by Buffon is in a book where one would least have looked for it—in the De generat. animal. v. 1, p. 780, Bekker. Closely translated, it is as follows:—"Keen sight means, on one side, the power of seeing far; and, on the other, an exact recognition of the differences between the things seen. Both are not the case at the same time in the same person; for a man holding his hand above his eyes, or looking through a tube, is not more or less able to judge of the difference between colours, but he will be able to see objects at a greater distance. Thus also it happens that those who are in vaults or cisterns sometimes see stars from them." Ορυγματα, and especially φρέατα, are subterranean cisterns or well-chambers, which, in Greece, are so constructed (as an eye-witness, Professor Franz, remarks) as to communicate with the air and light by a perpendicular shaft, widening below like the neck of a bottle. Pliny (Lib. ii. cap. 14) says—"Altitudo cogit minores videri stellas; affixas cœlo Solis fulgor interdiu non cerni, quum acque ac noctu luceant: idque manifestum fiat *defectu Solis et prœaltis puteis*." Cleomedes (Cycl. Theor. p. 83, Bake) does not speak of stars being seen in the day-time, but he states "that the Sun, seen from deep cisterns, appears larger by reason of the darkness and the damp air."

([110]) p. 54.—"We have ourselves heard it stated by a celebrated optician, that the earliest circumstance which drew his attention to astronomy, was the regular appearance, at a certain hour, for several successive days, of a considerable star through the shaft of a chimney" (John Herschel, Outlines of Astronomy, § 61). The chimney-sweepers from whom I have inquired, say pretty uniformly, "that they never see stars in the day-time; but that at night the sky seen through tall chimneys looks quite near, and the stars seem larger." I forbear from any consideration of the connection between these two illusions.

([111]) p. 54.—Saussure, Voyage dans les Alpes (Neuchatel, 1779, 4to.) T. iv. § 2007, p. 199.

([112]) p. 55.—Humboldt, Essai sur la Géographie des Plantes, p. 103. Compare also my Voy. aux Régions équinox. T. i. p. 143 and 248.

([113]) p. 56.—Humboldt, in Baron Zach's Monatlicher Correspondenz zur Erd- und Himmels-kunde, Bd. i. 1800, S. 396; and in Voy. aux Régions équin. T. i. p. 125. "On croyoit voir de petites fusées lancées dans l'air. Des points lumineux, élevés de 7 à 8 degrés, paroissoient d'abord se mouvoir dans le sens vertical, mais puis se convertir en une véritable oscillation horizontale. Ces points lumineux étoient des images de plusieurs étoiles agrandies (en apparence) par les vapeurs et revenant au même point d'où elles étoient parties."

([114]) p. 56.—Prinz Adalbert von Preussen, Aus meinem Tagebuche, 1847, S. 213. May the phænomenon described by me be connected with that which Carlini observed at the passage of the Pole star, and its oscillations of 10—12 seconds, with the strongly-magnifying meridian telescope at Milan? (See Zach, Correspondance astronomique et géogr. Vol. ii. 1819, p. 84). Brandes (Gehler's umgearb. phys. Wörterb. Bd. iv. S. 549) is disposed to refer them to mirage. The star-like light of the heliotrope has also been seen by an excellent and practised observer, Colonel Baeyer, often uctuating horizontally to and fro.

([115]) p. 60.—The distinguished merit as an artist of Constantine Huygens, who was secretary to King William III., has only recently been placed in its true light by Uptenbrock, in the Oratio de fratribus Christiano atque Constantino Hugenio, artis dioptricæ cultoribus, 1838; and by the learned Director of the Leyden Observatory, Professor Kaiser, in Schumacher's Astr. Nachr. No. 592, S. 246.

([116]) p. 60.—Arago, in the Annuaire for 1844, p. 381.

([117]) p. 60.—"Nous avons placé ces grands verres," says Dominique Cassini, "tantôt sur un grand mât, tantôt sur la *tour de bois venue de Marly;* enfin nous les avons mis dans un tuyau monté sur un support en forme d'échelle à trois faces, ce qui a eu (dans la découverte des satellites de Saturne) le succès que nous en avions espéré." (Delambre, Hist. de l'Astr. moderne, T. ii. p. 785.) These excessive lengths of optical instruments remind us of the Arabian quadrants of about 190 feet radius, in the divided limb of which the image of the sun fell, as in a gnomon, through a small round aperture. There was such a quadrant at Samarcand, probably imitated from an earlier-constructed sextant of Al-Chokandi, about 60 feet high. Compare Sédillot, Prolégomènes des Tables d'Oloug Beigh, 1847, p. lvii. and cxxix.

([118]) p. 60.—Delambre, Hist. de l'Astr. mod. T. ii. p. 594. The Capuchin Monk, Schyrle von Rheita, a mystic, but highly experienced in optical matters, had previously spoken, in his Oculus Enoch et Eliæ (Antv. 1645), of the expected possibility of soon obtaining magnifying powers of 4000 for telescopes, in order to give accurate maps of the Moon. Compare Kosmos, Bd. ii. S. 511, Note 48 (English edition, p. cxvi. Note 488).

([119]) p. 61.—Edinb. Encyclopædia, Vol. xx. p. 479.

([120]) p. 61.—Struve, Etudes d'Astr. stellaire, 1847, Note 59, p. 24. I have preserved in the text the denominations of Herschel's reflectors of 40, 20, and 7 English feet (though I use French measures everywhere else), not only as more convenient, but also because the great labours of the father and son in England and at Feldhausen, at the Cape of Good Hope, have given to the names of these instruments an historical interest. [The French measures are converted into English throughout this translation; retaining, however, the original measures in addition wherever precision seems important, and there could be room for doubt. But in the cases of the focal length by which the telescopes severally referred to in pp. 59 and 60 of the text are designated, the lengths specified by M. de Humboldt are left unchanged, for reasons similar to those adduced by himself in the case of the Herschelian telescopes.—Ed.]

(121) p. 62.—Schumacher's Astr. Nachr., No. 371 and 611. Cauchoix and Lerebours have also sent out object-glasses of more than 12½ (12·61 Eng.) Paris inches, and 23½ (24½ Eng.) feet focal length.

(122) p. 63.—Struve, Stellarum duplicium et multiplicium Mensuræ micrometricæ, p. 2—41.

(123) p. 64.—Mr. Airy has recently given a comparative description of the methods of construction of these telescopes,—the casting of the mirrors and mixing of the metal, the polishing and the mounting (Abstr. of the Astr. Soc. Vol. ix. No. 5, March 1849). Of the effect of the 6-foot metallic mirror of the Earl of Rosse, it is there said (p. 120):—"The Astronomer-Royal (Mr. Airy) alluded to the impression made by the enormous light of the telescope: partly by the modifications produced in the appearances of nebulæ already figured, partly by the great number of stars seen even at a distance from the Milky Way, and partly from the prodigious brilliancy of *Saturn*. The account given by another astronomer of the appearance of *Jupiter* was, that it resembled a coach-lamp in the telescope; and this well expresses the blaze of light which is seen in the instrument." Compare also Sir John Herschel, Outlines of Astronomy, § 870:—"The sublimity of the spectacle afforded by the magnificent reflecting telescope constructed by Lord Rosse of some of the larger globular and other clusters, is declared by all who have witnessed it to be such as no words can express. This telescope has resolved or rendered resolvable multitudes of nebulæ which had resisted all inferior powers."

(124) p. 64.—Delambre, Hist. de l'Astr. moderne, T. ii. p. 255.

(125) p. 65.—Struve, Mens. microm. p. xliv.

(126) p. 65.—Schumacher's Jahrbuch für 1839, S. 100.

(127) p. 65.—"*La lumière atmosphérique diffuse* ne peut s'expliquer par le reflet des rayons solaires sur la surface de séparation des couches de différente

densités dont on suppose l'atmosphère composée. En effet supposons le Soleil placé à l'horizon, les surfaces de séparation dans la direction du zénith seraient horizontales; par conséquent la réflexion serait horizontale aussi, et nous ne verrions aucune lumière au zénith. Dans la supposition des couches, aucun rayon ne nous arriverait par voie d'une première réflexion. Ce ne seraient que les réflexions multiples qui pourraient agir. Donc pour expliquer la *lumière diffuse,* il faut se figurer l'atmosphère composée de molécules (sphériques, par example) dont chacune donne une image du soleil à peu près comme les boules de verres que nous plaçons dans nos jardins. L'air pur est bleu, parce que d'après Newton les molécules de l'air ont l'*épaisseur* qui convient à a réflexion des rayons bleus. Il est donc naturel que les petites images du soleil que de tous côtés réfléchissent les molécules sphériques de l'air, et qui sont la lumière diffuse, aient une teinte bleue; mais ce bleu n'est pas du bleu pur, c'est un blanc dans lequel le bleu prédomine. Lorsque le ciel n'est pas dans toute sa pureté, et que l'air est mêlé de vapeurs visibles, la lumière diffuse reçoit beaucoup de blanc. Comme la lune est jaune, le bleu de l'air pendant la nuit est un peu verdâtre, c'est-à-dire mélangé de bleu et de jaune." (Arago, Manuscript, 1847.)

([128]) p. 65.—D'un des Effets des Lunettes sur la visibilité des étoiles (Lettre de M. Arago à M. de Humboldt, en Déc. 1847):—" L'œil n'est doué que d'une sensibilité circonscrite, bornée. Quand la lumière qui frappe la rétine n'a pas assez d'intensité, l'œil ne sent rien. C'est par un manque d'intensité que beaucoup d'*étoiles,* même dans les nuits les plus profondes, échappent à nos observations. Les lunettes ont pour effet, *quant aux étoiles* d'augmenter l'intensité de l'image. Le faisceau cylindrique de rayons parallèles venant d'une étoile, qui s'appuie sur la surface de la lentille objective, et qui a cette surface circulaire pour base, se trouve considérablement resserré à la sortie de la lentille oculaire. Le diamètre du premier cylindre est au diamétre du second comme la distance focale de l'objectif est à la distance focale de l'oculaire, ou bien comme le diamètre de l'objectif est au diamètre *de la portion d'oculaire* qu'occupe le faisceau émergent. Les intensités de lumière dans les deux cylindres en question (dans les deux cylindres incident et émergent) doivent être entr'elles comme les étendues superficielles des bases. Ainsi la lumière émergente sera plus condensée, *plus intense* que la lumière naturelle tombant sur l'objectif, dans le rapport de la surface de cet objectif â la surface circulaire de la base du faisceau émergent. Le faisceau *émergent, quand la lunette grossit,* étant plus étroit que le faisceau cylindrique qui tombe sur l'objectif, il est évident que la pupille, quelle que soit son ouverture, recueillera plus de rayons par l'intermédiaire de la lunette que sans elle. La lunette augmentera donc toujours l'intensité de la lumière *des étoiles.*

"Le cas *le plus favorable*, quant à l'effet des lunettes, est évidemment celui où l'œil reçoit la totalité du faisceau émergent, le cas où ce faisceau a moins de diamètre que la pupille. Alors *toute la lumière* que l'objectif embrasse, concourt, par l'entremise du télescope, à la formation de l'image. A l'œil nu, au contraire, *une portion* seule de cette même lumière est mise à profit : c'est la petite portion que la surface de la pupille découpe dans le faisceau incident naturel. L'intensité de l'image télescopique d'une *étoile* est donc à l'intensité de l'image à l'œil nu, *comme la surface de l'objectif est à celle de la pupille.*

"Ce qui précède est relatif à la visibilité d'un seul point—d'une seule étoile. Venons à l'observation d'un objet ayant des dimensions angulaires sensibles,—à l'observation d'une *planète.* Dans les cas les plus favorables, c'est-à-dire lorsque la pupille reçoit la totalité du pinceau émergent, l'intensité de l'image *de chaque point* de la planète se calculera par la proportion que nous venons de donner. La quantité *totale de lumière* concourant à former *l'ensemble* de l'image à l'œil nu, sera donc aussi à la *quantité totale de lumière* qui forme l'image de la planète, à l'aide d'une lunette, comme la surface de la pupille est à la surface de l'objectif. Les intensités comparatives, non plus de points isolés, mais des deux images d'une planète, qui se forment sur la rétine à l'œil nu, et par l'intermédiare d'une lunette, doivent évidemment *diminuer* proportionnellement aux *etendues superficielles* de ces deux images. Les dimensions *linéaires* des deux images sont entr'elles comme le diamètre de l'objectif est au diamètre du faisceau émergent. Le nombre de fois que la *surface* de l'image amplifiée surpasse la *surface* de l'image à l'œil nu, s'obtiendra donc en divisant le carré du *diamètre* de *l'objectif* par le carré du *diamètre du faisceau émergent,* ou bien la *surface de l'objectif par la surface de la base circulaire du faisceau émergent.*

"Nous avons déjà obtenu le rapport des *quantités totales de lumière* qui engendrent les deux images *d'une planète,* en divisant la surface de l'objectif *par la surface de la pupille.* Ce nombre est *plus petit* que le quotient auquel on arrive en divisant la *surface de l'objectif* par la *surface du faisceau émergent.* Il en résulte, quant aux planètes, qu'une lunette fait moins gagner en intensité de lumière qu'elle ne fait perdre en agrandissant *la surface* des images sur la rétine : l'intensité de ces images doit donc aller continuellement en s'affaiblissant à mesure que le pouvoir amplificatif de la lunette ou du télescope s'accroît.

"L'atmosphère peut être considérée comme une planète à dimensions indéfinies. La portion qu'on en verra dans une lunette subira donc aussi la *loi* d'affaiblissement que nous venons d'indiquer. Le *rapport* entre l'intensité de la lumière d'une *planète* et le champ de lumière atmosphérique à travers lequel on la verra, sera le même à l'œil nu et dans les lunettes de tous les grossissements, de toutes les dimensions. Les lunettes, *sous le rapport de l'intensité*, ne favorisent donc pas la visibilité *des planètes.*

"Il n'en est point ainsi des *étoiles.* L'intensité de l'image d'une étoile est plus forte avec une lunette qu'à l'œil nu; au contraire, le champ de la vision, uniformément éclairé dans les deux cas par la lumière atmosphérique, est plus clair à l'œil nu que dans la lunette. Il y a donc deux raisons, sans sortir des considérations d'intensité, pour que dans une lunette l'image de l'étoile prédomine sur celle de l'atmosphère notablement plus qu'à l'œil nu.

"Cette prédominence doit aller graduellement en augmentant avec le grossissement. En effet, abstraction faite de certaine augmentation du diamètre de l'étoile, conséquence de divers effets de *diffraction* ou *d'interférences;* abstraction faite aussi d'une plus forte réflexion que la lumière subit sur les surfaces plus obliques des oculaires de très courts foyers, *l'intensité de la lumière de l'étoile est constante* tant que l'ouverture de l'objectif ne varie pas. Comme on l'a vu, la *clarté du champ* de la lunette, au contraire, *diminue sans cesse* à mesure que le pouvoir amplificatif s'accroît. Donc, toutes autres circonstances restant égales, une étoile sera d'autant plus visible—sa prédominence sur la lumière du champ du télescope sera d'autant plus tranchée—qu'on fera usage d'un grossissement plus fort." (Arago, Manuscript, 1847.) I add from the Annuaire du Bureau des Long. pour 1846 (Notices scient. par M. Arago), p. 381:—"L'expérience a montré que pour le commun des hommes, deux espaces éclairés et contigus ne se distinguent pas l'un de l'autre; à moins que leurs intensités comparatives ne présentent, au minimum, une différence de $\frac{1}{60}$. Quand une lunette est tournée vers le firmament, son champ semble uniformément éclairé: c'est qu'alors il existe, dans un plan passant par le foyer et perpendiculaire à l'axe de l'objectif, une *image indéfinie* de la région atmosphérique vers laquelle la lunette est dirigée. Supposons qu'un astre, c'est-à-dire un objet situé bien au delà de l'atmosphère, se trouve dans la direction de la lunette: son image ne sera visible qu'autant qu'elle augmentera de $\frac{1}{60}$, au moins, l'intensité de la portion de l'image focale *indéfinie* de l'atmosphère sur laquelle sa propre image *limitée* ira se placer. Sans cela, le champ visuel continuera à *paraître* partout de la même intensité."

([129]) p. 67.—The earliest publication of Arago's explanation of the phænomenon of scintillation was in the Appendix to the 4th book of my Voyage aux Régions équinoxiales, T. i. p. 623. I have great pleasure in being enabled to enrich the section upon natural and telescopic vision with the following extracts from the MSS. of my friend, which, for reasons already given, I print in the original:—Des Causes de la Scintillation des Etoiles: "Ce qu'il y a de plus remarquable dans le phénomène de la scintillation, c'est le changement de couleur. Ce changement est beaucoup plus fréquent que l'observation ordinaire ne l'indique. En effet, en agitant la lunette on transforme l'image dans une ligne ou un cercle, et tous les points de cette ligne ou de ce cercle paraissent de couleurs différentes. C'est la résultante de la superposition de toutes ces images que l'on voit lorsqu'on laisse la lunette immobile. Les rayons qui se réunissent au foyer d'une lentille, vibrent d'accord ou en désaccord, s'ajoutent ou se détruisent, suivant que les couches qu'ils ont traversé, ont telle ou telle réfringence. L'ensemble des rayons rouges peut se détruire *seul* si ceux de droite et de gauche, et ceux de haut et de bas, ont traversé des milieux inégalement réfringents. Nous avons dit *seul*, parce que la différence de réfringence qui correspond à la destruction du rayon rouge n'est pas la même que celle qui amène la destruction du rayon vert, et réciproquement. Maintenant si des rayons rouges sont détruits, ce qui reste sera le blanc moins le rouge, c'est-à-dire du vert; si le vert, au contraire, est détruit par *interference*, l'image sera du blanc moins le vert, c'est-à-dire du rouge. Pour expliquer pourquoi les planètes à grand diamètre ne scintillent pas, ou très peu, il faut se rappeller que le disque peut être considéré comme une aggrégation d'étoiles ou de petits points qui scintillent isolément; mais les images de différentes couleurs que chacun de ces points pris isolément donnerait, empiétant les unes sur les autres, formeraient du blanc. Lorsqu'on place un diaphragme ou un bouchon percé d'un trou sur l'objectif d'une lunette, les étoiles acquièrent un disque entouré d'une série d'anneaux lumineux. Si l'on enfonce l'oculaire, le disque de l'étoile augmente de diamètre, et il se produit dans son centre un trou obscur; si l'on enfonce davantage, un point lumineux se substitue au point noir: un nouvel enfoncement donne naissance à un centre noir, etc. Prenons la lunette lorsque le centre de l'image est noir, et visons à une étoile qui ne scintille pas: le centre restera noir, comme il l'était auparavant. Si, au contraire, on dirige la lunette à une étoile qui scintille, on verra le centre de l'image lumineux et obscur par intermittence. Dans la position où le centre de l'image est occupé par un point lumineux, on verra ce point disparaître et renaître successivement. Cette disparition ou réapparition du point central est la preuve directe de l'*interférence* variable des rayons.

Pour bien concevoir l'absence de lumière au centre de ces images dilatées, il faut se rappeler que les rayons régulièrement réfractés par l'objectif ne se réunissent et ne peuvent par conséquent *interférer* qu'au foyer: par conséquent les images dilatées que ces rayons peuvent produire resteraient toujours pleines (sans trou). Si dans une certaine position de l'oculaire un trou se présente au centre de l'image, c'ést que les rayons régulièrement réfractés *interfèrent* avec des rayons *diffractés* sur les bords du diaphragme circulaire. Le phénomène n'est pas constant, parce que les rayons qui interfèrent dans un certain moment n'interfèrent pas un instant après, lorsqu'ils ont traversé des couches atmosphériques dont le pouvoir refringent a varié. On trouve dans cette expérience la preuve manifeste du rôle que joue dans le phénomène de la scintillation l'inégale réfrangibilité des couches atmospbériques traversées par les rayons dont le faisceau est très étroit.

"Il résulte de ces considérations que l'explication des scintillations ne peut être rattachée qu'au phénomènes des *interférences lumineuses*. Les rayons des étoiles, après avoir traversé une atmosphère où il existe des couches inégalement chaudes, inégalement denses, inégalement humides, vont se réunir au foyer d'une lentille, pour y former des images d'intensité et de couleurs perpétuellement changeantes, c'est-à-dire des images telles que la scintillation les présente. Il y a aussi scintillation hors du foyer des lunettes. Les explications proposées par Galilei, Scaliger, Kepler, Descartes, Hooke, Huygens, Newton et John Michell, que j'ai examinées dans un mémoire présenté à l'Institut en 1840 (Comptes rendus, T. x. p. 83), sont inadmissibles. Thomas Young, auquel nous devons les premières lois des interférences, a cru inexplicable le phénomène de la scintillation. La fausseté de l'ancienne explication par des vapeurs qui voltigent et déplacent, est déjà prouvée par la circonstance que nous voyons la scintillation des yeux, ce qui supposerait un déplacement d'une minute. Les ondulations du bord du Soleil sont de 4″ à 5″, et peut-être des pièces qui *manquent*, donc encore effet de l'interférence des rayons." (Extracted from MSS. of Arago, 1847.)

(130) p. 68.—Arago, in the Annuaire for 1831, p. 168.

(131) p. 69.—Aristot. de Cœlo, ii. 8, p. 290, Bekker.

(132) p. 69.—Kosmos, Bd. ii. S. 363 (English edition, p. 322).

(133) p. 69.—Causæ Scintillationis, in Kepler de Stella nova in pede Serpentarii, 1606, cap. 18, p. 92—97.

(134) p. 70.—Lettre de M. Garcin, Dr. en Méd., à M. de Réaumur, in the Hist. de l'Académie Royale des Sciences, Année 1743, p. 28—32.

(135) p. 71.—See Voyage aux Régions équin. T. i. p. 511 and 512, T. ii.

p. 202—208; also my Ansichten der Natur, 3te Ausg. Bd. i. S. 29 and 225. "En Arabie," says Garcin, "de même qu'à Bender-Abassi, port fameux du Golfe Persique, l'air est parfaitement serein presque toute l'année. Le printemps, l'éte et l'automme se passent, sans qu'on y voie la moindre rosée. Dans ces mêmes temps tout le monde couche dehors sur le haut des maisons. Quand on est ainsi couché, il n'est pas possible d'exprimer le plaisir qu'on prend à contempler la beauté du ciel, l'éclat des étoiles. C'est une lumière pure, ferme et éclatante, sans étincillement. Ce n'est qu'au milieu de l'hiver que la scintillation, quoique très-foible, s'y fait apercevoir." (Garcin, in Hist. de l'Acad. des Sciences, 1743, p. 30.)

([136]) p. 72.—Speaking of the illusions occasioned by the different velocities of sight and sound, Bacon says—"Atque hoc cum similibus nobis quandoque dubitationem peperit plane monstrosam; videlicet, utrum cœli sereni et stellati facies ad idem tempus cernatur, quando vere existit, an potius aliquanto post; et utrum non sit (quatenus ad visum cœlestium) non minus tempus verum et tempus visum, quam locus verus et locus visus, qui notatur ab astronomis in parallaxibus. Adeo incredibile nobis videbatur, species sive radios corporum cœlestium, per tam immensa spatia milliarium, subito deferri posse ad visum; sed potius debere eas in tempore aliquo notabili delabi. Verum illa dubitatio (quoad majus aliquod intervallum temporis inter tempus verum et visum) postea plane evanuit, reputantibus nobis." (The Works of Francis Bacon, Vol. i. Lond. 1740—(Novum Organum), p. 371.) He then, quite in the manner of the Ancients, recalls a true view just expressed. Compare Somerville, The Connexion of the Physical Sciences, p. 36; and Kosmos, Bd. i. S. 161 (English edition, Vol. i. p. 144—145).

([137]) p. 72.—See Arago's development of his method, in the Annuaire du Bureau des Longitudes pour 1842, p. 337—343: "L'observation attentive des phases d'Algol à six mois d'intervalle servira à déterminer directement la vitesse de la lumière de cette étoile. Près du maximum et du minimum le changement d'intensité s'opère lentement; il est, au contraire, rapide à certaines époques intermédiaires entre celles qui correspondent aux deux états extrêmes, quand Algol, soit en diminuant, soit en augmentant d'éclat, passe par la troisième grandeur."

([138]) p. 72.—Newton, Opticks, 2d edit. (Lond. 1718), p. 325: "Light moves from the Sun to us in seven or eight minutes of time." Newton compares the velocity of sound ("1140 feet in one second") with that of light. Reckoning for the latter, according to the occultations of Jupiter's satellites (Newton died about half a year before Bradley's discovery of aberration), 7′ 30″ from the Sun to the Earth, and assuming a distance of 70 millions of English (statute) miles,—light traverses, in every second of time, 155555$\frac{5}{9}$ English miles, the reduction of which to geographical miles would vary according to the assumption of the figure of the Earth. According to Encke's exact assumptions in the Jahrbuch for 1852 (taking, with Dove, 1 English mile = 5280 English feet = 4954·206 Paris feet), there are 691637 English statute miles to an equatorial degree. Newton's result would thus be 33736 German geographical miles 15 to a degree, (or 134944 English geographical miles 60 to a degree, which are generally used throughout this translation under the name of "geographical miles"). But Newton took the Sun's parallax at 12″: if it is 8″·57116, as given by Encke's calculation of the transit of Venus, the distance is greater, and we should have for the velocity of light (taking 7½′ from the Sun) 47232 German, or 188928 English geographical miles for a second of time,—too much, therefore, instead of, as before, too little. It is certainly very remarkable, though it was not noticed by Delambre (Hist. de l'Astronomie moderne, T. ii. p. 653), that whereas, from Römer's discovery in 1675 to the beginning of the 18th century, the times assigned for the passage of light over half the major axis of the Earth's orbit fluctuated between 11′ and 14′ 10″,—being always much too high,—Newton, supported perhaps by more recent English observations of the first satellite, came within about 47″ of the truth (or, at least, of the now accepted result of Struve). The oldest memoir in which Römer, who was Picard's pupil, presented his discovery to the Academy, bears date Nov. 22, 1675. He found, by forty emersions and immersions of Jupiter's satellites, "un retardement de lumière de 22 minutes par l'intervalle qui est le double de celui qu'il y a d'ici au Soleil" (Mémoires de l'Acad. de 1666—1699, T. x. 1730, p. 400). Cassini did not contest the fact of the retardation, but he contested the assigned amount of time, because (he very erroneously supposed) different satellites gave different results. Du Hamel, the Secretary of the Paris Academy (Regiæ Scientiarum Academiæ Historia, 1698, p. 145), seventeen years after Römer had left Paris, but still referring to him, gives from 10′ to 11′; but we know, by Peter Horrebow (Basis Astronomiæ, sive Triduum Roemerianum, 1735, p. 122—129), that in 1704—six years, therefore, before his death—when about to publish his own work on the velocity of light, Römer kept steadily to the result of 11′: so, also, did Huygens (Tract. de Lumine, cap. 1, p. 7). Cassini proceeded quite differently: he found for the first satellite 7′ 5″, for the second 14′ 12″; and he lays down, as the basis of his tables of Jupiter, 14′ 10″ "pro peregrando diametri semissi." The error was therefore on the increase. (Compare Horrebow, Triduum, p. 129; Cassini, Hypothèses et Satellites de Jupiter, in the Mém. de l'Acad. 1666—1699, T. viii. p. 435 and 475; Delambre, Hist. de l'Astr. moderne, T. ii. p. 751 and 782; Du Hamel, Physica, p. 435.)

(139) p. 72.—Delambre, Hist. de l'Astr. mod. T. ii. p. 653.

(140) p. 73.—Reduction of Bradley's Observations at Kew and Wansted, 1836, p. 22; Schumacher's Astr. Nachr. Bd. xiii. 1836, No. 309. (Compare Miscellaneous Works and Correspondence of the Rev. James Bradley, by Professor Rigaud, Oxford, 1832.) On the attempts hitherto made to explain the aberration of light on the undulatory theory, see Doppler, in the Abhandl. der kön. böhmischen Gesellschaft der Wiss. 5te Folge, Bd. iii. S. 745—765. It is a circumstance deserving of particular attention in the history of great astronomical discoveries, that more than half a century before Bradley's actual discovery and explanation of the cause of aberration (probably from 1667), Picard remarked a periodical movement of the Pole-star of about 20″, which "can neither be the effect of parallax or of refraction, and is very regular in the opposite seasons of the year" (Delambre, Hist. de l'Astr. moderne, T. ii. p. 616). Picard was on the path which might have led to the discovery of the velocity of direct light, half a century before his disciple Römer made known the velocity of reflected light.

(141) p. 73.—Schum. Astr. Nachr. Bd. xxi. 1844, No. 484; Struve, Etudes d'Astr. stellaire, p. 103 and 107 (compare Kosmos, Bd. i. S. 160; English edition, p. 144). In the Annuaire pour 1842, p. 287, the velocity of light is given at 308000 kilometres, or 77000 lieues (each 4000 metres), in a second: this result comes nearest to the present one of Struve. It gives 41507 German, or 166028 English geographical miles, in a second; that of the Pulkova Observatory being 41549 German, or 166196 English geographical miles in a second. On the difference between the aberration of the Pole-star and that of its companion, and on Struve's own recently-conceived doubts, see Mädler, Astronomie, 1849, S. 393. A still larger result for the passage of light from the Sun to the Earth is given by William Richardson, viz. 8′ 19″·28, to which belongs a velocity of 165688 geographical miles (Mem. of the Astron. Soc. Vol. iv. Pt. 1, p. 68).

(142) p. 74.—Fizeau gives his result in leagues, 25 to an equatorial degree, 70000 such leagues in a second (168000 English geographical miles). On earlier experiments of Fizeau, see Comptes rendus, T. xxix. p. 92. In Moigno, Répert. d'Optique moderne, P. iii. p. 1162, the result is given at

70843 (25 = 1°): therefore 42506 German, or 170024 English geographical miles, which comes nearest to Bradley's result, according to Busch.

([143]) p. 74.—D'après la théorie mathématique dans le système des ondes, les rayons de différentes couleurs, les rayons dont les ondulations sont inégales, doivent néanmoins se propager dans l'Ether avec la même vitesse. Il n'y a pas de différence à cet égard entre la propagation des ondes sonores, lesquelles se propagent dans l'air avec la même rapidité. Cette égalité de propagation des ondes sonores est bien établie expérimentalement par la similitude d'effet que produit une musique donnée à toutes distances du lieu où l'on l'exécute. La principale difficulté, je dirai l'unique difficulté qu'on eût élevée contre le système des ondes, consistait donc à expliquer comment la vitesse de propagation des rayons de différentes couleurs dans des corps différents pouvait être dissemblable et servir à rendre compte de l'inégalité de réfraction de ces rayons ou de la dispersion. On a montré récemment que cette difficulté n'est pas insurmontable; qu'on peut constituer l'Ether dans les corps inégalement denses de manière que des rayons à ondulations dissemblables s'y *propagent* avec des vitesses inégales: reste à déterminer si les conceptions des géomètres à cet égard sont conformes à la nature des choses. Voici les amplitudes des ondulations déduites expérimentalement d'une série de faits relatifs aux interférences:—

	Millimètres.
Violet	0·000423
Jaune	0·000551
Rouge	0·000620

La vitesse de transmission des rayons de différentes couleurs dans les espaces célestes est la même dans le système des ondes, et tout-à-fait indépendante de l'étendue ou de la vitesse des ondulations" (Arago, MSS. 1849). Compare also Annuaire pour 1842, p. 333—336. The length of the luminous wave of the ether and the rapidity of the vibrations determine the character of the coloured rays. The violet, which is the most refrangible ray, has 662, and red, which (with the greatest length of wave) is the least refrangible ray, has only 451, billions of vibrations in a second.

([144]) p. 75.—"J'ai prouvé, il y a bien des années, par des observations directes, que les rayons des étoiles vers lesquelles la Terre marche, et les rayons des étoiles dont la Terre s'éloigne, se réfractent exactement de la même quantité. Un tel résultat ne peut se concilier avec *la théorie de l'émission* qu'à l'aide d'une addition importante à faire à cette théorie: il faut admettre que les corps lumineux émettent des rayons de toutes les vitesses, et que les seuls rayons d'une vitesse déterminée sont visibles, qu'eux seuls produisent dans l'œil la sensation de lumière. Dans la théorie de l'émission, le rouge, le jaune, le vert, le bleu, le violet solaires sont respectivement accompagnés de rayons pareils, mais obscurs par défaut ou par excès de vitesse. A plus de vitesse correspond une moindre réfraction, comme moins de vitesse entraine une réfraction plus grande. Ainsi chaque rayon rouge visible est accompagné de rayons obscurs de la même nature, qui se réfractent les uns plus, les autres moins que lui: ainsi il *existe des rayons dans les stries noires* de la portion rouge du spectre; la même chose doit être admise des stries situées dans les portions jaunes, vertes, bleues et violettes"—Arago, in the Comptes rendus de l'Acad. des Sciences, T. xvi. 1843, p. 404. (Compare also T. viii. 1839, p. 326; and Poisson, Traité de Mécanique, éd. 2, 1833, T. i. § 168.) According to the undulatory theory, the heavenly bodies send out waves of infinitely different velocities of transverse vibration.

(145) p. 75.—Wheatstone, in the Phil. Trans. of the Royal Society for 1834, p. 589 and 591. From the experiments described in this memoir, it appears to follow that the human eye is capable of receiving impressions from luminous phænomena, of which the duration is limited to one-millionth part of a second (p. 591). On the hypothesis alluded to in the text, according to which the Sun's light is analogous to the Earth's polar light, see Sir John Herschel, Results of Astron. Observ. at the Cape of Good Hope, 1847, p. 351. The ingenious application of Wheatstone's revolving apparatus, improved by Breguet, to a critical experiment in the decision between the emission and undulatory theories,—as, according to the former, light should pass quicker, and according to the latter slower, through water than through air,—has already been spoken of by Arago in the Comptes rendus, T. vii. 1838, p. 956. (Compare Comptes rendus pour 1850, T. xxx. p. 489—495 and 556.)

(146) p. 77.—Steinheil, in Schumacher's Astr. Nachr. No. 679 (1849), S. 97—100; Walker, in the Proceedings of the American Philosophical Society, Vol. v. p. 128 (compare older propositions of Pouillet, in the Comptes rendus, T. xix. p. 1386). Still later ingenious experiments of Mitchel, Director of the Observatory of Cincinnati (Gould's Astron. Journal, Dec. 1849, p. 3, on the Velocity of the Electric Wave), and of Fizeau and Gounelle at Paris (April 1850), differ from Wheatstone's and Walker's results. Striking differences between iron and copper, in respect to conduction, are shown by experiments given in the Comptes rendus, T. xxx. p. 439.

(147) p. 77.—See Poggendorff, in his Annalen, Bd. lxxiii. 1848, S. 337; and Pouillet, Comptes rendus, T. xxx. p. 501.

(148) p. 77.—Riess, in Poggen. Ann. Bd. 78, S. 433. On the non-conduction through the earth, see the important experiments of Guillemin "sur le courant dans une pile isolée, et sans communication entre les pôles," in the Comptes rendus, T. xxix. p. 521. "Quand on remplace un fil par la terre dans les télégraphes électriques, la terre sert plutôt de réservoir commun que de moyen d'union entre les deux extrémités du fil."

(149) p. 78.—Mädler, Astr. S. 380. Laplace, according to Moigno, Répertoire d'Optique moderne, 1847, T. i. p. 72:—"Selon la théorie de l'émission, on croit pouvoir démontrer que si le diamètre d'une étoile fixe serait 250 fois plus grand que celui du soleil, sa densité restant la même, l'attraction exercée à sa surface détruirait la quantité de mouvement de la molécule lumineuse émise, de sorte qu'elle serait invisible à de grandes distances." If, with William Herschel, we ascribe to Arcturus an apparent diameter of 0″·1, it would follow from this assumption that the actual diameter of this star is only 11 times greater than that of our Sun (Kosmos, Bd. i. S. 153 and 415; English edition, p. 137—138, and Note 107). According to the above view of one of the causes of non-luminosity, it would follow that, with very different dimensions of the heavenly bodies, the velocity of their light would be also very different, which hitherto has by no means been confirmed by observation. (Arago, in the Comptes rendus, T. viii. p. 326, says:—"Les expériences sur l'égale déviation prismatique des étoiles vers lesquelles la terre marche ou dont elle s'éloigne, rend compte de l'égalité de vitesse apparente des rayons de toutes les étoiles.")

(150) p. 79.—Eratosthenes, Catasterismi, ed. Schaubach, 1795; and Eratosthenica, ed. God. Bernhardy, 1822, p. 110—116. The description distinguishes among stars λαμπροὺς (μεγάλους) and ἀμαυροὺς (cap. 2, 11, 41). So also Ptolemy: with whom οἱ ἀμόρφωτοι relate only to stars which are not included *formally* in a constellation.

(151) p. 80.—Ptol. Almag. ed. Halma, T. ii. p. 40; and in Eratosth. Catast. cap. 22, p. 18: *ἡ δε κεφαλὴ καὶ ἡ ἅρπη ἄναπτος ὁρᾶται, διὰ δὲ νεφελώδους συστροφῆς δοκεῖ τισιν ὁρᾶσθαι.* So also Geminus, Phæn. (ed. Hilder. 1590), p. 46.

(152) p. 80.—Kosmos, Bd. ii. S. 369 and 514 (Anm. 63); English edition, p. 328 and cxviii. (Note 503).

(153) p. 80.—Muhamedis Alfragani Chronologica et Astr. Elementa, 1590, cap. xxiv. p. 118.

(154) p. 81.—Some manuscripts of the Almagest point to such sub-divisions or intermediate classes, as they add to the determinations of magnitude the

words μείζων or ἐλάσσων (Cod. Par. N° 2389). Tycho Brahe expressed this increasing or diminishing by points.

([155]) p. 81.—Sir John Herschel, Outl. of Astr. p. 520—527.

([156]) p. 82.—This was the application of mirror sextants to the determination of the light of stars which I employed in the tropics still more than diaphragms, which had been recommended to me by Borda. I began the work under the fine sky of Cumana, and continued it subsequently up to 1803, under less favourable circumstances, on the high plains of the Andes, and on the coast of the Pacific at Guayaquil. I had formed for myself an arbitrary scale, in which I made Sirius, as the brightest of all the fixed stars, = 100; stars of the 1st magnitude between 100 and 80; 2d magnitude between 80 and 60; 3d magnitude between 60 and 45; 4th between 45 and 30; and 5th between 30 and 20. I passed in review more particularly the constellations of Argo and Grus, in which I believed I should find alterations since Lacaille's time. It appeared to me, after careful combinations of estimation, and employing other stars as intermediate gradations, that Sirius is as much superior in the strength of its light to Canopus, as α Centauri is to Achernar. On account of the above-mentioned mode of classification, my numbers do not admit of direct comparison with those given since 1838 by Sir John Herschel. (See my Recueil d'Observ. astr. Vol. i. p. lxxi.; and Relat. hist. du Voy. aux Régions équin. T. i. p. 518 and 624; also Lettre de M. de Humboldt à M. Schumacher en Févr. 1839, in the Astr. Nachr. N° 374.) In this letter I say:—"M. Arago, qui possède des moyens photométriques entièrement différents de ceux qui ont été publiés jusqu'ici, m'avait rassuré sur la partie des erreurs qui pouvaient provenir du changement d'inclinaison d'un miroir entamé sur la face intérieure. Il blame d'ailleurs le principe de ma méthode, et le regarde comme peu susceptible de perfectionnement, non-seulement à cause de la différence des angles entre l'étoile vue directement et celle qui est amenée par reflexion, mais surtout parce que le résultat de la mésure d'intensité dépend de la partie de l'œil qui se trouve en face de l'oculaire. Il y a erreur lorsque la pupille n'est pas très-exactement à la hauteur de la limite inférieure de la portion non entamée du petit miroir."

([157]) p. 82.—Compare Steinheil, Elemente der Helligkeit's-Messungen am Sternenhimmel München, 1836 (Schum. Astr. Nachr. No. 609) and John Herschel, Results of Astronomical Observations made during the years 1834—1838 at the Cape of Good Hope (Lond. 1847), p. 353—357. In 1846, Seidel attempted to determine with Steinheil's photometer the quantities of light of several stars of the 1st magnitude which appear at sufficient altitudes in our northern hemisphere. He makes α Lyræ = 1, and then finds Sirius = 5·13; Rigel, whose brightness seems to be increasing, = 1·30; Arcturus, 0·84; Capella, 0·83; Procyon, 0·71; Spica, 0·49; Atair, 0·40; Aldebaran 0·36; Deneb, 0·35; Regulus, 0·34; Pollux, 0·30; Betelgeuze is left out, because it is variable, as appeared particularly between 1836 and 1839 (Outlines, p. 523).

(158) p. 83.—For the numerical bases of the photometric results, compare four tables of Sir John Herschel, in his Cape Observations (*a.* p. 341; *b.* p. 367—371; *c.* p. 440; and *d.* in his Outlines of Astronomy, p. 522—525, and 645—646). For a mere arrangement in order of magnitude or brightness, but without any numbers being expressed, see the Manual of Scientific Enquiry prepared for the Use of the Navy, 1849, p. 12. In order to render more complete the conventional language which has been hitherto used (*i. e.* the old classification into magnitudes), Sir John Herschel, in the Outlines of Astronomy, p. 645, has appended to the vulgar scale of magnitudes, a scale of photometric magnitudes obtained merely by the addition of 0·41, as is more fully explained in the Cape Observations, p. 370. I subjoin such a table, combining in it the stars of the Northern and Southern Hemispheres without distinction. See p. xlii. to p. xlv. at the close of the Notes belonging to this section.

(159) p. 83.—Argelander, Durchmusterung des nördl. Himmels zwischen 45° und 80° Decl. 1846, S. xxiv.—xxvi.; Sir John Herschel, Ast. Obs. at the Cape of Good Hope, p. 327, 340, and 365.

(160) p. 83.—Same work, p. 304; and Outlines, p. 522.

(161) p. 84.—Phil. Trans. Vol. lvii. for the year 1767, p. 234.

(162) p. 84.—Wollaston's comparison of the light of the Sun and of the Moon was made in 1799, and was based on shadows cast by wax-lights, while in the experiments with Sirius in 1826 and 1827 images reflected from a glass-globe were employed. The earlier assigned ratios of the intensity of the solar light as compared to that of the Moon differ very much from the results here given. Michell and Euler, proceeding from theoretical grounds, had respectively concluded 450000 and 374000 to 1. Bouguer, from measurements of the shadows of wax-lights, had even made it only 300000 to 1. Lambert considers the light of Venus, when at the brightest, to be 3000 fainter than that of the full Moon. According to Steinheil, the Sun would require to be 3286500 times further off than it is in order to appear to the inhabitants of

the Earth like Arcturus (Struve, Stellarum compositarum mensuræ micrometricæ, p. clxiii.); and Arcturus, according to Sir John Herschel, has for us only half the strength of light of Canopus (Herschel, Observations at the Cape, p. 34). All these ratios of intensity, and particularly the important comparison of the Sun, the full Moon, and the ashy light of our satellite, so different according to its position in reference to the reflecting Earth, deserve a final and much more serious examination.

(163) p. 84.—Outl. of Astr. p. 553; Astr. Observ. at the Cape, p. 363.

(164) p. 85.—William Herschel on the Nature of the Sun and Fixed Stars, in the Phil. Trans. for 1795, p. 62, and on the changes that happen to the fixed stars, in the Phil. Trans. for 1796, p. 186. Compare also Sir John Herschel, Observ. at the Cape, p. 350—352.

(165) p. 85.—Extrait d'une lettre de M. Arago à M. de Humboldt (Mai 1850):—

"a. *Mesures photométriques.*

"Il n'existe pas de photomètre proprement dit, c'est-à-dire d'instrument donnant l'intensité d'une lumière isolée; le photomètre de Leslie, à l'aide duquel il avait eu l'audace de vouloir comparer la lumière de la lune à la lumière du soleil, par des actions calorifiques, est complètement defectueux. J'ai prouvé en effet, que ce prétendu photomètre monte quand on l'expose à la lumière du soleil, qu'il descend sous l'action de la lumière du feu ordinaire, et qu'il reste complètement stationnaire lorsqu'il reçoit la lumière d'une lampe d'Argand. Tout ce qu'on a pu faire jusqu'ici, c'est de comparer entr'elles deux lumières en présence, et cette comparaison n'est même à l'abri de toute objection que lorsqu'on ramène ces deux lumières à l'égalité par un affaiblissement graduel de la lumière la plus forte. C'est comme critérium de cette égalité que j'ai employé les anneaux colorés. Si on place l'une sur l'autre deux lentilles d'un long foyer, il se forme autour de leur point de contact des anneaux colorés tant par voie de réflexion que par voie de transmission. Les anneaux réflechis sont complémentaires en couleur des anneaux transmis; ces deux séries d'anneaux se neutralisent mutuellement quand les deux lumières qui les forment et qui arrivent simultanément sur les deux lentilles, sont égales entr'elles.

"Dans le cas contraire on voit des traces ou d'anneaux réfléchis ou d'anneaux transmis, suivant que la lumière qui forme les premiers, est plus forte ou plus faible que la lumière à laquelle on doit les seconds. C'est dans ce sens seulement que les anneaux colorés jouent un rôle dans les mesures de la lumière auxquelle je me suis livré.

" b. *Cyanomètre.*

" Mon cyanomètre est une extension de mon polariscope. Ce dernier instrument, comme tu sais, se compose d'un tube fermé à l'une de ses extrémités par une plaque de cristal de roche perpendiculaire à l'axe, de 5 millemètres d'épaisseur; et d'un prisme doué de la double refraction, placé du coté de l'œil. Parmi les couleurs variées que donne cet appareil, lorsque de la lumière polarisée le traverse, et qu'on fait tourner le prisme sur lui-même, se trouve par un heureux hasard la nuance du bleu de ciel. Cette couleur bleue fort affaiblie, c'est-à-dire très mélangée de blanc lorsque la lumière est presque neutre, augmente d'intensité—progressivement à mesure que les rayons qui pénètrent dans l'instrument, renferment une plus grande proportion de rayons polarisés.

" Supposons donc que le polariscope soit dirigé sur une feuille de papier blanc; qu'entre cette feuille et la lame de cristal de roche il existe une pile de plaques de verre susceptible de changer d'inclinaison, ce qui rendra la lumière éclairante du papier plus ou moins polarisée; la couleur bleue fournie par l'instrument va en augmentant avec l'inclinaison de la pile, et l'on s'arrête lorsque cette couleur parait la même que celle de la région de l'atmosphère dont on veut déterminer la teinte cyanométrique, et qu'on regarde à l'œil nu immédiatement à côté de l'instrument. La mesure de cette teinte est donnée par l'inclinaison de la pile. Si cette dernière partie de l'instrument se compose du même nombre de plaques et d'une même espèce de verre, les observations faites dans divers lieux seront parfaitement comparables entr'elles."

([166]) p. 85.—Argelander de fide Uranometriæ Bayeri, 1842, p. 14—23: " in eadem classe littera prior majorem splendorem nullo modo indicat" (§ 9). According to this it is by no means proved by Bayer's authority that Castor was brighter in 1603 than Pollux.

PHOTOMETRIC ARRANGEMENT OF THE FIXED STARS.

I CONCLUDE this section with a table taken from Sir John Herschel's Outlines of Astronomy (p. 645 and 646): I am indebted for its arrangement and lucid explanation to my learned friend, Dr. Galle, from whose letter to myself, dated in March 1850, I subjoin the following extract :—

"The numbers in the Photometric Scale in the Outlines of Astronomy are results obtained from the 'Vulgar Scale,' by an addition throughout of 0·41. The author (Sir John Herschel) has arrived at these more exact determinations of star-magnitudes by observed 'sequences' of brightness, and by the combination of these observations with the average of the assigned magnitudes in ordinary use (Cape Observations, p. 304—352), taking more particularly the data in the Astronomical Society's Catalogue for 1827 as a basis. The proper photometric results of several stars by means of the Astrometer (Cape Observations, p. 353, *et seq.*) have not been employed directly in this table, but have only served in a general way as a means of judging of the relation or correspondence of the scale in common use (1st, 2d, 3d, &c. magnitudes), to the real quantities of light in different stars. There has thus been found the result (at all events remarkable), that the decrease of our ordinary star-magnitudes (1, 2, 3......) is approximately as if a star of the 1st magnitude were placed successively at distances of 1, 2, 3, ... whereby, according to photometric law, its brightness would have successively the values 1, $\frac{1}{4}$, $\frac{1}{9}$, $\frac{1}{16}$...... (Cape Observations, p. 371, 372; Outlines, p. 521, 522); but in order to make accordance still greater, it is only necessary to raise our star-magnitudes, as hitherto employed, about half a magnitude (or more exactly 0·41); so that in future a star of the 2·00 magnitude should be called of the 2·41 magnitude; a star of 2·5 magnitude, 2·91, and so on. Sir John Herschel has proposed this 'photometric' (raised) scale for acceptance (Cape Obs. p. 372; Outl. p. 522), and his proposal will surely be assented to: for, the difference from the Common or Vulgar Scale would 'hardly be felt' (Cape Obs. p. 372); and the table in the 'Outlines of Astronomy,' p. 645, *et seq.*, may already serve as a basis as far down as the 4th magnitude. The determination of magnitudes of stars according to this rule—viz. that the brightnesses of stars of the 1, 2, 3, 4...... magnitudes should be to each other in the ratio of 1, $\frac{1}{4}$, $\frac{1}{9}$, $\frac{1}{16}$......exactly, as they already are approximately,—is thus already in part practicable. Sir John Herschel (Outlines, p. 523; Cape Obs. p. 372) takes *α* Centauri as a normal star for the 1st magnitude of the Photometric Scale, and as the unit for the quantity of light. If, therefore, we square the photometric magnitude of a star, we have the inverse ratio of its quantity of light to that of *α* Centauri. So, for example, if *κ* Orionis is of photometric magnitude 3, it has $\frac{1}{9}$ of the light of *α* Centauri. At the same time, the number 3 would show *κ* Orionis to be 3 times as far from us as *α* Centauri, if we assume the two stars to be bodies equal in real magnitude and brightness. If another star—*ex. gr.* Sirius, which is four times as bright—had been chosen as the unit of the photometric magnitudes indicating distances, the regular conformity to law would not have been seen with so much simplicity. Nor is it without interest that the distance of *α* Centauri is known with some probability, and that among the distances of fixed stars which have yet been investigated it is the least. The author treats in the Outlines, p. 521, of the inferiority, in point of suitability, of other scales as compared with the photometric one, which advances according to the squares 1, $\frac{1}{4}$, $\frac{1}{9}$, $\frac{1}{16}$....... He also notices geometrical progressions—as, for example, 1, $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$......or 1, $\frac{1}{3}$, $\frac{1}{9}$, $\frac{1}{27}$...... The gradations which you selected in the Observations at the Equator in your American Expedition follow an arithmetical progression (Recueil d'Observ. astron. Vol. 1, p. lxxi.; and Schumacher, Astron. Nachr. No. 374). All these scales adapt themselves less well to the vulgar scale than to the photometric (quadratic) progression." In the following table, the 190 stars of the "Outlines of Astronomy" are arranged solely according to their magnitudes, without regard to South or North Declination.

List of 190 STARS of the First, Second, and Third Magnitudes, arranged according to the determinations of Sir JOHN HERSCHEL, and giving the ordinary or "vulgar" magnitudes with greater exactness than usual; as well as the *photometric* scale proposed by him.

STARS OF THE FIRST MAGNITUDE.

Star.	Vulgar Scale.	Photo. Scale.	Star.	Vulgar Scale.	Photo. Scale.
Sirius . .	0.08	0.49	α Orionis . .	1.0 :	1.43
η Argûs (Var.)	—	—	α Eridani . .	1.09	1.50
Canopus . .	0.29	0.70	Aldebaran .	1.1 :	1.5 :
α Centauri . .	0.59	1.00	β Centauri . .	1.17	1.58
Arcturus . .	0.77	1.18	α Crucis . .	1.2	1.6
Rigel . . .	0.82	1.23	Antares . .	1.2	1.6
Capella . .	1.0 :	1.4 :	α Aquilæ . .	1.28	1.69
α Lyræ . . .	1.0 :	1.4 :	Spica . . .	1.38	1.79
Procyon . .	1.0 :	1.4 :			

STARS OF THE SECOND MAGNITUDE.

Star.	Vulgar Scale.	Photo. Scale.	Star.	Vulgar Scale.	Photo. Scale.
Fomalhaut .	1.54	1.95	α Ursæ (Var.) .	1.96	2.37
β Crucis . .	1.57	1.98	ζ Orionis . .	2.01	2.42
Pollux . .	1.6 :	2.0 :	β Argûs . . .	2.03	2.44
Regulus . .	1.6 :	2.0 :	α Persei . . .	2.07	2.48
α Gruis . . .	1.66	2.07	γ Argûs . . .	2.08	2.49
γ Crucis . .	1.73	2.14	ε Argûs . . .	2.18	2.59
ε Orionis . .	1.84	2.25	η Ursæ (Var.) .	2.18	2.59
ε Canis . . .	1.86	2.27	γ Orionis . .	2.18	2.59
λ Scorpii . .	1.87	2.28	α Triang. austr.	2.23	2.64
α Cygni . . .	1.90	2.31	ε Sagittarii . .	2.26	2.67
Castor . .	1.94	2.35	β Tauri . . .	2.28	2.69
ε Ursæ (Var.) .	1.95	2.36	Polaris . .	2.28	2.69

Stars of the Second Magnitude—*continued.*

Star.	Vulgar Scale.	Photo. Scale.	Star.	Vulgar Scale.	Photo. Scale.
ϑ Scorpii . .	2.29	2.70	δ Argûs . . .	2.42	2.83
α Hydræ . .	2.30	2.71	ζ Ursæ . . .	2.43	2.84
δ Canis . . .	2.32	2.73	β Andromedæ .	2.45	2.86
α Pavonis . .	2.33	2.74	β Ceti . . .	2.46	2.87
γ Leonis . .	2.34	2.75	λ Argûs . . .	2.46	2.87
β Gruis . . .	2.36	2.77	β Aurigæ . .	2.48	2.89
α Arietis . .	2.40	2.81	γ Andromedæ .	2.50	2.91
σ Sagittarii . .	2.41	2.82			

Stars of the Third Magnitude.

Star.	Vulgar Scale.	Photo. Scale.	Star.	Vulgar Scale.	Photo. Scale.
γ Cassiopeiæ .	2.52	2.93	ε Scorpii . .	2.71	3.12
α Andromedæ .	2.54	2.95	ζ Argûs . . .	2.72	3.13
ϑ Centauri . .	2.54	2.95	β Ursæ . . .	2.77	3.18
α Cassiopeiæ .	2.57	2.98	α Phœnicis . .	2.78	3.19
β Canis . . .	2.58	2.99	ι Argûs . . .	2.80	3.21
χ Orionis . .	2.59	3.00	ε Boötis . .	2.80	3.21
γ Geminorum .	2.59	3.00	α Lupi . . .	2.82	3.23
δ Orionis . .	2.61	3.02	ε Centauri . .	2.82	3.23
Algol (Var.) .	2.62	3.03	η Canis . . .	2.85	3.26
ε Pegasi . .	2.62	3.03	β Aquarii . .	2.85	3.26
γ Draconis . .	2.62	3.03	δ Scorpii . .	2.86	3.27
β Leonis . .	2.63	3.04	ε Cygni . . .	2.88	3.29
α Ophiuchi . .	2.63	3.04	η Ophiuchi . .	2.89	3.30
β Cassiopeiæ .	2.63	3.04	γ Corvi . . .	2.90	3.31
γ Cygni . . .	2.63	3.04	α Cephei . .	2.90	3.31
α Pegasi . .	2.65	3.06	η Centauri . .	2.91	3.32
β Pegasi . .	2.65	3.06	α Serpentis . .	2.92	3.33
γ Centauri . .	2.68	3.09	δ Leonis . .	2.94	3.35
α Coronæ . .	2.69	3.10	χ Argûs . . .	2.94	3.35
γ Ursæ . . .	2.71	3.12	β Corvi . . .	2.95	3.36

STARS OF THE THIRD MAGNITUDE—*continued.*

Star.	Vulgar Scale.	Photo. Scale.	Star.	Vulgar Scale.	Photo. Scale.
β Scorpii . .	2.96	3.37	ϑ Argûs . . .	3.26	3.67
ζ Centauri . .	2.96	3.37	β Hydri . . .	3.27	3.68
ζ Ophiuchi . .	2.97	3.38	ζ Persei . . .	3.27	3.68
α Aquarii . .	2.97	3.38	ζ Herculis . .	3.28	3.69
π Argûs . . .	2.98	3.39	ε Corvi . . .	3.28	3.69
γ Aquilæ . .	2.98	3.39	ι Aurigæ . .	3.29	3.70
δ Cassiopeiæ .	2.99	3.40	γ Urs. min. . .	3.30	3.71
δ Centauri . .	2.99	3.40	η Pegasi . .	3.31	3.72
α Leporis . .	3.00	3.41	β Aræ . . .	3.31	3.72
δ Ophiuchi . .	3.00	3.41	α Toucani . .	3.32	3.73
ζ Sagittarii . .	3.01	3.42	β Capricorni .	3.32	3.73
η Boötis . . .	3.01	3.42	ρ Argûs . . .	3.32	3.73
η Draconis . .	3.02	3.43	ζ Aquilæ . .	3.32	3.73
π Ophiuchi . .	3.05	3.46	β Cygni . . .	3.33	3.74
β Draconis . .	3.06	3.47	γ Persei . . .	3.34	3.75
β Libræ . . .	3.07	3.48	μ Ursæ . . .	3.35	3.76
γ Virginis . .	3.08	3.49	β Triang. bor. .	3.35	3.76
μ Argûs . . .	3.08	3.49	π Scorpii . .	3.35	3.76
β Arietis . .	3.09	3.50	β Leporis . .	3.35	3.76
γ Pegasi . .	3.11	3.52	γ Lupi . . .	3.36	3.77
δ Sagittarii . .	3.11	3.52	δ Persei . . .	3.36	3.77
α Libræ . . .	3.12	3.53	ψ Ursæ . . .	3.36	3.77
λ Sagittarii . .	3.13	3.54	ε Aurigæ (Var.)	3.37	3.78
β Lupi . . .	3.14	3.55	υ Scorpii . .	3.37	3.78
ε Virginis ? . .	3.14	3.55	ι Orionis . .	3.37	3.78
α Columbæ . .	3.15	3.56	γ Lyncis . .	3.39	3.80
ϑ Aurigæ . .	3.17	3.58	ζ Draconis . .	3.40	3.81
β Herculis . .	3.18	3.59	α Aræ . . .	3.40	3.81
ι Centauri . .	3.20	3.61	π Sagittarii . .	3.40	3.81
δ Capricorni .	3.20	3.61	π Herculis . .	3.41	3.82
δ Corvi . . .	3.22	3.63	β Can. min. ? .	3.41	3.82
α Can. ven. . .	3.22	3.63	ζ Tauri . . .	3.42	3.83
β Ophiuchi . .	3.23	3.64	δ Draconis . .	3.42	3.83
δ Cygni . . .	3.24	3.65	μ Geminorum .	3.42	3.83
ε Persei . . .	3.26	3.67	γ Boötis . .	3.43	3.84
η Tauri ? . .	3.26	3.67	ε Geminorum .	3.43	3.84
β Eridani . .	3.26	3.67	α Muscæ . .	3.43	3.84

STARS OF THE THIRD MAGNITUDE—*continued.*

Star.	Vulgar Scale.	Photo. Scale.	Star.	Vulgar Scale.	Photo. Scale.
α Hydri ? . .	3.44	3.85	ι Ursæ . . .	3.46	3.87
τ Scorpii . .	3.44	3.85	η Aurigæ . .	3.46	3.87
δ Herculis . .	3.44	3.85	γ Lyræ . . .	3.47	3.88
δ Geminorum .	3.44	3.85	η Geminorum .	3.48	3.89
q Orionis . .	3.45	3.86	γ Cephei . .	3.48	3.89
β Cephei . .	3.45	3.86	κ Ursæ . . .	3.49	3.90
ϑ Ursæ . . .	3.45	3.86	ε Cassiopeiæ .	3.49	3.90
ζ Hydræ . .	3.45	3.86	ϑ Aquilæ . .	3.50	3.91
γ Hydræ . .	3.46	3.87	σ Scorpii . .	3.50	3.91
β Triang. austr.	3.46	3.87	τ Argûs . . .	3.50	3.91

"The following statement of the Quantities of Light in 17 Stars of the First Magnitude (as they follow from the *photometric* magnitudes) may possess some interest:—

Sirius	4.165	α Orionis	0.489
η Argûs	—	α Eridani	0.444
Canopus	2.041	Aldebaran . . .	0.444
α Centauri	1.000	β Centauri	0.401
Arcturus	0.718	α Crucis	0.391
Rigel	0.661	Antares	0.391
Capella	0.510	α Aquilæ	0.350
α Lyræ	0.510	Spica	0.312
Procyon	0.510		

as may also the Quantities of Light in Stars which are *exactly* of the First to the Sixth Magnitudes:

Magnitude according to the vulgar scale.	Quantity of light.
1.00	0.500
2.00	0.172
3.00	0.086
4.00	0.051
5.00	0.034
6.00	0.024

the quantity of light in α Centauri being the unit throughout.'

([167]) p. 86.—Kosmos, Bd. iii. S. 49 and 57, Anm. 32 and 33 (English edition, p. 39, and Notes 78 and 79).

([168]) p. 87.—Kosmos, Bd. i. S. 185 and 428, Anm. 14 (English edition, p. 168, Note 144).

([169]) p. 89.—On the Space-penetrating Power of Telescopes, in Sir John Herschel's Outl. of Astr. § 803.

([170]) p. 89.—I cannot attempt to compress within the limits of a note *all* the reasons upon which Argelander's views are founded. It will be sufficient for me to insert the following extracts from some of his letters to myself:— "A few years ago (1843) you requested Captain Schwink to estimate for you the number of stars visible on the whole celestial vault, from the 1st to the 7th magnitude inclusive, according to the proportion of those entered in his Mappa cœlestis. He finds 12148 stars between −30° and +90° Decl.; consequently, assuming the same frequency of stars from −30° Decl. to the South Pole, there would be in the entire firmament 16200 stars of the above-named magnitudes. This estimation seems to me also to come very near the truth. We know that, if we only consider the general mass, each successive class or magnitude contains about three times as many stars as the preceding one (Struve, Catalogus Stellarum duplicium, p. xxxiv.; Argelander, Bonner Zonen, S. xxvi.) Now in my Uranomètrie I have 1441 stars of the 6th magnitude North of the Equator, whence there would follow, for the entire heavens, about 3000; but this does not include stars of the 6·7 magnitude, which yet, if whole classes only were counted, would be reckoned as belonging to the 6th class. I think we might take these at 1000: so that we should have 4000 stars of the 6th magnitude; and thus, according to the above-mentioned rule, 12000 stars of the 7th magnitude,—or 18000 stars from the 1st to the 7th magnitude inclusive. I arrive at a rather more exact conclusion, by means of other considerations respecting the number of stars of the 7th magnitude which I have marked in my zones, viz. 2251 (pag. xxvi.); having regard to stars which have been observed more than once, and to those which have probably been overlooked. In this way I find, between 45° and 80° North Decl., 2340 stars of the 7th magnitude, and thence, over the whole heavens, about 17000 stars. Struve, in the Description de l'Observatoire de Poulkova, p. 268, gives the number of stars down to the 7th magnitude, in the region of the heavens examined by him (*i. e.* −15° to +90°), 13400; whence there would follow, for the entire heavens, 21300. According to the Introduction to Weisse's Catal. e Zonis Regiomontanis ded. p. xxxii., Struve finds, by the calculus of probabilities, 3903 stars from the

1st to the 7th magnitude in the zone from $-15°$ to $+15°$; whence, in the whole heavens, 15050 such stars. This number is less than mine, because Bessel estimated the brighter stars about half a magnitude lower than I did. It is only a mean number which we can look for here; and this we might take, therefore, at 18000 stars from the 1st to the 7th magnitude inclusive. In the passage of the Outlines of Astronomy, p. 521, of which you remind me, Sir John Herschel speaks only of the stars already registered: 'The whole number of stars already registered, down to the 7th magnitude inclusive, amounting to from 12000 to 15000.' As respects the fainter stars of the 8th and 9th magnitudes, Struve finds, in the above-mentioned zone of $-15°$ to $+15°$, of stars of the 8th magnitude, 10557; and of stars of the 9th magnitude, 37739: consequently, for the whole heavens, 40800 stars of the 8th, and 145800 stars of the 9th magnitude. Thus we should have, according to Struve, from the 1st to the 9th magnitude inclusive, $15100+40800+145800=201700$ stars. These numbers were found by Struve by carefully comparing those zones or parts of zones which included the same parts of the heavens; and from the number of stars common to them, and the number of those which were different, concluding, by the calculus of probabilities, the number of stars actually existing. This calculation deserves very great confidence, as a large number of stars have contributed to form its basis. Bessel has entered in the whole of his zones between $-15°$ and $+45°$, about 61000 different stars from the 1st to the 9th magnitude inclusive (after deducting stars observed more than once, and stars of 9·10 magnitude); whence, taking into account those which have been probably overlooked, there would follow, for the part of the heavens which has been mentioned, about 101500 of the magnitudes in question. My zones between $+45°$ and $+80°$ contain about 22000 different stars (Durchmusterung des nördl. Himmels, S. xxv.): from this number we must deduct about 3000 of the 9·10 magnitude; leaving 19000. My zones are somewhat richer than Bessel's, and I do not think I can assume more than 28500 as the number of actually existing stars within their limits (between $+45°$ and $+80°$): so that we should have 130000, to the 9th magnitude inclusive, between $-15°$ and $+80°$. This is about 0·62181 of the entire heavens; so that, assuming a generally equable distribution, we should have over the entire firmament 209000 stars, or thus again nearly the same number as that assigned by Struve: perhaps even it may be one not inconsiderably greater, as Struve has reckoned the stars of 9·10 magnitude as belonging to the 9th magnitude. The numbers which, according to my views, I should say might be assumed for the entire heavens, would thus be—1st mag. 20, 2d mag. 65, 3d mag. 190, 4th mag. 425, 5th mag. 1100, 6th mag. 3200, 7th mag. 13000, 8th mag. 40000, 9th mag. 142000; making together, from the 1st to the 9th magnitudes inclusive, 200000 stars. If you should object to me, that Lalande (Hist. céleste, p. iv.) gives the number of stars visible to the naked eye, observed by himself, at 6000, I should remark in reply that there are amongst them very many observed more than once; and that, omitting these, we arrive approximately at only 3800 stars for the part of the heavens comprised by Lalande's observations—*i. e.* between $-26° 30'$ and $+90°$. As this is 0·72310 of the entire heavens, the resulting number of stars visible to the naked eye throughout the firmament would again be 5255. A review of the Uranography of Bode, composed from very heterogeneous elements (17240 stars), after deducting nebulæ and smaller stars, as well as stars of 6·7 magnitude raised to the 6th magnitude, gives not above 5600 stars from the 1st to the 6th magnitude inclusive. A similar estimation for the whole heavens, corresponding to the number of stars from the 1st to the 6th magnitude inclusive, registered by Lacaille, between the South Pole and the Tropic of Capricorn, confirms also the mean result previously given to you, since it falls between the limits of 3960 and 5900. You see that I have willingly endeavoured to fulfil your wish for a more thorough investigation of the numbers. I may add that Heis, of Aix-la-Chapelle, has been for several years engaged in an exceedingly careful revision of my Uranomètrie. According to the portion of this work which is already completed, and according to the considerable augmentations which have been made to my Uranomètrie by an observer gifted with more acute vision, I find for the Northern Hemisphere 2836 stars from the 1st to the 6th magnitude inclusive: and hence, on the assumption of equal distribution over the whole firmament, we have again 5672 stars visible to highly acute unassisted vision" (MS. communication from Professor Argelander, March 1850).

([171]) p. 90.—Of stars down to the 6th magnitude, Schubert reckoned the number for the whole heavens at 7000,—almost the same as the number assumed by me in the first volume of Cosmos (English edition, p. 140), and for the horizon of Paris above 5000; and down to the 9th magnitude inclusive for the whole sphere, 70000 (Astronomie, Th. iii. S. 54). All these numbers are considerably too high. Argelander finds, from the 1st to the 8th magnitude, only 58000.

([172]) p. 90.—"Patrocinatur vastitas cœli, immensa discreta altitudine, in duo atque septuaginta signa. Hæc sunt rerum et animantium effigies, in quas digessere cœlum periti. In his quidem mille sexcentas adnotavere stellas, insignes videlicet effectu visuve." . . . (Plin. ii. 41.) "Hipparchus nunquam satis laudatus, ut quo nemo magis approbaverit cognationem cum homine siderum animasque nostras partem esse cœli, novam stellam et aliam in ævo suo genitam deprehendit, ejusque motu, qua die fulsit, ad dubitationem est adductus, anne hoc sæpius fieret moverenturque et eæ quas putamus affixas; itemque ausus rem etiam Deo improbam, adnumerare posteris stellas ac sidera ad nomen expungere, organis excogitatis, per quæ singularum loca atque magnitudines signaret, ut facile discerni posset ex eo, non modo an obirent nascerenturve, sed an omnino aliqua transirent moverenturve, item an crescerent minuerenturque, cœlo in hereditate cunctis relicto, si quisquam qui cretionem eam caperet inventus esset" (Plin. ii. 26).

([173]) p. 91.—Delambre, Hist. de l'Astr. anc. T. i. p. 290; and Hist. de l'Astr. mod. T. ii. p. 186.

([174]) p. 91.—Outlines, § 831; Edouard Biot sur les Etoiles Extraordinaires observées en Chine, in the Connaissance des Temps pour 1846.

([175]) p. 91.—It is to Aratus that the Apostle Paul refers with implied praise in his discourse at Athens (Acts, ch. xvii., v. 28). The name is not, indeed, mentioned, but it is impossible to mistake the allusion to a passage from Aratus (Phæn. v. 5) on the community of mortals with the Deity. Aratus is also singularly enough referred to at a not very different date by Ovid (Amor. i. 15).

([176]) p. 92.—Ideler, Untersuchungen über den Ursprung der Sternnamen, S. 30—35. Baily, in the Mem. of the Astron. Soc., Vol. xiii. 1843, pp. 12 and 15, also treats of the dates according to the Christian era, with which we should connect the observations of Aristyllus, as well as the Star-tables of Hipparchus (128, not 140, B.C.), and of Ptolemy A.D. 138.

([177]) p. 92.—Compare Delambre, Hist. de l'Astr. anc. T. i. p. 184; T. ii. p. 260. The statement, that although Hipparchus always designates the stars by their Right Ascension and Declination, yet that his Star-catalogue, like that of Ptolemy, was arranged according to longitude and latitude, appears to have little probability in its favour; and is in contradiction to the Almagest, book vii. cap. 4, where the relations to the Ecliptic are spoken of as something novel, tending to facilitate the knowledge of the movement of the fixed stars round the pole of the Ecliptic. The Star-table with appended longitudes, discovered by Petrus Victorius in a Medicean codex, and published with the life of Aratus, at Florence, in 1567, is indeed attributed by him to Hipparchus but without proof. It appears to be a mere transcript of Ptolemy's Table, from an old manuscript of the Almagest, omitting all the latitudes. As Ptolemy was but imperfectly acquainted with the amount of the retrogression of the equinoctial and solstitial points, (Almag. vii. c. 2, p. 13, Halma), and had assumed it about 0·28 too slow, his table (Ideler, in the work above cited, p. 34), which he intended to correspond to the beginning of the reign of Antoninus, gives the places of the stars for a much earlier epoch (*i. e.* for the year A.D. 63). Compare also considerations and tables for facilitating the reduction of modern star places to the time of Hipparchus, given by Encke in Schumacher's Astr. Nachr., No. 608, S. 113 to 126. The earlier epoch for which, unknown to its author, Ptolemy's table represents the firmament, coincides very probably with the epoch to which we may refer the Catasterisms of the Pseudo-Eratosthenes, which, as I have already remarked elsewhere, are later than the Augustean Hyginus, appear to be taken from him, and are unconnected with the poem of Hermes by the true Eratosthenes. (Eratosthenica, composuit God. Bernhardy, 1822, p. 114, 116, and 129.) These Catasterisms of the Pseudo-Eratosthenes contain barely 700 separate stars distributed among the mythical constellations.

(178) p. 93.—Kosmos, Bd. ii. S. 260 and 433; English edition, p. 224, and lxix. note 354. The Paris Library possesses a manuscript of the Ilkhanian Tables, written by the hand of the son of Nassir-Eddin. They take their name from the title Ilkhan, assumed by the Tartar princes who reigned in Persia. Reinaud Introd. de la Géogr. d'Aboulféda, 1848, p. 139.

(179) p. 93.—Sédillot fils, Prolégomènes des Tables Astr. d'Olong-Beg, 1847, p. 134; Note 2; Delambre, Hist. de l'Astr. du moyen âge, p. 8.

(180) p. 93.—In my examinations into the relative value of astronomical determinations of geographical positions in the interior of Asia, (Asie Centrale, T. iii. p. 581—596), I have given the latitudes of Samarcand and Bokhara according to the different Arabian and Persian manuscripts in the Paris Library. I have shewn that the latitude of Samarcand is probably above 39° 52′, while the greater number and best MSS. of Ulugh Beig have 39° 37′, and the Kitab al-athual of Alfares, and the Kanun of Albyruni, 40°. I think it right again to call attention to the importance to geography and to the history of astronomy, of a new and trustworthy determination of the latitude and longitude of Samarcand. We know the latitude of Bokhara by culminations of stars from Burnes' Travels; they make it 39° 43′ 41″. This would give the errors of the two fine Persian and Arabian MSS. (Nos. 164 and 2460) in the Paris Library at only 7 to 8 minutes; but Major Rennell, generally so happy in his combinations, would have been in error 19′ for the latitude of Bokhara.

(Humboldt, Asie Centrale, T. iii. p. 592; and Sédillot in the Prolégomènes d'Oloug-Beg, p. 123—125.)

(181) p. 94.—Kosmos, Bd. ii. S. 327—332, and 485 Anm. 5—8; English edition, p. 287—292, and notes 446—448; Humboldt, Examen Critique de l'Histoire de la Géographie, T. iv. p. 321—336; T. v. p. 226—238.

(182) p. 94.—Cardani Paralipomenon, lib. viii. cap. 10; (Opp. T. ix. ed. Lugd. 1663, p. 508).

(183) p. 95.—Kosmos, Bd. i. S. 90—93: Eng. edition, p. 78—80.

(184) p. 96.—Baily, Catalogue of those Stars in the Histoire Céleste of Jérôme De Lalande, for which tables of reduction to the epoch 1800 have been published by Prof. Schumacher, 1847, p. 1195. On the benefits of complete Star-catalogues, see the remarks of Sir John Herschel, Cat. of the British Assoc., 1845, p. 4, S. 10. Compare also, respecting Missing Stars, Schumacher, Astr. Nachr., No. 624, and Bode's Jahrb. for 1817, S. 249.

(185) p. 97.—Memoirs of the Royal Astron. Soc., Vol. xiii. 1843, pp. 33 and 168.

(186) p. 97.—Bessel, Fundamenta Astronomiæ pro anno 1755, deducta ex observationibus viri incomparabilis James Bradley in Specula astronomica Grenovicensi, 1818. (Compare also Bessel, Tabulæ Regiomontanæ reductionum observationum astronomicarum ab anno 1750 usque ad annum 1850 computatæ, 1830.)

(187) p. 97.—I compress into a note a brief list of Star-Catalogues containing lesser masses, or a smaller number of positions, adding the name of the observer, and the number of the determinations of place. Lacaille (who observed for barely ten months in 1751 and 1752, and with a magnifying power of only eight times), 9766 southern stars to the 7th magnitude inclusive, reduced to the year 1750 by Henderson; Tobias Mayer, 998 stars for 1756; Flamsteed, originally 2866, but augmented by Baily's care by 564 additional (Mem. of the Astr. Soc. Vol. iv. p. 129—164); Bradley, 3222, reduced by Bessel to the year 1755; Pond, 1112; Piazzi, 7646 stars for 1800; Groombridge, 4243, mostly circumpolar stars, for 1810; Brisbane and Rümker, 7385 southern stars, observed in New Holland in the years 1822—1828; Airy, 2156 stars, reduced to the year 1845; Rümker, 12,000, on the Hamburg horizon; Argelander (Cat. of Abo), 560; Taylor (Madras), 11015. The British Association Catalogue, 1845, reduced under Mr. Baily's superintendence, contains 8377 stars, from the 1st magnitude to the 7½. For the most southern stars, we have besides, the rich registers of Henderson, Fallows, Maclear, and Johnson at St. Helena.

([188]) p. 98.—Weisse, Positiones mediæ stellarum fixarum in Zonis Regiomontanis a Besselio inter—15° et + 15° decl. observatarum ad annum 1825, reductæ (1846); with an important Preface by Struve.

([189]) p. 99.—Encke, Gedächtniss rede auf Bessel, S. 13.

([190]) p. 99.—Compare Struve, Etudes d'Astr. stellaire, 1847, p. 66 and 72; Kosmos, Bd. i. S. 156 (English edition, p. 140); and Mädler Astr. 4th Aufl. S. 417.

([191]) p. 102.—Kosmos, Bd. ii. S. 197 and 432, Anm. 11 (English edition, p. 163, and note 251).

([192]) p. 102.—Ideler, Unters. über die Sternnamen, S. xi. 47, 139, 144, and 243; Letronne sur l'Origine du Zodiaque grec 1840, p. 25.

([193]) p. 103.—Letronne, id. p. 25, and Carteron, Analyse des Recherches de M. Letronne sur les Représentations Zodiacales, 1843, p. 119; "Il est très douteux qu'Eudoxe (Ol. 103) ait jamais employé le mot ζωδιακός. On le trouve pour la première fois dans Euclide et dans le Commentaire d'Hipparque sur Aratus (Ol. 160). Le nom d'écliptique ἐκλειπτικός est aussi fort récent." (Compare Martin in the Commentary to Theonis Smyrnæi Platonici Liber de Astronomia, 1849, p. 50 and 60.)

([194]) p. 103.—Letronne, Orig. du Zod. p. 25, and Analyse crit. des Représ. Zod. 1846, p. 15. Ideler and Lepsius also consider it probable that "the knowledge of the Chaldean zodiac, both as respects the division and the name, had reached the Greeks as early as the 7th century before our era, but that the reception of the several zodiacal figures into the Grecian astronomical literature was later, and only followed gradually" (Lepsius, Chronologie der Ægypter, 1849, S. 65 and 124). Ideler is inclined to believe that the Orientals had for their twelve divisions (Dodecatomery) names, but without figures; Lepsius thinks it natural to suppose "that the Grecks, at a time when their sphere was in great part unoccupied, would add to their own the Chaldean constellations from which the twelve divisions were named." But, on this supposition, might we not ask why the Greeks should have had at first only eleven signs, and not all the twelve signs of the Chaldean Dodecatomery? If they had received twelve figures, they would surely not have cut out one to replace it subsequently.

([195]) p. 104.—On the passage referred to in the text, and interpolated by a transcriber as if belonging to Hipparchus, see Letronne, Orig. du Zod. 1840, p. 20. As early as 1812, when I was myself still inclined to suppose that the Greeks had been very early acquainted with the sign of the Balance, I pointed out, in a carefully written memoir on the passages from Greek and

Roman Antiquity, in which the name of the Balance as a zodiacal sign occurs, the passage of Hipparchus (Comment. in Aratum, lib. iii. cap. 2), in which there is mention of the *θηρίον* which holds the Centaur (by his fore-foot), as well as the remarkable passage of Ptolemy, lib. ix. cap. 7 (Halma, T. ii. p. 170). In this latter passage the southern Balance is named, with the addition *κατὰ Χαλδαίους*, and is opposed to the Pincers (Scheeren) of the Scorpion, in an observation certainly not made in Babylon, but by the astrological Chaldeans scattered in Syria and Alexandria (Vues des Cordillères et Monumens des peuples indigènes de l'Amérique, T. ii. p. 380). Buttmann was disposed to think, but which seems little probable, that the *χηλαι* had originally signified the two scales of the Balance, and were afterwards by a misunderstanding converted into the pincers of a scorpion. (Compare Ideler "Untersuchungen über die astronomischen Beobachtungen der Alten," S. 374, and the same writer, "über die Sternnamen," S. 174—177, with Carteron, "Recherches de M. Letronne," p. 113). In the analogy between many names of the twenty-seven "houses of the moon," and the Dodecatomery of the zodiac, it has always appeared to me remarkable that we find the sign of the Balance among the certainly very ancient Indian Nakschatras (moon-houses). (Vues des Cordillères, T. ii. p. 6—12.)

([196]) p. 104.—Compare A. W. von Schlegel über Sternbilder des Thierkreises im alten Indien, in der Zeitschrift für die Kunde des Morgenlandes, Bd. i. Heft 3, 1837, and his Commentatio de Zodiaci antiquitate et origine, 1839, with Adolph Holtzmann über den griechischen Ursprung des indischen Thierkreises, 1841, S. 9, 16, and 23. In the last-named work, it is said:—The passages adduced from the Amarakoscha and the Ramayana are not of doubtful interpretation—they speak in the clearest terms of the zodiacal circle itself; but if the works which contain them were composed before the knowledge of the Greek Zodiac could have reached India, it ought to be closely examined whether those passages are not more recent interpolations."

([197]) p. 105—Compare Buttmann in the Berlin Astron. Jahrbuch for 1822, S. 93; Olbers, on the more modern constellations, in Schumacher's Jahrbuch for 1840, S. 238—251, and Sir John Herschel, Revision and Rearrangement of the Constellations with special reference to those of the Southern Hemisphere, in the Memoirs of the Astr. Soc., Vol. xii. p. 201—224 (with a very exact distribution of the Southern Stars of the 1st to 4th magnitudes). On the occasion of the formal discussion between Lalande and Bode, respecting the introduction of Lalande's house-cat and of a harvest-man (Messier!), Olbers complains, that in order to make room for new figures, "Andromeda must lay her arm in another place than that which it has occupied for 3000 years."

([198]) p. 105.—Kosmos, Bd. iii. S. 37 and 53 (English edition, p. 28 and note 52).

([199]) p. 105.—According to Democritus and his scholar Metrodorus, Stob Eclog. phys. p. 582.

([200]) p. 106.—Plut. de Plac. Phil. ii. 11; Diog. Laert. viii. 77; Achilles. Tat. ad Arat. cap. 5; Εμπ, *κρυσταλλώδη τοῦτον* (*τὸν οὐρανὸν*) *εἶναί φησιν, ἐκ τοῦ παγετώδους συλλεγέντα*; so also we find only the expression crystal-like or crystalline in Diog. Laert. viii. 77, and Galenus, Hist. phil. 12 (Sturz, Empedocles Agrigent, T. i. p. 321). Lactantius de opificio Dei, c. 17: an si mihi quispiam dixerit *æneum* esse cœlum, aut *vitreum*, aut, ut Empedocles ait, ærem *glaciatum*, statimne assentiar, quia cœlum ex qua materia sit ignorem? Respecting this cœlum vitreum, we have no earlier Hellenic evidence; for only one celestial body, the Sun, is termed by Philolaos a glass-like or vitreous body, which receives and throws back to us the rays from the central fire. The view of Empedocles, referred to in the text, of the reflection of the solar light from the Moon, speaking of the latter as a body which had consolidated in the manner of hail stones, is mentioned by Plutarch, apud Euseb. Praep. Evangel. i. p. 21, D, and de facie in orbe Lunæ, cap. 5. When in Homer and Pindar the epithets *χάλκεος* and *σιδήρεος* are applied to Uranos, it is only in a figurative sense, like hearts of brass, voice of brass, as signifying stedfast, enduring, imperishable (Völcker über Homerische Geographie, 1830, S. 5). The word *κρύσταλλος* applied to the ice-like, transparent substance of rock-crystal, first occurs before Pliny, in Dyonisius Periegetes, 781, Ælian, xv. 8, aud in Strabo, xv. p. 717, Casaub. The supposition that the idea of the crystal heavens, as a vault of ice (äer glaciatus of Lactantius), had arisen among the ancients, from observing, when travelling among mountains, the increasing cold in ascending, and from the sight of snow-capped mountains, is refuted by our knowing that they imagined a fiery ether to exist at the limit of our atmosphere (Aristot. Meteorol. i. 3; de Cælo, ii. 7, p. 289). In speaking of the music of the spheres, which, "according to the Pythagoreans, is unheard by men because it never ceases, and sounds are only heard if interrupted by silence," Aristotle (de Cœlo, ii. p. 290) affirms, singularly enough, that the motion of the spheres produces heat in the air below, but without heating themselves. Their vibrations produce heat, not sound. "The motion of the sphere of the fixed stars is the most rapid (Aristot. de Cælo, ii. 10, p. 291); and while this sphere and the bodies attached to it revolve around, the space nearest thereto is continually heated by this movement, and thus there is produced a warmth which extends down to the surface of the earth" (Meteorol. i. 3, p. 340). I have always been struck by the circumstance that Aristotle avoids the term "crystal heaven," although the expression affixed to stars, *ἐνδεδεμένα ἄστρα,* seems to indicate the general idea of solid spheres, but without specifying the kind of material. Cicero is not very intelligible on this point, but in his commentator (Macrobius in Cic. Somnium Scipionis, i. c. 20, p. 99, ed. Bip.) we find traces of freer ideas respecting the decrease of heat in increasing height. According to him, the extreme zones of the heavens are subject to perpetual cold. "Ita enim non solum terram sed ipsum quoque cœlum, quod vere mundus vocatur, temperari a sole certissimum est, ut extremitates ejus, quæ a via solis longissime recesserunt, omni careant beneficio caloris et una frigoris perpetuitate torpescant." These "extremitates cœli," in which the Bishop of Hippo (Augustinus, ed. Antv. 1700, i. p. 102, and iii. p. 99) placed, as in a region of ice-cold water, the uppermost and therefore the coldest of all planets, Saturn, still belong to the atmosphere, for it is only still higher above this extreme limit that, according to an earlier statement of Macrobius (i. c. 19, p. 93), is placed the fiery æther, which, strangely enough, does not prevent that eternal cold. "Stellæ supra cœlum locatæ, in ipso purissimo æthere sunt, in quo omne, quidquid est, lux naturalis et sua est (the seat of self-luminous heavenly bodies), quæ tota cum igne suo ita sphæræ solis incumbit, ut cœli zonæ, quæ procul a sole sunt, perpetuo frigore oppressæ sint." If I enter into so much detail respecting the connection of ideas in meteorology and physics entertained by the Greeks and Romans, it is only because, excepting in the works of Ukert, Henri Martin, and the excellent fragment of Meteorologia Veterum by Julius Ideler, these subjects have hitherto been treated only in a very incomplete, and, most often, superficial manner.

([201]) p. 106.—That fire had the power of rigidifying (Aristot. Probl. xiv. 11), and that the formation of ice itself is promoted by heat, were deeply-rooted opinions in the Physics of the Ancients, resting on a fanciful antithetical theory (Antiperistasis), or obscure ideas of polarity (a calling forth of opposite qualities or states); Kosmos, Bd. iii. S. 15 and 29 (English edition, p. 15 and note 22). Hail, it is said, is formed in larger masses when the atmospheric strata are warmer (Aristot. Meteor. i. 12). In winter fishing on the shores of the Euxine, hot water was used to increase the formation of ice, in the vicinity of an upright tube (Alex. Aphrodis. fol. 86, and Plut. de Primo Frigido, c. 12).

([202]) p. 107.—Kepler says expressly, in Stella Martis, fol. 9, "Solidos orbes rejeci; and in Stella Nova, 1606, cap. 2, p. 8, "planetæ in puro æthere, perinde atque aves in aere, cursus suos conficiunt." (Compare also p. 122.) Earlier, however, his opinion had been inclined in favour of a solid icy celestial vault (orbis ex aqua factus gelu concreta propter solis absentiam). Kepler, Epit. Astr. Copern. i. 2, p. 51. Two thousand years before Kepler, Empedocles said that the fixed stars were fastened to the crystal heaven, but that the planets were free and unrestrained (*τοὺς δὲ πλανήτας ἀνεῖσθαι*). (Plut. Plac. Phil. ii. 13; Emped. i. p. 335, Sturz; Euseb. Praep. Evang. xv. 30, Col. 1688, p. 839.) It is difficult to conceive in what manner the fixed stars were imagined to be attached to solid spheres, and yet to revolve singly, as supposed by Plato in the Timæus (Tim. p. 40, B), but not by Aristotle.

([203]) p. 108.—Kosmos, Bd. ii. S. 352 and 506 (English edition, p. 312, and note 478).

([204]) p. 108.—Kosmos, Bd. iii. S. 67 and 113 (English edition, p. 50, and note 105).

([205]) p. 108.—"Les principales causes de la vue indistincte sont: aberration de sphéricité de l'œil, diffraction sur les bords de la pupille, communication d'irritabilité à des points voisins sur la rétine. La vue confuse est celle où le foyer ne tombe pas exactement sur la rétine, mais tombe ou devant ou derrière la rétine. Les queues des étoiles sont l'effet de la vision indistincte autant qu'elle depend de la constitution du cristallin. D'après un très ancien mémoire de Hassenfratz (1809), 'les queues au nombre de 4 ou 8 qu'offrent les étoiles ou une bougie vue à 25 mètres de distance, sont les caustiques du cristallin formées par l'intersection des rayons refractés.' Ces caustiques se meuvent à mesure que nous inclinons la tête. La propriété de la lunette de terminer l'image fait qu'elle concentre dans un petit espace la lumière qui sans cela en aurait occupé un plus grand. Cela est vrai pour les étoiles fixes et pour les disques des planètes. La lumière des étoiles qui n'ont pas de disques réels, conserve la même intensité quelque soit le grossissement. Le fond de l'air duquel se détache l'étoile dans la lunette, devient plus noir par le grossissement qui dilate les molécules de l'air qu'embrasse le champ de la lunette. Les planètes à vrais disques deviennent elles-mêmes plus pâles par cet effet de dilatation.—Quand la peinture focale est nette, quand les rayons partis *d'un point* de l'objet se sont concentrés en *un seul point* dans l'image, l'oculaire donne des résultants satisfaisants. Si au contraire les rayons émanés d'un point ne se réunissent pas au foyer en un seul point, s'ils y forment *un petit cercle*, les images de deux points contigus de l'objet empiètent nécessairement l'une sur l'autre; leurs rayons se confondent. Cette confusion la lentille oculaire ne saurait la faire disparaître. L'office qu'elle remplit exclusivement, c'est de grossir; elle grossit tout ce qui est dans l'image, les defauts comme le reste. Les étoiles n'ayant pas de diamètres angulaires sensibles, ceux qu'elles conservent toujours tiennent pour la plus grande partie au manque de perfection des instrumens (à la courbure moins regulière donnée aux deux faces de la lentille objective) et à quelques défauts et aberrations de notre œil. Plus une étoile semble petite, tout étant égal quant au diamètre de l'objectif, au grossissement employé et à l'éclat de l'étoile observée, et plus la lunette a de perfection. Or le meilleur moyen de juger si les étoiles sont très petites, si des points sont représentés au foyer par de simples points, c'est évidemment de viser à des étoiles excessivement rapprochées entr'elles et de voir si dans les étoiles doubles connues les images se confondent, si elles empiètent l'une sur l'autre, ou bien si on les aperçoit bien nettement séparées." Arago MSS. of 1834 and 1847.

([206]) p. 108.—Hassenfratz sur les Rayons Divergens des Etoiles, in Delamétherie's Journal de Physique, T. lxix. 1809, p. 324.

([207]) p. 109.—Horapollinis Niloi Hieroglyphica, ed. Conr. Leemans, 1835, cap. 13, p. 20. The learned editor, (Leemans) however, in opposition to Jomard, (Descr. de l'Egypte, T. vii. p. 423), remarks that neither on monuments nor rolls of papyrus has the figure of a star been found employed as a sign for the number 5 (Horap. p. 194).

([208]) p. 109.—On board Spanish ships in the Pacific I found a persuasion prevailing among the sailors, that the moon's age could be determined, before her first quarter, by looking at her face through a piece of silk, and counting the number of images; a phenomenon of diffraction through narrow longitudinal apertures.

([209]) p. 109.—Outlines, § 816. Arago made the diameter of the spurious disk of Aldebaran, shewn by a telescope, increase from 4″ to 15″ by diminishing the diameter of the object glass.

([210]) p. 110.—Delambre, Hist. de l'Astr. Moderne, T. i. p. 193; Arago, Annuaire 1842, p. 366.

([211]) p. 110.—"Minute and very close companions, the severest tests which can be applied to a telescope."—Outlines, § 837. Compare also Sir John Herschel, Cape Observations, p. 29, and Arago, in the Annuaire pour 1834, p. 302—305. Of bodies belonging to our solar system, we may employ, for testing the power of light of a highly magnifying optical instrument, the 1st and 4th satellites of Uranus, seen again by Lassel and Otto Struve in 1847; the two innermost and the 7th satellites of Saturn, (Mimas, Enceladus, and Bond's Hyperion), and the satellite of Neptune, discovered by Lassel. The power of penetrating the depths of celestial space, afforded by telescopes, led Bacon, in an eloquent passage in praise of Galileo to whom he erroneously ascribed their invention, to compare them to ships which conduct men into an unknown ocean; "ut propriora exercere possint cum cœlestibus commercia." Works of Francis Bacon, 1740, Vol. i. Novum Organon, p. 361.

(212) p. 111.—"The expression *υπόκιῤῥος*, which Ptolemy uniformly employs in his catalogue for the six stars named by him, indicates a slight degree of transition from fiery yellow to fiery red, thus, speaking precisely, it would signify a fiery reddish colour. To the other fixed stars, he seems to apply generally the epithet *ξανθός*, a fiery yellow. (Almag. viii. 3 ed.; Halma, T. ii. p. 94). Κιῤῥὸς is, according to Galen, (Meth. med. 12) a pale fire red, verging towards yellow. Gellius compares the word to melinus, which, according to Servius, means the same as gilvus and fulvus. As Sirius is called by Seneca (Nat. Quæst. i. 1) 'redder than Mars,' and as it is one of the stars called in the Almagest *ὑπόκιῤῥοι*, there remains no doubt that the word indicates the predominance, or at least the presence of a certain portion of red rays. The assertion that the epithet *ποικίλος*, applied to Sirius by Aratus, v. 327, is ranslated by Cicero, rutilus, is erroneous. Cicero says, indeed, v. 348—

> Namque pedes subter rutilo cum lumine claret
> Fervidus ille Canis stellarum luce refulgens;

but rutilo cum lumine is not a *translation* of *ποικιλος*, but an addition made by a free translator." (Extracts from letters to myself from Professor Franz.) Arago in the Annuaire for 1842, p. 351, says, "Si en substituant *rutilus* au terme grec d'Aratus, l'orateur romain renonce à dessein à la fidélité, il faut supposer que lui-même avait reconnu les propriétés rutilantes de la lumière de Sirius."

(213) p. 111.—Cleom. Cycl. Theor. i. 11. p. 59.

(214) p. 111.—Mädler, Astr. 1849, S. 391.

(215) p. 111.—Sir John Herschel in the Edinb. Review, vol. lxxxvii. 1848, p. 189, and in Schum. Astr. Nachr. 1839, No. 372,—"It seems much more likely that in Sirius a red colour should be the effect of a medium interfered, than that in the short space of 2000 years, so vast a body should have actually undergone such a material change in its physical constitution. It may be

supposed the existence of some sort of *cosmical cloudiness*, subject to internal movements, depending on causes of which we are ignorant." (Compare Arago in the Annuaire pour 1842, p. 350—353.)

([216]) p. 112.—In Muhamedis Alfragani chronologica et astronòmica elementa, ed. Jacobus Christmannus, 1590, cap. 22, p. 97, it is said,—"stella ruffa in Tauro Aldebaran; stella ruffa *in Geminis* quæ appellatur *Hajok*, hoc est Capra." But Alhajoc, Aijuk, are, in the Arabo-Latin Almagest, the usual names of Capella. Argelander also remarks justly that Ptolemy in the astrological work (Τετράβιβλος σίνταξις), vouched as genuine by style and ancient testimony, connects planets and stars according to similarity of colour, and thus joins together Capella and Martis stella, (quæ urit sicut congruit igneo ipsius colori,) with Aurigæ stella. (Compare Ptol. quadripart. construct. libri iv. Basil 1551, p. 383). Riccioli (Almagestum novum ed. 1650, T. i. Pars 1, lib. 6, cap. 2, p. 394) also reckons Capella, with Antares, Aldebaran, and Arcturus, among the red stars.

([217]) p. 113.—See Chronologie der Ægypter, by Richard Lepsius, Bd. i. 1849, S. 190—195, and 213. The complete construction of the Egyptian calender is placed in the earliest part of the year 3285 before the Christian era—*i. e.* about a century and a half before the building of the great pyramid of Cheops-Chufu, and 940 years before the epoch usually assigned to the Deluge. (Compare Kosmos, Bd. ii. S. 402, English edition, p. xxvii., Note 146). In the calculations which have been made in reference to the circumstance, that the inclination of the narrow subterranean passage leading into the interior of the pyramid, measured by Colonel Vyse, corresponds very nearly to the angle 26° 15′, which, in the time of Cheops-Chufu, the star *α* Draconis which marked the pole attained at its inferior culmination at Gizeh,—the epoch of the building of the pyramid is taken, not at 3430 B.C., as given in Kosmos from Lepsius, but at 3970 B.C. as in the Outlines of Astr. § 319. This difference of 540 years is the less opposed to the assumption of *α* Draconis having been the pole-star, as in 3970 its polar distance was still 3° 44′.

([218]) p. 113.—I have taken what follows from letters of Professor Lepsius to myself (February 1850):—"The Egyptian name of Sirius, marked as a female star, is Sothis; hence, in Greek, ἡ Σῶθις is identified with the goddess Sote (oftener Sit in hieroglyphics), and in the temple of the great Ramses at Thebes with Isis-Sothis. (Lepsius, Chronol. der Ægypter, Bd. i. S. 119 and 136). The signification of the root is found in Coptic, and allied with a numerous family of words, the different members of which, though apparently departing widely from each other, may, however, be arranged as follows:—By a threefold transference of the verbal signification, we obtain from the original meaning—to project, projicere (sagittam, telum)—1st, seminare, to sow; then extendere, to extend or stretch (as spun threads); and lastly, what is here most important, 'to radiate light,' 'to shine' (as do stars and fire). The names of the divinities—Satis (the archer, *female*), Sothis (the radiant, *female*), and Seth (the fiery, *male*), may be connected with this series of ideas. There may be pointed out hieroglyphically—sit or seti, the arrow or dart, as well as the ray; seta, to spin; setu, scattered grains. Sothis is especially the *bright-beaming* star, regulating seasons and periods. The small triangle, always painted yellow, which is a symbolical sign of Sothis, is employed in the designation of the *radiant sun*, being placed in triple rows, the triangles always pointing downwards from the sun. Seth is the fire-god, the burning or scorching; in opposition to the warming and fertilizing waters of the inundation of the Nile—the female divinity Satis. She is the goddess of the Cataracts, because the swelling of the Nile began with the appearance of the star Sothis, at the time of the summer solstice. In Vettius Valens, the star itself is called Σηϑ instead of Sothis; but we cannot by any means, as Ideler has done (Handbuch der Chronologie, Bd. i. S. 126), identify Thoth with Seth or Sothis, either as to name or person." (Lepsius, Bd. i. S. 136.)

To these considerations, taken from the earliest Egyptian antiquity, I subjoin some Greek, Zend, and Sanscrit etymologies. "Σείρ, the sun," says Professor Franz, "is an ancient radical, differing only in pronunciation from *ϑερ, ϑέρος*, heat, summer, where the sound of the vowel is altered, as in *τεῖρος* and *τέρος*, or *τέρας*. The correctness of the assigned relations between the radicals *σεὶρ*, and *ϑερ, ϑέρος*, is confirmed, not only by the application of *ϑερείτατος* in Aratus, v. 149 (Ideler, Sternnamen, S. 241), but also by the later use of the forms derived from *σεὶρ, σειρὸς, σεὶριος, σειρινός*, hot, burning. It deserves remark that *σειρὰ*, or *σειρινὰ ἱμάτια*, is pronounced quite like *ϑερινὰ ἱμάτια*, light summer clothing. But the peculiar form *σείριος* is of wider application, it is the epithet given to all the heavenly bodies which influence the heat of summer: thus, according to the poet Archilochus, the Sun was called *σείριος ἀστὴρ*; and Ibycus calls the heavenly bodies *σείρια*, 'the shining.' That it is really the sun which is meant in the words of Archilochus, *πολλοὺς μὲν αὐτοῦ σείριος καταυανεῖ ὀξὺς ἐλλάμπων*, cannot be doubted. It is true that, according to Hesychius and Suidas, Σείριος signifies both the Sun and the dog-star; but I am as certain as is the new editor of Theon of Smyrna,

M. Martin, that the passage of Hesiod (Opera et Dies, v. 417) refers, as Tzetzes and Proclus make it do, to the Sun, and not to the dog-star. The verb *σειριᾶν*, which may be translated 'to sparkle,' comes from the adjective *σείριος*, which has established itself as the epitheton perpetuum of the dog-star. Aratus, v. 331, says of Sirius, *ὀξέα σειριάει*, 'it sparkles strongly. When standing alone, the word *Σειρήν*, the Siren, has quite a different etymology; and your conjecture, that it is only a case of accidental similarity of sound to the bright star Sirius, is perfectly well founded. They are quite in error who, according to Theon Smyrnæus (Liber de Astronomia, 1850, p. 202), would derive *Σειρὴν* from *σειριάζειν* (a, moreover, quite unaccredited form for *σειριᾶν*). While the motion of heat and light are expressed in *σείριος*, the word *Σειρὴν* has a root which represents the flowing tone of the natural phenomenon. It seems to me probable that *Σειρὴν* is connected with *εἴρειν*; (Plato, Cratyl. 398 D. *τὸ γὰρ ἔιρειν λέγειν ἐστί*;) the originally sharp aspiration passing into the hissing sound." Extracted from letters to myself from Prof. Franz, January 1850.

According to Bopp, "the Greek *Σειρ*, the Sun, can be easily connected by intermediate links with the Sanscrit word 'svar,' which indeed does not signify the Sun, but the Heavens (as something bright or shining). The usual Sanscrit name for the Sun is 'sûrya,' a contraction of 'svarya.' The root 'svar,' signifies in general, to shine. The Zend name for the Sun is 'hvare,' with *h* instead of *s*. The Greek *θερ*, *θέρος*, and *θερμός*, comes from the Sanscrit word, gharma (Nom. gharmas), warmth, heat."

The acute Max. Muller, who has edited the Rigveda, remarks "that the Indian astronomical name for the dog-star, Lubdhaka, which signifies 'hunter,' regarded in connection with the neighbouring constellation of Orion, seems to point to a highly ancient Aric community of view in the contemplation of this group of stars." He is most inclined to derive *Σείριος* from the Vedic word "sira" (whence the adjective sairya), and the root "sri," to go, to walk; so that the Sun and the brightest of stars, Sirius, would have had the term moving or wandering star as their original name. (Compare also Pott. Etymologische Forschungen, 1833, S. 130.)

(219) p. 113.—Struve, Stellarum compositarum Mensuræ micrometricæ, 1837, p. lxxiv. and lxxxiii.

(220) p. 114.—Sir John Herschel, Cape Observations, p. 34.

(221) p. 114.—Mädler, Astronomie, S. 436.

(222) p. 114.—Kosmos, Bd. ii. S. 367 and 513, Anm. 63, English edition, p. 327, and Note 503.

([223]) p. 114.—Arago, Annuaire pour 1842, p. 348.

([224]) p. 114.—Struve, Stellæ comp. p. lxxxii.

([225]) p. 115.—Sir John Herschel, Cape Observations, pp. 17 and 102 (Nebulæ and Clusters, No. 3435).

([226]) p. 115.—Humboldt, Vues des Cordillères et monumens des peuples indigènes de l'Amérique, T. ii. p. 55.

([227]) p. 115.—Julii Firmici Materni Astron. libri viii. Basil, 1551, lib. vi. cap. 1, p. 150.

([228]) p. 115.—Lepsius, Chronol. der Ægypter, Bd. i. S. 143. "In the Hebrew text they are called Asch, the Giant (Orion?), the 'many stars,' (the Pleiades, Gemut?), and the Chambers of the South. The Septuagint version is: *ὁ ποιῶν Πλειάδα καὶ Ἕσπερον καὶ Ἀρκτοῦρον καὶ ταμεῖα νότου.*"

([229]) p. 116.—Ideler, Sternnamen, S. 295.

([230]) p. 116.—Martianus Capella changes Ptolemæon into Ptolemæus. Both names were given by the flatterers at the Egyptian Court. Amerigo Vespucci believed he had seen three Canopuses, one of which was quite dark (fosco), Canopus ingens et niger in the Latin translation: no doubt one of the black coal sacks (Humboldt, Examen crit. de la Géogr. T. v. p. 227—229). In the Elem. Chronol. et Astron. of El-Fergani (p. 100), it is related that the Christian pilgrims were wont to call the Sohel of the Arabs (Canopus), the Star of St. Catherine, because they were accustomed to welcome and admire it as their guiding star in journeying from Gaza to Mount Sinai. In a fine episode in the oldest heroic poem of Indian antiquity, the Ramayana, the stars near the southern pole are declared to be more recently created than the more northern ones for a singular reason. When the Brahminic Indians,—entering the lands of the Ganges from the north-west, advanced from 30° N. latitude farther into the tropics, subjecting the aborigines,—as they approached Ceylon they saw stars before unknown rise above the horizon. According to ancient custom, they combined these stars into new constellations. By a bold fiction, the later-seen stars were said to have been created later by the wonder-working power of Visvamitra, who "threatened the old gods, that, with his more richly-starred southern hemisphere, he would overpower the northern one" (A. W. von Schlegel, in the Zeitschrift für die Kunde des Morgenlandes, Bd. i. S. 240). This Indian myth, expressive of the astonishment of wandering nations at the aspect of regions of space before unseen (as the celebrated Spanish poet, Garcilaso de la Vega, said of those who travel, "they change at once their country and their stars," "mudan de pays y de estrellas"), reminds us vividly of the impression which must have been made even on the rudest nations, when at the same part of the Earth's surface they first saw rise above the horizon large stars such as those in the feet of the Centaur, the Southern Cross, Eridanus, and the constellation of the Ship, whilst others before familiar disappeared. By the precession of the equinoxes, fixed stars approach and again recede from our view. I have already remarked, in another place, that 2900 years before our Era,—at a time, therefore, when the great pyramid had already stood five hundred years,—the constellation of the Southern Cross was 7° above the horizon of the countries bordering on the Baltic Sea. (Compare Kosmos, Bd. i. S. 155, and Bd. ii. S. 333. Eng. ed. Vol. i., p. 139. Vol. ii. p. 293). "Canopus, on the other hand, can never have been visible in the locality of Berlin; its distance from the South Pole of the Ecliptic is only 14°, and it would have required that the distance should have been 1° greater for the star to have ever reached the limit of visibility in our horizon."

(231) p. 116.—Kosmos, Bd. ii. S. 203 (English edition, p. 169—170).

(232) p. 116.—Olbers in Schumacher's Jahrb. für 1840, S. 249; and Kosmos, Bd. iii. S. 151.

(233) p. 117.—Etudes d'Astr. stellaire, Note 74, p. 31.

(234) p. 117.—Outlines of Astr. § 785.

(235) p. 118.—Id. § 795 and 796; Struve, Etudes d'Astr. stellaire, p. 66—73 (also Note 75).

(236) p. 118.—Struve, p. 59. Schwink finds in his maps, R. A. 0°—90°, 2858 stars; R. A. 90°—180°, 3011 stars; R. A. 180°—270°, 2688 stars; R. A. 270°—360°, 3591 stars; total 12,148 stars down to the 7th magnitude.

(237) p. 119.—On the circular nebula in the right hand of Perseus (near the sword handle), see Eratosth. Catast. c. 22, p. 51, Schaubach.

(238) p. 119.—Sir John Herschel's Cape Observations, § 105, p. 136.

(239) p. 119.—Outlines, § 864—869, p. 591—596; Mädler, Astr. S. 764.

(240) p. 120.—Cape Observations, § 29, p. 19.

(241) p. 122.—Sir John Herschel says:—"A stupendous object, a most magnificent *globular* cluster *completely insulated*, upon a ground of the sky perfectly *black* throughout the whole breadth of the sweep." (Cape, p. 18 and 51, Pl. iii. fig. 1; Outlines, § 895, p. 615.

(242) p. 122.—Bond, in the Memoirs of the American Academy of Arts and Sciences, new series, Vol. iii. p. 75.

(243) p. 123.—Outlines, § 874, p. 601.

([244]) p. 123.—Delambre, Hist. de l'Astr. Moderne, T. i. p. 697.

([245]) p. 124.—We are indebted for the first and the only thoroughly complete description of the Milky Way in both hemispheres to Sir John Herschel, in his "Results of Astronomical Observations made during the years 1834—1838, at the Cape of Good Hope," § 316—335, and still more recently in his Outlines of Astronomy, § 787—799. I have followed him throughout the entire section of Kosmos which is devoted to the direction, branchings, and varied contents of the Milky Way. Compare also Struve, Etudes d'Astr. stellaire, p. 35—79; Mädler, Astr. 1849, § 213; Kosmos, Bd. i. S. 109 and 156 (English edition, pp. 96 and 140). I need scarcely remark here, that, in order not to mingle uncertainties with certainties, I have not introduced into the description of the Milky Way, what I observed and recorded respecting the very unequal light of the different parts of the gallactic zone during my long sojourn in the Southern Hemisphere, where the instruments with which I was provided commanded but little light.

([246]) p. 124.—The comparison of the Milky Way to a Celestial River caused the Arabs to give to parts of the constellation of Sagittarius, whose bow falls in a region full of stars, the name of "cattle going to drink," and even accompanying them by the ostrich, which requires so little water. (Ideler, Untersuchung über den Ursprung und die Bedeutung der Sternnamen, S. 78, 183, and 187; Niebuhr, Beschreibung von Arabien, S. 112.)

([247]) p. 124.—Outlines, p. 529; Schubert, Astr. Th. iii. S. 71.

([248]) p. 124.—Struve, Etudes d'Astr. stellaire, p. 41.

([249]) p. 125.—Kosmos, Bd. i. S. 156 and 415 Anm. 79 (English edition, p. 140, and Note 109).

([250]) p. 125.—"Stars standing on a clear black ground" (Cape Observations, p. 391). This remarkable belt (the Milky Way, 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." Outlines, p. 182, 537, and 539.

([251]) p. 125.—"*Globular clusters*, except in one region of small extent (between 16h. 45m. and 19h. in R. A.) and *nebulæ of regular elliptic forms*, are comparatively rare in the Milky Way, and are found congregated in the greatest abundance in a part of the heavens the most remote possible from that circle." Outlines, p. 614. Huygens, as early as 1656, had had his attention drawn to the absence of nebulæ and nebulous patches in the Milky Way. In the same place in which he mentions the discovery and representation of the great nebula in the belt of Orion, by means of a 28-feet refractor (1656), he said (as I have already remarked in the 2nd Vol. of Kosmos, S. 514, English edition, Note 503, p. cxviii): "viam lacteam perspicillis inspectam nullas habere nebulas"; and that the Milky Way, like all that had been taken for nebulous stars, was a great cluster of stars. The passage is printed in Hugenii Opera Varia, 1724, p. 593.

([252]) p. 125.—Cape Observations, § 105, 107, and 328. On the annular nebula, No. 3686, see p. 114.

([253]) p. 126.—"Intervals absolutely dark and *completely void of any star* of the smallest telescopic magnitude." Outlines, p. 536.

([254]) p. 127.—"No region of the heavens is fuller of objects beautiful and remarkable in themselves, and rendered still more so by their mode of association, and by the peculiar features assumed by the Milky Way, which are without a parallel in any other part of its course" (Cape Observations, p. 386). This animated expression of Sir John Herschel's agrees perfectly with the impressions which I myself received. Captain Jacob (Bombay Engineers), in speaking of the intensity of light of the Milky Way in the vicinity of the Southern Cross, says, with striking truth,—"such is the general blaze of starlight near the Cross from that part of the sky, that a person is immediately made aware of its having risen above the horizon, though he should not be at the time looking at the heavens, by the increase of general illumination of the atmosphere, resembling the effect of the young moon." See Piazzi Smyth on the orbit of α Cent. in the Transactions of the Royal Society of Edinburgh (Vol. xvi. p. 445).

([255]) p. 127.—Outlines § 789 and 791; Cape Observations, § 325.

([256]) p. 127.—Almagest, lib. viii. cap. 2 (T. ii. p. 84 and 90, Halma) Ptolemy's description is in particular parts excellent, especially compared with Aristotle's treatment of the subject of the Milky Way. (Meteor. lib. 1. pp. 29 and 34, according to Ideler's Edition.)

([257]) p. 129.—Outlines, p. 531. Also between α and γ Cassiopeiæ, a strikingly dark spot or patch is ascribed to the contrast with the bright parts by which it is surrounded. See Struve, Etudes stell. Note 58.

([258]) p. 130.—An extract from the exceedingly rare work of Thomas Wright of Durham (Theory of the Universe, London 1750), has been given by de Morgan in the Philosophical Magazine (Series iii. No. 32, p. 241). Thomas Wright, to whose writings the attention of astronomers has been permanently directed since the beginning of the present century, by the influence of the ingenious speculations of Kant and William Herschel on the form of our sidereal stratum, observed only with a reflector of 1 foot focal length.

([259]) p. 130.—Pfaff in W. Herschel's sämmtl. Schriften Bd. i. 1826, (S. 78—81; Struve, Etudes stell. p. 35—44).

([260]) p. 130.—Encke in Schumacher's Astr. Nachr. No. 622, (1847) S. 341—346.

([261]) p. 130.—Outlines, p. 536. On the next page it is said, on the same subject, "In such cases it is equally impossible not to perceive that we are looking *through* a sheet of stars of no great thickness compared with the distance which separates them from us."

([262]) p. 131.—Struve, Etudes stell. p. 63. Sometimes the largest telescopes reach a part of celestial space in which the existence of a remotely glimmering sidereal stratum is only indicated "by an uniform dotting or stippling of the field of view." See in the Cape Observations, p. 390, the section "on some indications of very remote telescopic branches of the Milky Way, or of an independent sidereal System, or Systems, bearing a resemblance to such branches."

([263]) p. 131.—Cape Observations, § 314.

([264]) p. 131.—Sir William Herschel in the Phil. Trans. for 1785, p. 21; Sir John Herschel, Cape Observations, § 293. (Compare also Struve, Descr. de l'Observatoire de Poulkova, 1845, p. 267—271).

([265]) p. 131.—"I think," says Sir John Herschel, "it is impossible to view this splendid zone from α Centauri to the Cross, without an impression, amounting almost to conviction, that the Milky Way is not a mere stratum, but annular; or, at least, that our system is placed within one of the poorer or almost vacant parts of its general mass, and that eccentrically, so as to be much nearer to the region about the Cross than to that diametrically opposite to it" (Mary Somerville on the Connection of the Physical Sciences, 1846, p. 419).

([266]) p. 131.—Cape Observations, § 315.

([267]) p. 136.—De admiranda Nova Stella anno 1572 exorta, in Tychonis Brahe Astronomiæ instauratæ Progymnasmata 1603, p. 298—304 and 578. I have followed in the text Tycho Brahe's own narrative. The unwarranted assertion, repeated in many books on Astronomy, that Tycho's attention was first called to the newly-appeared star by a concourse of country people has not, therefore, been noticed.

([268]) p. 136.—Cardanus, in his dispute with Tycho Brahe, went back to the star of the Magi, which he was disposed to identify with the star of 1572. Ideler, from his calculations of conjunctions of Saturn with Jupiter, and from suppositions similar to those enounced by Kepler on the appearance of the new star in Ophiuchus in 1604, believed the star of the Wise Men, from the frequent confusion between *αστὴρ* and *ἄστρον*, to have been not a single great star, but a remarkable arrangement of stars, presented by the near approximation of two bright planets within less than a diameter of the moon from each other. (Compare Tychonis Progymnasmata, p. 324—330, with Ideler, Handbuch der Mathematischen und Technischen Chronologie. Bd. ii. (S. 399—407).

(269) p. 136.—Progymn. p. 324—330. Tycho Brahe supports himself in his theory of the formation of new stars from the cosmical vapour, or nebulous matter of the Milky Way, on the remarkable passages of Aristotle, to which I have alluded in the 1st Vol. of Kosmos (Bd. i. S. 109 and 390, Note 18, Engl. ed. p. 96 and xviii. Note 48,) respecting the supposed relations subsisting between the tails of comets and the gaseous emanations from the nuclei of comets, and the Milky Way.

(270) p. 140.—Other statements place the phenomenon in the year 388 or 398; Jacques Cassini, Élémens d'Astronomie, 1740 (Œtoiles nouvelles), p. 59.

(271) p. 148.—Arago Annuaire pour 1842, p. 332.

(272) p. 149.—Kepler de Stella nova in pede Serp. p. 3.

(273) p. 152.—On instances of stars which have not disappeared, see Argelander in Schumacher's Astronom. Nachr. No. 624, S. 371. To cite an example connected with antiquity, I will here recall how the carelessness of Aratus, in drawing up his poetic Catalogue of stars, has led to the often-renewed question, whether Vega (*α* Lyræ), may be either a new star or one which varies in long periods, since Aratus says that the constellation of the Lyre has only small stars. It may, indeed, seem surprising that Hipparchus does not notice this as an error in his Commentary; whilst yet he blames Aratus for his statements respecting the relative brightness of the stars in Cassiopeia, and in Ophiuchus. However, all this is merely accidental, and proves nothing; for, Aratus having ascribed to the constellation of the Swan only stars of middling brightness, Hipparchus (i. 14), in expressly contradicting this error, adds, that the bright star in the tail (Deneb) is but little inferior to the star in the Lyre (Vega). Ptolemy places Vega among the stars of the first order of magnitude; and in the Catasterisms of Eratosthenes (cap. 25), it is called *λευκον καί λαμπρὸν*. Seeing the many inaccuracies of a poet who was not himself an observer, would it be reasonable to found upon his statement the belief that *α* Lyræ (Pliny's Fidicula, xviii. 25) first

shone forth as a star of the 1st magnitude between the years 272 and 127 B.C., or between the time of Aratus and that of Hipparchus?

(274) p. 155.—Compare Mädler, Astr. S. 438, Note 12, with Struve, Stellarum compos. Mensuræ microm. p. 97 and 98, star 2140. "I believe," says Argelander, "that it is very difficult to estimate correctly in a telescope of great power of light the brightness of such exceedingly different stars as are the two components of α Herculis. My experience is decidedly against the variability of the companion; for, in my numerous day observations with the telescopes of the Meridian circles at Abo, Helsingfors, and Bonn, I have never seen α Herculis single, which yet would have been the case, if the companion were only of the 7th magnitude when at its minimum. I believe it to be constant 5m. or 5·6m.

(275) p. 155.—Mädler's Table (Astron. S. 435) contains 18 stars, having very different numerical elements. Sir John Herschel enumerates, including those alluded to in a note, above 45 (Outlines, § 819—826).

(276) p. 156.—Argelander in Schumacher's Astr. Nachr. Bd. xxvi. (1848) No. 624, S. 369.

(277) p. 158.—"If," says Argelander, "I take the least light of Algol, 1800 January 1, 18 h. 1 m., mean time at Paris, as my zero epoch, I obtain the following table:—

Epoch.	Duration of Period.				Seconds.	Probable Errors. Seconds.
− 1987	2 days,	20 hours,	48 min.		59.416	± 0·316
− 1406	„	„	„		58·737	± 0·094
− 825	„	„	„		58·393	± 0·175
+ 751	„	„	„		58·454	± 0·039
+ 2328	„	„	„		58·193	± 0·096
+ 3885	„	„	„		57·971	± 0·045
+ 5441	„	„	„		55·182	± 0·348

In this table the numbers signify as follows:—The epoch of the minimum, on the 1st of January 1800, being zero, the next preceding is − 1, the next following is + 1, &c.; the duration, or interval of time between the epochs − 1987 and − 1986, is exactly 2 d. 20 h. 48 m. 59.416 s.; whilst that between + 5441 and + 5442 is 2 d. 20 h. 48 m. 55.182 s.; the first corresponding to the year 1784, the last to the year 1842. The final column, with the ± sign, contains the probable errors. That the decrease is becoming more and more rapid is shewn by the last number, as well as by my observations since 1847.

(278) p. 158.—Argelander's formula for representing all the observed maxima of Mira Ceti, as communicated to me by himself, is the following:—

$$1751,\ \text{Sept. } 9, 76 + \overset{\text{days}}{331.3363} + \overset{\text{d.}}{10.5}\ \text{Sin.}\left(\frac{360^\circ}{11}\text{E} + 86^\circ\ 23'\right)$$

$$+ \overset{\text{d.}}{18.2}\ \text{Sin.}\left(\frac{45^\circ}{11}\text{E} + 231^\circ\ 42'\right) + \overset{\text{d.}}{33.9}\ \text{Sin.}\left(\frac{45^\circ}{22}\text{E} + 170^\circ\ 19'\right)$$

$$+ \overset{\text{d.}}{65.3}\ \text{Sin.}\left(\frac{15^\circ}{11}\text{E} + 6^\circ\ 37'\right):$$

Where E signifies the number of maxima which have occurred since Sept. 9, 1751, and the coefficients are given in days. Hence, for the year now in progress, we have the maximum:—

$$1751,\ \text{Sept. } 9, 76 + \overset{\text{d.}}{36115{\cdot}65} + \overset{\text{d.}}{8{\cdot}44} - \overset{\text{d.}}{12{\cdot}24}$$
$$+ \overset{\text{d.}}{18.59} + \overset{\text{d.}}{27.34} = 1850,\ \text{Sept. } 8.54.$$

The circumstance which appears most in favour of this formula is, that it represents the observation of the maximum in 1596, (Kosmos, Bd. ii. S. 367; Eng. ed. p. 326—327), which, on the supposition of a uniform period, would deviate more than 100 days. Yet the law of the variations of light in this star is apparently so complicated, that in single cases (ex. gr. for the very exactly-observed maximum of the year 1840) the formula still deviates many days (almost 25).

(279) p. 158.—Compare Argelander's Memoir at the secular festival of the Königsberg University, under the title of De Stella β Lyræ Variabili, 1844.

(280) p. 159.—One of the first earnest endeavours to investigate the mean duration of the period of variability of Mira Ceti, is that of Jacques Cassini, Élémens d'Astronomie, 1740, p. 66—69.

(281) p. 172.—Newton (Philos. Nat. Principia Mathem, ed. Le Sueur et Jacquier, 1760, T. iii. p. 671) distinguishes only two kinds of these sidereal phenomena: "Stellæ fixæ quæ per vices apparent et evanescunt quæque paulatim crescunt, videntur revolvendo partem lucidam et partem obscuram per vices ostendere." This explanation of the change of light had been previously proposed by Riccioli. Respecting the caution which should be exercised in assuming the existence of periodicity, see the important considerations of Sir John Herschel in the Cape Observations, § 261.

(282) p. 172.—Delambre, Hist. de l'Astr. Ancienne, T. ii. p. 280; and Hist. de l'Astr. au 18ème siecle, p. 119.

(283) p. 174.—Compare Sir John Herschel in the Cape Observations,

§ 71—78, and Outlines of Astronomy, § 830, (Kosmos, Bd. i. S. 160—416; Eng. ed., p. 144—Note, 120).

([284]) p. 174.—Letter from Lieut. Gilliss to Dr. Flügel, Consul of the United States at Leipzic (MS.) The untroubled purity and serenity of the atmosphere at Santiago de Chile, lasting for 8 months, is so great that, with the *first* large telescope made in America, having an aperture of 6½ inches (constructed by Henry Fitz in New York and William Young in Philadelphia), Lieutenant Gilliss distinctly recognised the 6th star in the trapezium of Orion.

([285]) p. 175.—Sir John Herschel, Cape Observations, p. 334—350, Note 1 and 440. (On older observations of Capella and α Lyræ, see William Herschel in the Phil. Trans. for 1797, p. 307, and for 1799, p. 121; and in Bode's Jahrbuch for 1810, S. 148). Argelander, on the other hand, entertains great doubts respecting the variability of Capella and of the stars in the Bear.

([286]) p. 176.—Herschel's Cape Observations, § 259, No. 260.

([287]) p. 176.—Heis, in manuscript notices in May 1850. Compare also Cape Observations, p. 325, and P. Von Boguslawski; " Uranus" for 1848, p. 186. (The assumed variability of η, α, and δ, Ursæ maj., is also supported in Herschel's Outlines, p. 559.) See Mädler Astr. S. 432, on the series of stars which are successively to mark the North Pole by their vicinity, until, at the end of 12,000 years, the place should be taken by the most brilliant of all possible pole-stars, α Lyræ.

([288]) p. 176.—Kosmos, Bd. iii. S. 134; English edition, note 165.

([289]) p. 176.—William Herschel, on the changes that happen to the fixed stars, in the Phil. Trans. for 1796, p. 186; Sir John Herschel in the Cape Observations, p. 350—352; and also in Mary Somerville's excellent work entitled Connexion of the Physical Sciences, 1846, p. 407.

([290]) p. 178.—Encke, Betrachtungen über die Anordnung des Sternsystems, 1844, S. 12 (Kosmos, Bd. iii. S. 36, Engl. ed. p. 27); Mädler, Astr. S. 445.

([291]) p. 180.—Halley in the Phil. Trans. for 1717—1719, Vol. xxx. p. 736. The consideration, however, referred only to variations in latitude; Jacques Cassini first added variations in longitude (Arago in the Annuaire pour 1842, p. 387).

([292]) p. 180.—Delambre Hist. de l'Astr. Moderne, T. ii. p. 658; the same author in the Hist. de l'Astr. au 18ème siècle, p. 448.

([293]) p. 181.—Phil. Trans. Vol. lxxiii. p. 138.

(294) p. 181.—Bessel in Schumacher's Jahrbuch for 1839, S. 38; Arago Annuaire for 1842, p. 389.

(295) p. 182.—See on α Centauri, Henderson and Maclear, in the Memoirs of the Astron. Soc. Vol. xi. p. 61; and Piazzi Smyth, in the Edinb. Trans. Vol. xvi. p. 447. The proper motion of Arcturus, 2″·25 (Baily, in the Memoirs of the Astr. Soc. Vol. v. p. 165), as belonging to a very bright star, may be called large in comparison with that of Aldebaran 0″·185 (Mädler, Central sonne S. 11), and that of α Lyræ 0″·400. Among stars of the 1st magnitude α Centauri, with its very large proper motion of 3″·58, forms a remarkable exception. The proper motion of the binary star-system in Cygnus, amounts according to Bessel (Schum. Astr. Nachr. Bd. xvi. S. 93), to 5″·123.

(296) p. 182.—Schumacher's Astr. Nach. No. 455.

(297) p. 182.—The same No. 618, S. 276. D'Arrest founds the result on comparisons of Lacaille (1750) with Brisbane (1825), and of Brisbane with Taylor (1835). The star 2151 Puppis has a proper motion of 7″·871, and is of the 6th magnitude (Maclear in Mädler's Unters. über die Fixstern-Systeme, Th. ii. S. 5).

(298) p. 182.—Schum. Astr. Nachr. No. 661, S. 201.

(299) p. 183.—The same, No. 514—516.

(300) p. 183.—Struve, Etudes d'Astr. Stellaire, Texte, p. 47, Notes, p. 26, and 51—57; Sir John Herschel, Outl. § 859 and 860.

(301) p. 184.—Origenes in Gronov. Thesaur. T. x. p. 271.

(302) p. 184.—Laplace, Expos. du Systeme du Monde, 1824, p. 395. Lambert, in his Cosmological Letters, shews a remarkable leaning to the assumption of dark cosmical bodies of great size.

(303) p. 184.—Mädler, Untersuch. über die Fixstern-Systeme, Th. ii. (1848,) S. 3, and the same Author's Astronomie, S. 416.

(304) p. 185.—Compare Kosmos, Bd. iii. S. 96 and 130 (Engl. ed. p. 77—78, Note 149); Laplace, in Zach's Allg. Geogr. Ephem. Bd. iv. S. i.; Mädler, Astr. S. 393.

(305) p. 186.—Opere di Galileo Galilei, Vol. xii. Milano, 1811, p. 206. This remarkable passage, which expresses the possibility of a measurement, and a project for its execution, was discovered by Arago; see his Annuaire pour 1842, p. 382.

(306) p. 187.—Bessel, in Schumacher's Jahrb. für 1839, S. 5 and 11.

(307) p. 188.—Struve Astr. Stell. p. 104.

(308) p. 188.—Arago, in the Connaissance des tems pour 1834, p. 281:

"Nous observâmes avec beaucoup de soin, M. Mathieu et moi, pendant le mois d'août 1812, et pendant le mois de novembre suivant, la hauteur angulaire de l'étoile au-dessus de l'horizon de Paris. Cette hauteur, à la seconde époque, ne surpasse la hauteur angulaire de l'étoile au-dessus de l'horizon de Paris. Cette hauteur, à la seconde époque, ne surpasse la hauteur angulaire à la première que de 0″·66. Une parallaxe absolue d'une seule seconde aurait nécessairement amené entre ces deux hauteurs une difference de 1″·2. Nos observations n'indiquent donc pas que le rayon de l'orbite terrestre, que 39 millions de lieues soient vus de la 61[eme] du Cygne sous un angle de plus *d'une demi-seconde.* Mais une base vue perpendiculairement soutend un angle d'une demi-seconde quand on en est éloigné de 412 mille fois sa longueur. Donc la 61[e] du Cygne est *au moins* à une distance de la Terre égale à 412 mille fois 39 millions de lieues."

(309) p. 188.—Bessel published in Schum. Jahrb. 1839, S. 39-49, and in the Astr. Nachr. No. 366, the result 0″·3136, as a first approximation. His subsequent final result was 0″·3483 (Astr. Nachr. No. 402 in Bd. xvii. S. 274). Peters found by his own observations, the almost identical result of 0″·3490. (Struve, Astr. stell. p. 99.) The alterations which, after Bessel's death, Professor Peters made in that astronomer's calculation of the angular measurements obtained with the Königsberg Heliometer, were founded on the circumstance that Bessel himself (Astr. Nachr. Bd. xvii. S. 267) had promised to subject the influence of temperature on the results with the heliometer to a fresh examination, which intention he executed partially in the 1st Vol. of his "Astronomischen Untersuchungen," but did not apply the temperature correction to the observations of parallax. This application was made by Peters (Ergänzungsheft zu den Astr. Nachr. 1849, S. 56), and in consequence this distinguished astronomer found 0″·3744, instead of 0″·3483.

(310) p. 188.—This result of 0″·3744 gives, according to Argelander, the distance of the double star 61 Cygni from the Sun = 550900 mean distances of the Earth from the Sun, or 11394000 German (45576000 English) geographical miles; a distance which light traverses in 3177 mean days. By the three successive assignments of parallax given by Bessel, 0″·3136, 0″·3483, and 0·3744, this star has come (apparently) gradually nearer to us; they correspond respectively to light-passages of 10, 9¼, and $8\frac{7}{10}$ years.

(311) p. 188.—Sir John Herschel, Outlines, p. 545 and 551. Mädler (Astr. S. 425) gives for α Centauri, instead of 0″·9128, the parallax 0″·9213.

(312) p. 189.—Struve, Stell. compos. Mens. microm. p. clxix.—clxxii. Airy considers the parallax of α Lyræ, which Peters has already diminished

to 0″·1, to be still less; *i. e.* to be too small for measurement with our present instruments (Mem. of the Royal Astr. Soc. Vol. x. p. 270).

(313) p. 189.—Struve on Micrometer-measurements in the large refractor of the Dorpat Observatory (Oct. 1839) in Schum. Astr. Nachr. No. 396, S. 178.

(314) p. 189.—Peters in Struve's Astr. stell. p. 100.

(135) p. 189.—Idem, p. 101.

(316) p. 191.—On the relation of the amount of proper motion to the proximity of the brightest stars, compare Struve, Stell. compos. Mensuræ microm. p. clxiv.

(317) p. 192.—Savary, in the Connaissance des Tems pour 1830, p. 56—69, and p. 163—171; and Struve, Stell. compos. Mensuræ microm. p. clxiv.

(318) p. 193.—Kosmos, Bd. i. S. 150 and 414; English edition, p. 134, and xxxvii. note 101.

(319) p. 193.—Mädler, Astronomie, S. 414.

(320) p. 193.—Arago (Annuaire pour 1842, p. 383) first called attention to this remarkable passage of Bradley; compare in the same Annuaire the section on the movement of translation of the entire solar system, p. 389—399.

(321) p. 195.—According to a letter to myself, see Schum. Astr. Nachr. No. 622, S. 348.

(322) p. 195.—Galloway on the Motion of the Solar System, in the Phil. Trans. 1847, p. 98.

(323) p. 196.—The value or otherwise of such views is discussed by Argelander in a memoir entitled Über die eigene Bewegung des Sonnensystems, hergeleitet aus der eigenen Bewegung der Sterne, 1837, S. 39, "on the proper motion of the solar system, deduced from the proper motion of stars," p. 39.

(324) p. 197.—Compare Kosmos, Bd. i. S. 149 (English edition, p. 134), and Mädler's Astr. S. 400.

(325) p. 197.—Argelander, work above quoted, S. 42; Mädler Centralsonne, S. 9, and Astr. S. 403.

(326) p. 197.—Argelander, last cited work, S. 43, and in Schum. Astr. Nachr. No. 566. Guided not by numerical investigations, but only by fanciful conjectures, Kant had taken Sirius, and Lambert the Nebula in Orion's belt, for the central body of our sidereal stratum. Struve Astr. stell. p. 17, No. 19.

(327) p. 197.—Mädler, Astr. S. 380, 400, 407, and 414; his Centralsonne 1846, S. 44—47; his Untersuchungen über die Fixstern Systeme, Th. ii. 1848, S. 183—185 (Alcyone is in R. A. 54° 30′, Decl. 23° 36′, for the year

1840. If the parallax of Alcyone were really 0″·0065, then its distance would amount to 31½ million times the semi-diameter of the Earth's orbit; thus it would be fifty times more distant from us than the double star 61 Cygni, according to Bessel's earliest determination. Light which comes from the Sun to the Earth in 8′ 18″·2, would require 500 years to travel from Alcyone to the Earth. The Imagination of the Greeks delighted in wild estimations of space fallen through. In Hesiod's Theogony, v. 722—725, it is said, speaking of the fall of the Titans to Tartarus, "When once an iron anvil fell from heaven, nine days and nights it fell, and on the tenth it reached the Earth." To this fall taking place in 777600 seconds of time, the corresponding distance (taking into account, according to Galle's calculation, the great decrease of the Earth's attractive force at planetary distances) is 77356 German (309424 English) geographical miles, or once and a half the distance from the Moon to the Earth. But according to Homer, Il. i. 952, Hephæstos fell down to Lemnos in only one day, and merely "still breathed a little." The length of the chain hanging down from Olympus to the Earth, by which all the gods were to essay to draw Zeus down (Il. viii. 18), is left indefinite. It is an image intended to express, not the height of heaven, but the strength and surpassing might of Jupiter.

(328) p. 198.—Compare the doubts expressed by Peters in Schum. Astr. Nachr. 1849, S. 661, and by Sir John Herschel in the Outlines of Astr. p. 589. "In the present defective state of our knowledge respecting the proper motion of the smaller Stars, we cannot but regard all attempts of the kind as to a certain extent premature, though by no means to be discouraged as forerunners of something more decisive."

(329) p. 199.—Compare Kosmos, Bd. i. S. 152—154 and 414 (Eng. ed. p. 136—138, and xxxvii.) (Struve über Doppelsterne nach Dorpater Micrometer-Messungen von 1824 bis 1837, S. 11).

(330) p. 200.—Kosmos, Bd. iii. S. 64—67, 110—113 and 166—168 (Eng. ed. p. 47—50, and 108—110). As remarkable examples of visual power in particular individuals, I may mention that Kepler's instructor, Möstlin, saw with the naked eye 14, and some of the Ancients 9, stars in the group of the Pleiades. (Mädler, Untersuch. über die Fixstern-Systeme, Th. ii. S. 36.)

(331) p. 200.—Kosmos, Bd. iii. S. 271 (Eng. ed. p. 185.) Dr. Gregory of Edinburgh also recommended the same method in 1675 (33 years therefore after Galileo's death); compare Thomas Birch, Hist. of the Royal Society, Vol. iii. 1757, p. 225. Bradley (1748) alludes to this method at the end of his celebrated treatise on Nutation.

(332) p. 201.—Mädler, Astr. S. 447.

(333) p. 201.—Arago in the Annuaire for 1842, p. 400.

(334) p. 201.—"An Inquiry into the probable Parallax and Magnitude of the fixed Stars, from the quantity of light which they afford us, and the particular circumstances of their situation, by the Rev. John Michell; in the Phil. Trans. Vol. lvii. p. 234—261.

(335) p. 202.—John Michell, same work, p. 238. "If it should hereafter be found, that any of the stars have others revolving about them (for no satellites by a borrowed light *could possibly be visible*), we should then have the means of discovering . . . ." He denies throughout the whole discussion, that one of two revolving stars can be a dark planet, reflecting light not its own, since both are visible to us notwithstanding the distance. He compares both the stars, the larger of which he calls the "Central Star," with the density of our sun, and applies the term "Satellite" only for the purpose of conveying the idea of revolution, or reciprocal motion. He speaks of the "greatest apparent elongation of those stars that revolved about the others as satellites." Further on he says, "We may conclude with the highest probability (the odds against the contrary opinion being many million millions to one) that stars form a kind of system by mutual gravitation. It is highly probable in particular, and next to a certainty in general, that such double stars as appear to consist of two or more stars placed near together, are under the influence of some general law, such perhaps as gravity." (Compare also Arago in the Ann. 1834, p. 308, and in the Ann. 1842, p. 400.) No great weight can be ascribed to the numerical results of the calculus of probabilities, as given by Michell, taken separately; as the suppositions laid down, that there are in the entire heavens 230 stars equal in intensity of light to β Capricorni, and 1500 equal to the light of the six larger Pleiades, are not at all correct. The ingenious cosmological memoir of John Michell terminates with the very hazardous attempt to explain the scintillation of the fixed stars by a kind of "pulsation in material effluxes of light," an attempt as little fortunate as that put forth by Simon Marius, one of the discoverers of Jupiter's satellites (Kosmos, Bd. ii. S. 357 and 509, Eng. ed. p. 316, note 484) at the end of his Mundus Jovialis (1614). Michell, however, has the merit of having called attention (p. 263) to the circumstance that scintillation is always combined with change of colour; "besides their brightness, there is in the twinkling of the fixed stars a change of colour." (See Kosmos, Bd. iii. S. 122, Eng. ed. note 129.)

(336) p. 203.—Struve in the Recueil des Actes de la Séance publique de

l'Acad. Imp. des Sciences de St. Petersbourg, le 29 déc. 1832, p. 48—50; Mädler, Astr. S. 478.

(337) p. 203.—Phil. Trans. for the year 1782, p. 40—126; for 1783, p. 112—124, for 1804, p. 87. On the observational basis of the 846 double stars of Sir William Herschel, compare Mädler in Schumacher's Jahrbuch für 1839, S. 59, and the same author's Untersuchungen über die Fixstern-Systeme, Th. i. 1847, S. 7.

(338) p. 205.—Mädler in the last-named work, Th. i. S. 255. We have for Castor, two old observations of Bradley's, 1719 and 1759, the first taken conjointly with Pond's, the second with Maskelyne's, and two of William Herschel's, of 1799 and 1803. For the time of revolution of λ Virginis, see Mädler, Fixstern-Syst., Th. ii. 1848, S. 234—240.

(339) p. 205.—Struve, Mensuræ microm., p. xl. and p. 234—248. There are, in all, 2641 + 146; therefore, 2787 observed multiple stars. (Mädler, in Schum. Jahrb. 1839, S. 64).

(340) p. 205.—Sir John Herschel, Astron. Observ. at the Cape of Good Hope, p. 165—303.

(341) p. 206.—Idem, p. 167 and 242.

(342) p. 206.—Argelander, in examining a large number of fixed stars for a most careful investigation of their proper motion. See his memoirs, DLX Stellarum fixarum positiones mediæ ineunte anno 1830, ex observ. Aboæ habitis (Helsingforsiæ, 1825). Mädler (Astr. S. 625), estimates at 600 the number of multiple stars discovered in the northern celestial hemisphere at Pulkova since 1837.

(343) p. 247.—The number of fixed stars in which *proper motion* has been perceived (while we may conjecture its existence in all), is a little greater than the number of multiple stars in which a *difference of relative position* has been observed. Mädler, Astr. S. 394, 490, and 520—540. Struve, in his Mens. microm., p. xciv., gives the results of the application of the calculus of probabilities to these relations, according as the distances apart of the double or multiple stars are between 0″ and 1″, 2″ and 8″, or 16″ and 32.″ Distances less than 0″·3 have been appreciated, and experiments with very closely placed artificial double stars have confirmed the observer's hopes of such estimations being for the most part secure, as far as 0″.1. Struve über Doppelsterne nach Dorpater Beob. S. 29.

(344) p. 208.—John Herschel, Cape Observations, p. 166.

(345) p. 208.—Struve Mensuræ microm., p. lxxvii. to lxxxiv.

(346) p. 208.—John Herschel, Outlines of Astr., p. 579.

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

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

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

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

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

([352]) p. 210.—"This superb double star (α Centauri) is beyond all comparison the most striking object of the kind in the heavens, and consists of two individuals, both of a high ruddy or orange colour, though that of t smaller is of a somewhat more sombre and brownish cast." Sir John Herschel, Cape Observations, p. 300. According to the valuable observations of Captain Jacob, of the Bombay Engineers, in 1846—1848, the principal star is estimated at the 1st magnitude, and the companion from the 2·5 to the 3rd magnitude.

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

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

(355) p. 211.—Same work, S. 36.

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

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