ART. IV.—1. *Spectrum Analysis.* Six Lectures delivered in 1868. By HENRY E. ROSCOE, F.R.S. 8vo. London: 1869.

2. *Le Stelle: Saggio di Astronomia Siderale.* Del P. A. SECCHI. Milano: 1878.

3. *Researches in Spectrum Analysis in connexion with the Spectrum of the Sun.* By J. NORMAN LOCKYER, F.R.S. 'Proceedings of the Royal Society,' vol. xxviii.: 1879.

4. *On the Spectra of some of the Fixed Stars.* By WILLIAM HUGGINS, F.R.A.S., and W. A. MILLER, M.D., LL.D. 'Philosophical Transactions of the Royal Society,' vol. cliv.: 1864.

5. *Further Investigations on the Spectra of some of the Stars and Nebulæ, with an Attempt to determine therefrom whether these Bodies are moving towards or from the Earth.* By WILLIAM HUGGINS, F.R.S. 'Philosophical Transactions of the Royal Society,' vol. clviii.: 1868.

6. *The Universe of Stars.* By RICHARD A. PROCTOR. Second Edition. London: 1878.

WHEN Kirchhoff demonstrated, twenty-one years ago, the existence of sodium in the atmosphere of the sun, he made an advance of which we are even yet hardly in a position to estimate the full importance. The discovery supplied one more proof of the harmony of nature and the fundamental unity of science. The 'corruptible' materials of our mother-earth were shown by conclusive evidence to form part of the 'incorruptible' substance of the radiant orbs of heaven. Astronomy, which had hitherto taken cognisance of matter only in its most general form, was now compelled to descend into the laboratory in order to study its various kinds and qualities, together with their mutual actions and relations. The science of celestial mechanics became, all at once, the science of celestial chemistry. From the new point of departure thus unexpectedly provided, untried fields of research were gradually perceived to stretch farther and farther away into the illimitable distance. The invention of the telescope does not, indeed, form a more noteworthy epoch in the history of astronomy than does the application of the prism to the physical investigation of the heavenly bodies. Yet, marvellous as are the results already achieved by spectrum analysis, they are as nothing compared with the crowd of unsolved problems which continually stimulate the curiosity, and baffle the skill,

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of the spectroscopist. Nor should this occasion surprise. Since creation is modelled on a scale utterly incommensurable with human faculties, the progress of science necessarily proposes more questions than it answers, and opens up, one after the other, vistas of the unknown, each forming, as it were, a separate pathway towards the one infinity.

Thus each new discovery, by revealing previously unsuspected ignorance, suggests fresh efforts, and promotes fresh advances. Already the more hopeful among men of science look forward with confidence to the recognition of a law, higher and wider than that of Newton, embracing all the operations upon matter of the so-called 'physical forces,' and reducing under a common denomination the actions of gravity and cohesion, the phenomena of light, heat, and electricity. We venture indeed to assert that no one who earnestly and intelligently looks nature in the face can escape the conviction that such a principle regulates the apparent anomalies, and harmonises the apparent contradictions, visible in the world around us. The generalisation of knowledge, however, becomes increasingly difficult with its extension; by the accumulation of particulars induction is rendered more sure, but is also rendered more arduous; and science is impeded in its progress in proportion as it is amplified in its details. We may then have to wait long for the realisation of the hopes held out to us, and must for the present content ourselves with noting effects where we would willingly penetrate into causes. Nevertheless, the close relationship more and more clearly perceived to unite the physical sciences forms in itself a species of generalisation, and will doubtless contribute in the future to maintain and increase the high intellectual importance of natural investigations.

The discovery of spectrum analysis has most markedly emphasised this relationship. The sciences of astronomy and chemistry can no longer be said to exist independently one of the other. The astronomer demands from the chemist an interpretation of what he observes; the chemist turns to the astronomer for confirmation of what he divines. The working of this new alliance is strikingly exemplified in Mr. Norman Lockyer's recent investigations into the nature of the chemical elements. The sixty-five to seventy * different substances at

* The exact number cannot at present be determined. Since 1877, claims have been put forward to the discovery of no less than fourteen new metals, in many cases, probably, on very insufficient grounds. See a paper in 'Nature,' July 8, 1880.

present known to enter into the composition of the earth have long been regarded by chemists as only provisionally elementary in their character. The term 'element' was simply meant to convey that hitherto they had not been decomposed; but it was clearly foreseen that with improved laboratory appliances many such bodies would be reduced to a simpler condition—a prevision already verified in the case of the allied substances, chlorine, bromine, and iodine.

But theory has, in this direction, far outstripped experiment. Between the atomic weights of the various elements, numerical relations, as remarkable as those connecting the different members of the solar system, have been perceived to exist. Empirical laws, of similar character to 'Bode's law' of planetary distances, regulate the combining proportions of certain groups of substances analogous in their qualities, indicating, it is argued, varying degrees of complexity in their composition.* These ingenious speculations have even been made the basis of successful prediction. A gap in the series indicated by his 'periodic law' enabled Professor Mendelejeff, in 1869, to announce the existence and describe the qualities of a new metal, discovered, six years later, by M. Lecoq de Boisbaudran in a blende from the mines of Pierrefitte, and named by him 'gallium.'† Moreover, the striking fact that nearly all atomic weights are simple multiples of the weight of the hydrogen-atom gave rise to Prout's celebrated hypothesis of a primordial substance no other than hydrogen. But even this is not enough. Still bolder speculators derive from luminiferous ether—the refuge and the reproach of science—every form of ponderable matter; and the remarkable theory of 'vortex-atoms,' elaborated from profound mathematical considerations by Sir William Thomson and the late Professor Clerk Maxwell, has lent plausibility (it would be going too far to say probability) to what seemed at first sight an extravagant conjecture.

We learn then, without surprise, from a paper communicated to the Royal Society, December 12, 1878, the title of which we have prefixed to this article, that Mr. Lockyer has been led by his spectroscopic studies to doubt the elementary character of some, if not all, of those bodies which have hitherto successfully maintained that reputation. We are not prepared to deny his conclusions; but we venture to dissent from some at least of the arguments by which he seeks to support them.

* Chemical News, vol. xxxviii. p. 66.
† Comptes Rendus, t. lxxxi. pp. 493, 969.

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His observations are of the highest interest and importance; but they seem to us hardly to warrant the interpretation which he puts upon them.

We need not here dwell upon the first principles of spectrum analysis; they were ably expounded in the pages of this Journal * shortly after their discovery, and are dwelt upon with still fuller detail in the valuable work by Professor Roscoe which stands at the head of this article. It may, however, be well to remind our readers that while further enquiry has amply confirmed the fundamental theorem upon which the science rests—namely, that vapours absorb rays of the same refrangibilities that they radiate—a multitude of secondary facts have been recognised, which, although they at present tend somewhat to embarrass our conclusions, will no doubt eventually contribute to define them. Thus, while it may be looked upon as established that an incandescent solid or liquid body gives a continuous spectrum—in other words, emits light of every shade of colour—the converse no longer holds good. A continuous spectrum is *not* necessarily due to a solid or liquid, but may be derived from a vapour at considerable pressure. Many physicists, indeed, believe that the vast mass of the sun consists of glowing and enormously compressed gases, the fine black lines which rule the rainbow-tinted ribbon unrolled out of its light by the prism, owing their origin to the selective absorption of the same vapours at a higher level and reduced temperature and density. They in fact stop on their passage the identical rays that they more feebly emit, thus producing those innumerable minute gaps of comparative darkness in the sun's light known as 'Fraunhofer lines.' Now each of these vapours or gases gives forth, when heated to incandescence, a more or less numerous set of light-waves, strictly definite in their respective colours and consequent positions in the spectrum; and it is by the identification of these beams, or bright lines, with corresponding dark lines in the solar spectrum, that inferences, surprising but entirely trustworthy, have been drawn regarding the physical constitution of our great luminary.

The spectroscopic evidence adduced by Mr. Lockyer in proof of the compound character of the 'elements' may be conveniently divided into three classes—terrestrial, solar, and stellar. His position would, indeed, be much more clearly intelligible if founded on some settled theory of luminous radiation by matter in its various conditions. But on this

* Edinburgh Review, vol. cxvi., art. 'Solar Chemistry.'

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point modern science has nothing to offer beyond some vague and unsatisfactory conjectures. We find ourselves, at the very threshold of enquiry, confronted by the (at present) inscrutable relations subsisting between that enigmatical substance whose vibrations are light, and the gross matter originating those vibrations by its movements. This much, however, we may safely say. A vibrating molecule is, speaking generally, not a simple body, but a system, probably of extremely complex constitution. Now any disturbance affecting that system will be faithfully reflected in the rays of light, which are the visible translation of its intimate thrillings. Such disturbances may be almost infinitely various in kind and degree, the actual severance of the atoms, or parts constituting a molecule, being only one extreme case amongst a multitude of possible modifications. But, while it is certain that each infinitesimal variation of molecular relations must produce a corresponding effect in the spectrum, this severance of atoms, or 'dissociation,' is adopted by Mr. Lockyer as a general rationale of all spectroscopic changes.

His main argument under this head is founded on analogy. He observes that the spectra of bodies supposed to be simple undergo, in like circumstances, changes precisely similar to those of bodies known to be compound. In the latter case the explanation is obvious and undeniable. The spectrum characteristic of the compound gives place, as the temperature rises and dissociation proceeds, to the spectrum characteristic of its principal constituent. The easy and natural course seems to be to transfer this explanation to the other case. And it is this which Mr. Lockyer has taken. Now we are far from denying that chemical separations play a certain part in producing the appearances revealed by the prism; what we contend is that the cause in question, far from being universally active, is most likely only exceptionally so. In the first place, marked changes occur in cases where there can be no question of dissociation. By the mere condensation or rarefaction of an incandescent vapour, the bright lines of which its spectrum is composed can be increased or diminished at pleasure. If we suppose, according to the received theory, the light-producing vibrations of minute particles of matter to be maintained by the mutual impacts of those particles, then the fewer the impacts, the more feeble the vibrations. And, just as the harmonics * of a musical note can

* For an account of Mr. Johnstone Stoney's ingenious harmonic theory of line spectra, see Schellen's 'Spectrum Analysis,' Appendix A (English translation).

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no longer be detected by the ear when the note is sounded faintly, so the secondary oscillations of a vibrating particle cease, as their amplitude is diminished, to produce a visible effect in the spectrum, long before the fundamental vibration is extinguished. Moreover, the spectroscope affords as yet absolutely no criterion for distinguishing between the division of dissimilar and the separation of similar atoms—two essentially different operations, although both included under the somewhat unsatisfactory term 'dissociation.' Other instances might be alleged, suggestive at once of the obscurity which still involves this subject, and of the subtle complication of causes which we have to unravel in dealing with it; but we believe we have said enough to show that, as a universal explanation of spectroscopic phenomena, the 'dissociation theory' is untenable.

This is not the place to discuss Mr. Lockyer's striking and suggestive remarks on the behaviour in solar eruptions of lines called by him 'basic,' because due, in his opinion, to the presence of an identical base in two or more metals to whose spectra they are common. He notes that these lines appear predominantly when metallic vapours are injected from beneath the surface of the sun into the glowing atmosphere of hydrogen constituting the 'chromosphere,' and infers dissociation at the elevated temperature of the interior, followed by re-association in the cooler regions above. It is a subject well worthy of further investigation; but in the meantime we may be permitted to observe that, even apart from the probability that many such coincidences are only apparent,* they possibly indicate molecular affinities other than identity of substance.

We have now, to some extent, cleared the ground for the consideration of Mr. Lockyer's 'appeal to the stars.' His view is, that, heat being the great dissociating agent, our observation of chemical separations may be indefinitely extended, with the range of temperature at our command, by studying the comparative effects produced by the variously graduated, but inconceivably potent, furnaces of the celestial spaces. In other words, bodies which maintain their union at the highest temperature available in the laboratory, may be discovered, with the aid of the spectroscope, to exist in a divorced condition

* As the dispersive power of the spectroscope is increased, lines, previously supposed coincident, are in many cases found to be divided by a minute interval. We may mention, as an example, the coronal ray, numbered 1,474 on Kirchoff's scale, believed, until Professor Young succeeded, in 1876, in separating them, to agree in position with a line in the spectrum of iron.

in the atmospheres of the stars. The idea is doubtless a just one, and will perhaps some day fructify; but of its actual realisation we cannot find that any valid evidence has yet been offered.

The first to analyse stellar light with the prism was Fraunhofer. As early as 1823 he observed that the dark solar line, named by him F, and long afterwards shown to proceed from the absorptive action of hydrogen in the sun's atmosphere, was repeated in the spectrum of Sirius; while D (the characteristic orange-yellow line of sodium) was visible in the spectra of Betelgeux, Castor, Pollux, and Capella. Shortly after the publication of Kirchhoff's great discovery, the subject was resumed, although with little result, by Donati of Florence; and it was not until 1862, when it was almost simultaneously taken in hand by Father Secchi in Rome, and by Dr. Huggins in this country, that any notable advance was made towards founding a science of stellar spectroscopy. Exceptional difficulties of observation attended and impeded their labours. In the largest telescopes hitherto constructed, the most brilliant stars appear only as points of light; their spectra have consequently no sensible breadth, and present no surface for study. This inconvenience can, it is true, be remedied by the use of a cylindrical lens, which lengthens the luminous point into a line, again extended into a band by the action of the prism; but this involves dispersion in two directions, and entails a considerable loss of light, the very subject-matter of enquiry. Moreover, the continual fluctuations of our atmosphere incredibly embarrass exact measurements; while the necessary restrictions of position in the object to be examined, together with the chances and changes of weather, render the thorough investigation of a single star spectrum the work of many years.*

The main results of Father Secchi's work among the stars are contained in the volume with the title of which we have headed this article. The death of the author, which took place at the Collegio Romano, February 26, 1878, followed closely upon its publication, so that we have in it the final utterance of the eminent Jesuit astronomer. Owing to the relatively imperfect instrumental means at his command, he aimed at extent rather than accuracy of observation. Accordingly, the first systematic attempt at the classification of star spectra is due

* For a description of the apparatus employed in the observation of stellar spectra, see Roscoe, 'Spectrum Analysis,' pp. 232–4; Huggins and Miller, 'On the Spectra of some of the Fixed Stars,' 'Phil. Trans.,' ii. 1864.

to him. A sweeping survey of the heavens, embracing over 4,000 stars, enabled him to define four spectral orders or types, which serve usefully as at least a provisional framework within which to fit and shape our knowledge as it grows.

The first order is the most numerously and brilliantly represented. It is composed exclusively of stars shining with a white or bluish light, and includes many of the most conspicuous jewels of our midnight skies—Sirius, Vega (the principal star in the Lyre), Castor, Regulus, Altair in the Eagle, Rigel in the knee of Orion, &c. The spectra of these stars are characterised by the exceptional breadth and blackness of the four hydrogen lines, and by the faintness of the metallic lines of absorption. Those, however, belonging to sodium, calcium, magnesium, and iron, have been recognised, and innumerable others await future determination. More than half the visible stars belong to this class.

The second order comprises yellow stars, such as Capella, Arcturus, Aldebaran in the eye of the Bull, Pollux, Dubhe* (the brightest star in the Great Bear), and our own sun. They exhibit spectra closely and finely ruled in black, precisely analogous to the solar spectrum, many of the lines in which have been identified in the light of these sister-suns. Hydrogen lines are present, but less marked than in the preceding class. About a third of the classified stars are of this type.

The spectrum characteristic of the third order is of a composite nature, the usual dark metallic lines being, as it were, superposed upon a fluted background, presenting the appearance of a strongly illuminated row of columns seen in perspective, the bright sides turned towards the red or less refrangible end of the spectrum. The hydrogen lines are faint, and in some cases absent. About thirty stars, most of them of a reddish tint, and some of them noted variables, have been recognised as belonging to this class, which includes Mira in the Whale, called 'Wonderful' because of its strange waxings and wanings; Betelgeux in the shoulder of Orion, *a* Herculis, and Antares in the Scorpion.

The fourth order is composed of small blood-red stars, none above the fifth magnitude. Their spectra, consisting of

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* *Dubhe* is *Dub*, the Arabic name for 'bear,' pronounced soft. In this instance, as in many others, the title of the entire constellation was transferred to the brightest of the stars composing it. The name was handed down to modern times through the medium of the Alphonsine Tables. Ideler, 'Ueber den Ursprung und die Bedeutung der Sternnamen,' p. 23.

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three broad columnar bands, *reversed*, i.e. illuminated from the violet side, show a striking general resemblance to those given by the nuclei of comets, which again have been almost certainly identified with the banded spectrum of carbon, or one of its compounds.

Mr. Lockyer considers these four orders as representing, broadly, four stages on the road from formation to extinction. He argues that the whitest and brightest, and he presumes the hottest and *youngest*, stars exhibit the simplest spectra, and therefore contain the fewest elements, and those of the lowest atomic weights; that, with decreasing temperature and advancing years, heavier and more complex bodies are formed, free hydrogen disappears, and metallic lines are replaced by the bands and flutings characteristic of oxides and metalloids. He sees the substances with which we are familiar progressively developed, as the first fierce heat of stellar existence declines, out of their primordial elements or element, and traces, in the continual advance of matter towards more complex forms, the consequence of stellar refrigeration and decay.

This view presents a seductive, but in a theory of nature suspicious appearance of completeness. It is too plausible to be altogether sound. We believe it can be shown that evidence is wholly wanting either of the activity in the heavenly bodies of what we may call 'elemental evolution,' or of such a succession of stellar ages as that assumed by Mr. Lockyer's hypothesis.

The spectra of stars of the first order are, to begin with, only at first sight less complex than those of stars of the second. Their apparent simplicity vanishes on closer inspection. Dr. Huggins, from whose testimony on this point there is no appeal, describes the spectrum of Sirius as throughout 'crossed by a 'very great multitude of faint and fine lines.'* That of Vega, he adds, 'is as full of fine lines as the solar spectrum.' There is, then, no reason to suppose that the number of 'elements' contained in this class of stars is less than in our sun, although, from the feebleness of their absorptive action, they are far more difficult of detection. What is truly characteristic of the type is the immense predominance of the hydrogen lines, indicating the presence of that substance in large mass, and under considerable pressure. Indeed, the varying conditions under which hydrogen is found in different stars form probably the most reliable index to their respective physical constitu-

* Phil. Trans., vol. cliv. p. 428.

tions.* Mr. Lockyer attributes the progressive weakening or even effacement of the well-known hydrogen lines, in passing from the first to the fourth order of star spectra, to the gradual cooling and consequent withdrawal of the gas from a free condition to a state of combination with other substances. We hold, on the contrary, that this enfeeblement is occasioned, not by the disappearance of free hydrogen, but by its presence in a more exalted condition of incandescence, causing it to replace, partially or wholly, the light that it absorbs. This opinion is strengthened by the remarkable fact that in certain stars these lines actually appear *bright* as compared with the rest of the spectrum. We have only to consider what takes place in the central star of our planetary world to understand the significance of this phenomenon.

The sun is encompassed with an atmosphere of flaming hydrogen. This, when seen isolated, as in eclipses, exhibits the peculiar bright rays so familiar to spectroscopists; but because its temperature is lower than that of the glowing mass it surrounds, it absorbs more light than it radiates, and its lines, consequently, show dark when projected on the dazzling surface of the photosphere. But if the incandescence of this fiery 'sierra' be gradually increased, until its light equals and then surpasses that of the central mass, the obscure gaps in the spectrum caused by its absorption will first disappear, as in Betelgeux,† and finally be replaced by bright rays, as in the second star of the Lyre.‡ This is actually observed to occur in sun-spots. The nucleus or darkest portion, owing doubtless to the downrush of cooler vapours, shows increased absorption; the faculæ, brilliant eruptive hydrogen jets, closely associated with spots, display bright lines; while in the intermediate or penumbral region the hydrogen rays, as might have been expected, usually fade out and vanish. Thus, so far as the evidence afforded by this particular substance is concerned, progression would seem to be in the opposite direction from that contemplated in Mr. Lockyer's theory. We, however, by no means desire to convey that red stars are, as a rule, hotter

* Huggins, 'Proceedings R. Society,' vol. xv. p. 149.

† With the best instruments traces of hydrogen absorption can be discovered in this star.

‡ β Lyræ is a variable star, showing bright lines at its maximum. γ Cassiopeiæ, by a singular exception, displays an unvarying spectrum of vivid rays. Both shine with a white light, but evidently belong to a totally different order of stellar existence from Sirius and Vega. All other stars showing bright lines are variable, giving, as a rule, banded spectra.

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than white. We undertake to prove nothing of the kind. Our contention is merely that the *difference* of temperature between the body of a star and its surrounding atmosphere diminishes in passing from the first to the second, and from the second to the third and fourth orders. Heat is, in fact, in red stars more diffused, in white stars more concentrated. The full import of this distinction will become apparent further on.

The complete worthlessness of *negative* evidence as regards stellar constitution is forcibly illustrated by Professor H. Draper's recent discovery of the bright lines of oxygen in the solar spectrum. The conclusions to be drawn from the prismatic analysis of the heavenly bodies receive thereby an important qualification. From the appearance of certain lines we can still confidently argue the presence of the substance which they characterise; but we can no longer infer the absence of any particular body from the non-appearance of its representative rays. This objection applies equally to Mr. Lockyer's argument on the effacement of hydrogen lines, and to his reasoning on the emergence of metalloidal bands in the spectra of the stars. The 'metalloids,' or non-metallic elements, of which oxygen, carbon, and sulphur may be taken as specimens, are fourteen in number (exclusive of hydrogen, which possesses most of the qualities of a true metal). Many of these bodies are believed, and a few are now ascertained, to be reducible to a simpler state; and it is on this ground that Mr. Lockyer alleges their presence in the atmospheres of some stars as a proof of lowered temperature. He supposes that, at the white heat of Sirius, and even in the less vehement solar furnace, their constituent particles are incapable of uniting, and come together only in the relaxing fires of such waning luminaries as Betelgeux and Antares. Now the existence of oxygen in the sun is already proved, that of nitrogen is strongly suspected, and Mr. Lockyer has himself found traces of carbon in the coronal atmosphere.* It is hardly possible to doubt that in Sirius and its sister-orbs the same substances are found under similar conditions. Dr. Draper's discovery has at least made it evident that their presence can hardly be established, and can never be disproved.

The facility with which this class of bodies may escape detection is due to their pre-eminent, though not exclusive, possession of an attribute which we may call—to borrow a phrase of Mr. Lockyer's coining—'molecular plasticity.' The vagueness of the expression (although as good a one as could

* Proceedings R. Society, vol. xxvii. pp. 308-9.

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be chosen) accurately represents the indefiniteness of our present knowledge; we may, however, describe the quality meant to be conveyed by it as a certain adaptability of structure in the vibrating particles, causing them to change their manner of oscillation, and consequently their mode of radiation, with varying conditions. Indeed, we believe (as already hinted) that most of the hitherto unexplained anomalies in metallic spectra can be accounted for on the same principle. In the case of oxygen, Dr. Schuster's researches * have enabled him to distinguish four entirely different spectra, corresponding to four grades of temperature, of which the first (that due to the greatest heat) is found bright in the sun, while the next in order appears as dark rays. The peculiar value of this observation consists in the prospect it offers of determining with some approach to accuracy the temperature of the solar atmosphere; since it is obvious that the diminution of heat necessary to effect the change of spectrum occurs somewhere between the solar surface and the 'reversing layer,' or envelope of heterogeneous vapours extending to about one thousand miles from the sun's surface, and producing by its absorption the significant Fraunhofer lines.

It is indeed true that a marked increase of metalloidal absorption at a comparatively low temperature is probably indicated by the columnar or fluted structure of stellar spectra of the third and fourth orders. But this circumstance tells us nothing as to the thermal condition of the central parts of such stars. We have only to suppose the absorption to take place at a considerable elevation above their photospheres, in order to arrive at any degree of coolness that may be needed to produce it. This view is, in fact, alleged by Mr. Lockyer to explain the presence of certain remnants or survivals of carbon bands in the solar spectrum. He adds the suggestive remark that the outer atmosphere of the sun, and perhaps also the exterior planets, are 'more metalloidal than metallic 'in their composition.' † Now, if, owing to increased eruptive activity or any other cause, the density of these coronal vapours were largely augmented, we should have the precise state of things indicated by the spectra under consideration. It may be added that metallic lines are found by Dr. Huggins to abound in the spectra of Betelgeux and $\beta$ Pegasi—both typical stars of the banded class—so that we may dismiss as

* 'On the Spectra of Metalloids,' Phil. Trans. vol. clxx. part i.; Nature, vol. xvii. p. 148.

† Proceedings R. Society, vol. xxvii. p. 309.

unwarranted by observation the presumption of a progressive disappearance of these bodies *pari passu* with the more conspicuous development of metalloids.

An argument much relied on by Mr. Lockyer in support of his theory of elemental evolution is founded on the (apparently) abnormal behaviour of calcium in the spectra of some of the brightest stars. Two closely associated lines in the extreme violet, characteristic of this metal at high temperatures (named respectively H and K), have been perceived to vary markedly in their mutual relations as observed in analysed stellar light. From the spectrum of Sirius K is absent, and in that of Vega is barely discoverable, while in both H is conspicuous, as a wide and deeply-grooved furrow; in that of *α* Aquilæ (Altair), on the other hand, K is indeed plainly visible, but its width is only half that of its companion. From these facts it has been plausibly argued that, in the hottest stars, calcium is dissolved into two constituents, radiating respectively these two violet rays, the relative intensities of which, it was hoped, might prove a valuable index to stellar temperature and condition. Unfortunately, no such convenient finger-post has been provided for us. Dr. H. W. Vogel's recent investigations * overturn, in our judgment, the whole fabric of this reasoning. The photographs † obtained by him of the hydrogen spectrum not only prove the entire series of twelve lines photographed by Dr. Huggins in the spectra of the white stars to be derived from that substance, but show an unmistakeable coincidence between one of these remarkable lines and the dark band hitherto ascribed to the absorption of the vapour of calcium. Indeed, a simple inspection of Dr. Huggins's admirable photographs is sufficient to convince the most casual observer that the H line, falling in, as it does, with the rhythmical progression of its associates, forms one of the same group, and is attributable to the same molecular vibration with them. The true calcium line is thus overlapped and concealed by the wider and stronger hydrogen line with which it has been confounded.

One unimpeachable instance, and one only, is on record of a permanent and marked change in a star's colour within the historical period. Sirius—the 'sparkler,' or 'star,' *par excellence*, of the Greeks, the 'canicula' of the Romans, at present

* For an account of these researches, see 'Nature,' vol. xxi. p. 410; 'Chemical News,' March 12, 1880.

† Published at Berlin, in 'Monatsberichte der Akad. der Wiss.,' July 1879, p. 550.

the most conspicuously white star in the sky—is expressly described by Seneca * as ruddier than Mars, and is qualified by Ptolemy † as 'reddish' (ὑπόκιῤῥος). We might add that Homer could not fitly have compared the brazen refulgence of the divinely forged armour of Achilles to the steely glitter of our dog-star, although 'the brightest of all that shine in the 'silence of the night.'‡ But the old bard's eye for colour was notoriously faulty, so that we need not bring him into court. His testimony is indeed superfluous, since the witnesses already cited prove beyond the possibility of cavil that the complexion of Sirius has changed from rubicund to pallid within the last eighteen hundred years. This fact alone appears to dispose of the view that a rosy tint is symptomatic of a declining stage in stellar existence.

Yet more striking examples of instability in the aspects of the heavenly bodies are, however, afforded by actual observation. Although it is improbable that the light emitted by any of the suns in space (our own not excepted) is absolutely constant, the number of stars recognised as 'variable' hardly exceeds 150. Of these the great majority are of an orange or crimson colour, and it may be stated broadly that all the more deeply tinted stars are subject to marked fluctuations in brilliancy. To the converse proposition—namely, that white stars display a sensibly steady lustre—there is (besides $\beta$ Lyræ, which is set apart by the peculiarity of its spectrum) one notable exception, but one which, by the singularity of its nature, seems to confirm the rule. Algol in the head of Medusa, a bright star of the Sirian type, shines equably during two days and thirteen hours, then suddenly begins to decline, and at the end of three and a half hours has sunk from the second to the fourth magnitude, after which it recovers, in an equal time, its original splendour. The entire cycle of these changes is completed in 2 days, 20 hours, 48½ minutes, but the period is subject to slight perturbations. Now these appearances—of uniform radiance, interrupted by a relatively short phase of eclipse—contrast strongly with the gradual fading and flushing of other variables, and instantly suggest the intervention of an opaque body cutting off, at each revolution, a portion of the light of its primary. This view, although not entirely free from difficulties, is favoured

* Natur. Quæst. i. 1.

† Catalogue (Baily's edition), Memoirs R. Astronomical Society, vol. xiii. p. 62; Secchi, 'Le Stelle,' p. 64.

‡ Iliad, xxii. 27.

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by the evidence of the prism, showing the radiations emitted by Algol unaltered in quality even at its minimum.

Information of a more positive kind is, however, afforded by the spectroscope regarding periodical stars of normal character. Variables, such as Aldebaran and Arcturus, whose spectra, in their brighter phases, resemble that of our sun, display, as their lustre wanes and their hue deepens, manifest symptoms of approach to the fluted type; while others definitely pass from one class to the other. In stars of the third and fourth orders, the bands of absorption are perceived, as their light diminishes, to darken and extend, their maxima, on the contrary, being frequently marked by the appearance of bright lines due to the presence of various incandescent substances. We have then in periodical stars those 'migratory instances,' the importance of which in natural enquiries Francis Bacon was the first to point out; and it is accordingly to them principally that our attention should be directed if we would penetrate the secrets of stellar constitution. But, before adverting to the various explanatory conjectures which have been hazarded on this subject, we must dedicate a few words to those strange cosmical apparitions now generally regarded as extreme cases of variability. We allude to new or temporary stars.

Twenty-three such instances are authentically recorded, from the memorable object which suggested the star-census of Hipparchus to the brief blaze seen four years ago in the constellation Cygnus; and no doubt many more have escaped notice. The suddenness of these celestial conflagrations is one of their most surprising features. On the evening of November 11, 1572, Tycho Brahe, lifting his eyes to the heavens, beheld near the zenith a star brighter than Jupiter, which he felt certain had not been visible half an hour previously. Such was its brilliancy that keen-sighted persons were able to detect it at noon when the air was clear, and at night when the sky was so thickly overcast as to hide all other stars. After a few weeks, however, it began to wane, and at the end of seventeen months entirely disappeared. It is now supposed to be represented by a minute red star discovered by M. d'Arrest close to the spot in Cassiopeia indicated by the Danish astronomer. The recorded appearance of a similar phenomenon in the same region of the sky in the years 945 and 1264 suggested the very probable surmise that all three were luminous outbursts, at intervals of somewhat over three hundred years, of the same body. If this be so, its re-appearance might be looked for about the present time. It is worth noting that an overwhelming majority of such apparitions have occurred within or

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near the limits of the Milky Way. This circumstance was, indeed, alleged by Tycho in support of a theory (closely resembling that of Sir William Herschel) of stellar genesis by the condensation of nebulous matter; and it was even maintained by some that the *hiatus* in the Galaxy could be discerned, whence the aerial substance of the phantom star of 1572 had been drawn! Without going to similar lengths, we may safely assert that such coincidences in position are not fortuitous, but indicate physical relations, the nature of which we can at present but imperfectly conceive.

Two 'star-guests' (to borrow a Chinese phrase) * have, since the invention of the spectroscope, presented themselves for examination by the new method. On May 12, 1866, a star of the second magnitude, first seen by Mr. Birmingham of Tuam, suddenly flamed out in Corona Borealis. In twelve days it had declined to the sixth magnitude, and is now just discoverable as a faint telescopic object. Ten years later, November 24, 1876, M. Schmidt, Director of the Athens Observatory, discovered, in the constellation of the Swan, a new star of the third magnitude, which continued for two or three months, although with constantly diminishing lustre, to be visible to the naked eye. The spectra of both these sidereal strangers were studied—that of the first by Dr. Huggins, that of the second by M. Cornu of the Paris Observatory—and with very significant results.† Superposed upon a continuous spectrum crossed by dark bands and lines, analogous to that of Betelgeux, shone a series of brilliant rays, in which the greater part of the star's light was concentrated. Several of these coincided with lines of hydrogen and magnesium; one appeared identical with the green coronal line, another with the yellow line of the chromosphere derived from an unknown substance named 'helium.'‡ Thus it may be regarded as certain that the incandescent vapours which shone with such extraordinary splendour in these two singular objects were precisely the main constituents of the gaseous envelopes of the sun. So far, both gave concordant testimony; but a divergence subsequently showed itself. In T Coronæ (the new star in the Northern Crown) the continuous spectrum of an ordinary small star survived the extinction of the bright lines; but in 'Nova' Cygni exactly the

* Cosmos, iii. p. 210.

† Proceedings R. Society, vol. xv. p. 146; Comptes Rendus, t. lxxxiii. p. 1172.

‡ Both 'helium' and the substance radiating the coronal line are believed by Mr. Lockyer to be different modifications of hydrogen.

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reverse occurred. On September 2, 1877, the spectrum of this star (which, having sunk nearly to the twelfth magnitude, had ceased to attract special notice) was examined in Lord Lindsay's Observatory at Dunecht. A singular and unexpected piece of information resulted. The light when analysed was perceived to be almost entirely homogeneous—that is to say, it emerged from the prism as a single green ray, coinciding in position with one of the three bright lines emitted by gaseous nebulæ.* We are then, by this discovery, forced to admit the possibility of a stellar body radiating, under certain conditions, distinctively nebular light.

We may now briefly consider the different interpretations which have been put upon these appearances. It should, however, be steadily borne in mind, that since no line of demarcation can be drawn between periodic and temporary stars, we cannot accept as satisfactory any hypothesis which excludes from consideration either class of facts. What accounts for one should be capable of accounting for the other, since uniformity of cause ordinarily underlies an uninterrupted succession of phenomena. Variable stars are of all degrees of irregularity, from the steady phases of Algol to the fitful outbursts of $\eta$ Argûs,† which may indeed be regarded as a link between stars showing a maximum and minimum of brightness, and those emerging from long obscurity into brief splendour. We must then instantly reject, on the one side, theories seeking to explain periodic, while neglecting temporary stars; and, on the other, theories postulating sudden and extraordinary conflagrations to the exclusion of gradual and orderly ebbings and flowings of lustre. To the first category belong the ideas that variability may be caused by the rotation of the star itself, showing alternately a bright and a darker side, or by the revolution of an eclipsing satellite (admissible, possibly, in the exceptional case of Algol); to the other, the suppositions that new stars may owe their temporary splendour either to a fortuitous collision with another stellar body, or to a sudden plunge into a nebulous ocean. Such catastrophes are indeed possible, but they stand apart from our present enquiry.

There remain the 'meteoric' theory, the 'dissociation' theory, and the 'sun-spot' theory. The first of these is open to many

* Astronomische Nachrichten (No. 2158), vol. xc. p. 351.

† The variations of this southern luminary may be approximately represented by fluctuations from the first to the sixth or seventh magnitude in a period of seventy years, including a threefold maximum. Chambers' 'Descriptive Astronomy,' p. 501, 3rd ed.

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objections; we need mention but one. The undisputed fact that red stars are pre-eminently inconstant sufficiently shows that variability is not due to the action of an extrinsic cause, such as the in-pouring of meteoric matter, whose motion is instantaneously converted into heat, but is a quality inherent in a certain form of stellar existence. The view that the phases of sidereal brilliancy are the result of a 'delicate balance of 'temperature,' compelling, as the equilibrium is shifted in the direction either of heat or cold, extensive dissociations, or equally extensive combinations of chemically related substances, with the variations of absorption and brightness thence ensuing, was originated independently by the late M. Angström of Upsala, and by Mr. Lockyer. The theory gives a tolerably plausible account of some of the facts, but can hardly be said to include them all. In many variables, for example, the increase of light is accompanied by the appearance of brilliant rays in the ordinary spectrum of absorption. Now we do not clearly see how to account for their presence on the hypothesis of dissociation. It may be suggested that they arise not from simple incandescence, but from actual burning, or combination, with development of light and heat. Even if we set aside the objection that the theory would be inverted and distorted beyond recognition by making the maxima of stellar brilliancy to coincide with the occurrence, not of dissociation, but of energetic association, we are confronted by the fact that hydrogen and many other gases emit, during combustion, rays of all refrangibilities. In other words, they give a continuous, not a line spectrum. Of such an emission there has never been perceived any trace in variable stars. No hypothesis, then, involving literal conflagration, can be regarded as admissible.

We are driven, in the last resort, to what we have termed the 'sun-spot theory.' This was suggested to Father Secchi by his observation of the strong resemblance exhibited by the spectra of solar spots to those of some periodical stars in their obscure phases. According to this view, variability would be the result of increased or diminished eruptive energy, causing increased or diminished absorption. The analogy between such cycles of change and the solar 'eleven-year period' is drawn closer by the circumstance that variable stars are commonly subject to a secondary period of longer duration, corresponding to the 'sixty-year period' of sun-spots, by which their maxima and minima are alternately accelerated and retarded. It must not be supposed, however, that the fluctuations of stellar light can be explained as mere differences in the amount of superficial 'maculation.' Sun-spots are but one of the least symptoms—

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perhaps a surviving relic—of the condition which we contemplate, not only in such capricious luminaries as 'Mira' Ceti and $\eta$ Argûs, but even in the comparatively steady orbs of Aldebaran and Arcturus. The absorption producing marked obscuration no doubt occurs in the coronal atmospheres, or at least at some considerable height above the photospheres of such stars. Vast masses of incandescent vapour are, we may conceive, ejected from the central body during epochs of disturbance—precisely as hydrogen, helium, and other substances are flung forth from the interior of the sun in the fantastic forms known as 'prominences'—and produce, as they cool in the higher regions to which they are projected, the bands observed in the darkening spectra of variables. The bright lines frequently visible would meet with a similar explanation. We see in fact in the solar chromosphere a repetition, on a much diminished scale, of their immediate cause. The effect of a sudden augmentation in extent and incandescence of the glowing envelope of the sun, such as tends to take place with every access of eruptive energy, would be the manifestation in its spectrum of the identical vivid rays emitted by temporary as well as by periodical stars. It will not, indeed, have escaped the notice of our readers that this rationale of variability implies an inversion of maxima and minima similar to that involved in the 'dissociation' theory. Under normal circumstances, the minimum of light coincides with the maximum of disturbance and consequent absorption; but when the phase attains the stage of intensity at which bright rays begin to appear, the greatest splendour is reached simultaneously with the highest point of internal activity. There seems, however, no reason why this apparent incongruity should prove fatal to the hypothesis at present under consideration, which we are at any rate indisposed to reject until something more satisfactory can be substituted for it.

In what aspect, we may now enquire, does the general problem of stellar constitution present itself to our minds? In the first place, it cannot be too emphatically stated that whatever theory of variability we may adopt must necessarily include an explanation of distinctions in optical characteristics, since variable stars, by their migrations from one spectroscopic class to another, afford convincing proof that the condition of change is no other than the condition of difference. In accordance with the hypothesis just enúnciated, we should then reply that the various degrees of absorption revealed by the spectroscope in the atmospheres of different stars, correspond to as many stages of eruptive activity in their central masses—those of white and equable splendour standing at the bottom of the scale, those of deep tint and irregular lustre at the top. Far from finding any evidence to support the view that the latter class represent, so to speak, the expiring embers of the former, we believe it might be plausibly argued that development, if traceable at all, takes the contrary direction. Stars of the fourth order, for example, wear the aspect of luminaries whose photospheres are in course of formation, rather than of orbs slowly cooling into invisibility. They might, in fact, be more reasonably regarded as juvenile than as decrepit suns. Their apparent minuteness is most probably occasioned by the enormous loss sustained by their light in traversing a dense and profound vaporous envelope, while the bright rays with which their lustre is frequently enhanced bear witness to their exalted condition of volcanic activity. As the process of condensation advanced, the heavier substances would—with the relaxation of the unexplained repulsive force conspicuously at work in so many solar phenomena—withdraw more and more into the interior of the star, whose gradually clearing atmosphere would permit a freer escape of light and consequent increase of brilliancy.

As regards the relative temperatures of the stars, we are still, to a great extent, in the region of speculation. It is true that Dr. Huggins and Mr. Stone * have, by some extremely delicate observations, placed us in possession of the facts that Sirius, the brightest of white stars, sends us only two-thirds of the heat which reaches us from Arcturus, while Vega's thermal powers are surpassed, in the same proportion, by those of the golden star that holds watch and ward over the Great Bear. We need hardly observe, however, that radiation is no reliable test of temperature; and its evidence, in this case, seems to be contradicted by the richness in photographic emanations of the stars deficient in heat-rays. On the whole, we incline to the belief that, while the deep-hued orbs possess a greater store of energy, their paler brethren realise that energy in a more tangible form, and collect it into a more limited space. In other words, their photospheres are hotter, and their atmospheres clearer and cooler, than those of more volcanic luminaries. But on this and many similar points the *data* are wanting to enable us to form more than a probable opinion. These we may hope that the future will to some extent supply. The true field of stellar discovery is solar observation; and here Mr. Lockyer is one of the foremost among a band of labourers

* Proceedings R. Society, vol. xvii. p. 309; vol. xviii. p. 165.

whose zeal, industry, and skill need no encomium from us. With the aid of the prism, many of the doubts and difficulties which still beset enquiry into the physical condition of the sun will perhaps ere long be dispelled; and we may then with renewed courage attack the strictly analogous problems offered to our consideration by the stars.

In 1612, a German astronomer named Simon Marius, detected in the constellation of Andromeda an elliptical patch of hazy light, 'like a candle,' as he described it, 'shining 'through horn.' Forty-four years later, the celebrated Dutch philosopher, Huygens, discovered the great nebula in the sword-handle of Orion. Although both these singular appearances are distinctly visible to the naked eye, they attracted no intelligent observation from uncounted generations of star-gazers, but were reserved to figure among the numerous trophies of the Galilean 'cylinder.' The number of nebulæ now known to astronomers considerably exceeds 5,000,* and fresh discoveries are of frequent occurrence. We must regard as one of the most noteworthy achievements of modern science the revelations made by the spectroscope concerning the nature of these enigmatical bodies. They not only gratify that noble curiosity which irresistibly impels our often baffled yet ever renewed search into the secrets of nature, but afford a significant warning against the undue extension of apparently legitimate inference. Between a comparatively loose aggregation of stars, such as the Pleiades, and a dim blur of nebulous light just discernible in the most powerful telescope, no dividing line can be drawn. Star-groups merge, by insensible gradations, into star-clusters, star-clusters into star-dust, star-dust into star-mist, while, with every addition to the space-penetrating power of the instruments employed in observation, a certain proportion of objects hitherto deemed 'irresolvable' belie that character, and show symptoms of stellar constitution. The conclusion seems inevitable, and is nevertheless fallacious, that difference of distance forms the only distinguishing circumstance, and that nebulæ are, in fact, sidereal systems plunged, at various depths, in the tremendous abysses of space, and sending us, by a few feeble rays, faint tidings of an existence manifold and glorious as that of our own sparkling galaxy. This view was accordingly adopted by many astronomers, notwithstanding the obvious association of nebular and stellar matter both in 'nebulous stars' and in such cosmical aggregations as

* 5,079 nebulæ and star-clusters are included in Sir J. Herschel's catalogue, published in 'Phil. Trans.' 1864.

the Magellanic Clouds. New and irrefragable evidence is now, however, available.

On August 29, 1864, Dr. Huggins turned, for the first time, his spectroscope upon a nebula—one of the 'planetary' kind, situated in the constellation Draco, and presenting the appearance of a blue-green shield embossed with a shining nucleus.* The result took the observer somewhat by surprise. At the first glance, its light seemed to be absolutely monochromatic, a single ray of a sea-green tint being alone visible. By degrees, however, two other lines, both slightly more refrangible than the first, were made out; and these three lines may be regarded as forming the typical spectrum of a certain class of nebulæ. It follows obviously and incontestably that such bodies are, in great part, if not wholly, composed of glowing gas. But inference does not stop here. By careful measurements and comparisons Dr. Huggins was able to assign the principal nebular ray—that which is never found absent,† though often alone—to incandescent nitrogen; while the third and most refrangible was perceived to coincide with the F line of hydrogen. These conclusions are fortified by the observation, that when the spectra of hydrogen and nitrogen are, by suitable manipulation of temperature and pressure, respectively reduced to one ray, that ray is, in each case, found to be identical with the nebular line.‡ It is then beyond doubt that gaseous nebulæ are composed of nitrogen, hydrogen, and a third vapour, as yet unidentified, giving the middle line of their spectra; and it may moreover be confidently asserted that their temperature is comparatively low, and their density extremely small—not much greater, probably, than that of the residual gas in 'vacuum tubes.'

The excessive simplicity of nebular spectra is not then due to the dissociative energy of heat; and if we are to adopt Sir William Herschel's hypothesis, and regard nebulæ as 'star-'protoplasm,' the question arises, in what condition do the multifarious substances found in a full-grown star exist in these sidereal nurseries? If it be said that they have as yet no being save in the affinities of their elements, we would ask what force holds those affinities in check, and suspends the production of the various forms of matter known to us in sun and stars? On the other hand, if they exist neither *in esse* nor *in*

* D'Arrest, 'Astronomische Nachrichten,' vol. lxxix. p. 195.
† Phil. Trans. vol. clviii. p. 540.
‡ Frankland and Lockyer on Gaseous Spectra, 'Proceedings R. Society,' vol. xvii. p. 453.

*posse*, we must look elsewhere for the secret of stellar formation. Indeed, progressive chemical combination would inevitably betray itself in the increasing complexity of nebular spectra.* New lines would become visible as new substances were evolved, and we should naturally expect to find specimens of every stage of development, from the monochromatic radiations of the 'Dumb-bell' to the continuous spectrum of the Andromeda nebula. No trace, however, of such an advance is perceptible. One invariable type is common to all the gaseous nebulæ whose light has been analysed. In a very few cases, it is true (notably in the Orion nebula), a fourth ray—the dark blue of hydrogen—is visible; in several, all except the nitrogen line are too faint to be discernible; but the chemical composition of all is evidently the same. We may then reasonably doubt whether the intimate connexion obviously existing between stars and nebulæ is of the precise nature contemplated by the advocates of the 'nebular hypothesis.' It is at least premature to affirm that it is that of simple development. Take the case of the solar system. If any vestige of the primitive nebula out of which it is supposed to have been formed be discoverable, it must be in that vast lenticular envelope, extending far beyond the earth's orbit, known as the 'Zodiacal Light.' But the physical constitution of this perplexing appendage, as disclosed by its spectrum,† shows no analogy whatever with any known nebula. In fact, of 'nebulous fluid,' properly so called, no trace can be found within the precincts of the sun's dominion.

Out of about 140 nebulæ hitherto submitted to the scrutiny of the prism, thirty-one or thirty-two show bright lines,‡ the remainder emitting continuous light of too feeble a character to endure searching exploration of its minor peculiarities. Some of these spectra are singularly truncated at the red end, as if by the interposition of a veil of absorbent material, and present a mottled and unequal appearance, suggesting an aggregation of lucid beams rather than an uninterrupted sequence of radiations. The stellar nature of the bodies from which they are derived is thus seen to be extremely problematical.§

It is a significant fact that the whole of that class of nebulæ named by Sir William Herschel 'planetary,' because exhibiting

* Huggins, 'Proceedings R. Institution,' vol. iv. p. 448.
† Monthly Notices, vol. xxxvi. p. 48.
‡ Astr. Nach. (No. 1908), vol. lxxx. p. 189.
§ Huggins, 'Phil. Trans.' vol. clvi. (1866), p. 382, *note*.

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a tolerably defined and almost uniformly illuminated disc, give, without exception, a spectrum of bright lines. These bodies, according to one view of their constitution, are globular masses of feebly luminous gas, of such vast extent that the least of them, if placed centrally with the sun, would in all probability embrace many times over the remote orbit of Neptune. The total absence or slight amount of central condensation is accounted for by the internal absorption of their light, causing them to offer to our vision only, as it were, a shell of ignited vapour. Another view, which has of late received considerable support, regards them as enormously remote nebulous stars or star-clusters. It is a well-established optical principle that the brightness of a luminous surface is not lessened by distance, for the simple reason that the superficial area included in the visual angle increases in exact proportion as the light from each unit of that area diminishes. A light-giving surface (so long as it subtends any appreciable angle) will thus gain rapidly upon a light-giving point with the equal withdrawal of both from the eye of the observer, and will eventually outshine and survive it, whatever the original disparity in their respective splendours. It follows from this reasoning that a stellar nucleus, surrounded by a luminous atmosphere of great extent, which, at a certain remoteness, wears the aspect of a nebulous star, will, if the distance be sufficiently increased, cease to show any appreciable stellar light, and will finally shine with the dim radiance of a planetary nebula.*

The theory is neat and plausible; but it must be owned that it encounters a serious difficulty in the tendency to annular and spiral formation detected in this class of objects by the great Parsonstown reflector. We have seen, however, by the example of the new star in Cygnus, that a stellar body may undergo an apparent metamorphosis into a nebula—in other words, that nebular light may occasionally serve as a garment to be put off and on; and another instance of this species of celestial masquerade is afforded by Mr. Pogson's surprising observation of the sudden transformation of a nebula into a star, and its return after a few days to its original condition.† Indeed, the phenomena of variability presented by some of these bodies are among the most curious in nature. On October 11, 1852, Mr. Hind discovered a small nebula in the constella-

* Arago, 'Annuaire du Bureau des Longitudes,' 1842, pp. 410–12 and 441; Stone, 'Proceedings R. Society,' vol. xxvi. p. 156.

† Chambers, 'Descriptive Astronomy,' p. 545. Pogson's observations were fully confirmed by those of E. Luther and Auwers.

tion Taurus. On October 3, 1861, M. d'Arrest found that it had totally vanished. Two months later it was again observed. It is now invisible in the most powerful instruments.* Again, the nebula surrounding Merope in the Pleiades, detected in 1859 by that admirable observer M. Tempel, is certainly subject to fluctuations in brightness. A strong case of (probably periodical) change has been made out for the vast nebular regions in Orion and Argo, while the incessant contraction and dilatation of a minor object of the same kind have been remarked by M. Schultz. Conjecture itself is silent in the presence of these strange stirrings of mysterious cosmical activities.

Looking upwards at the vast expanse of a moonless sky on a clear night, we are at once dazzled and delighted with the multitudinous blazing of the celestial watch-fires. Like Jessica, we sit and see

> 'How the floor of heaven
> Is thick inlaid with patines of bright gold;'

but to submit that exquisite and elaborate workmanship to the prosaic analysis of number seems, at first sight, not only unpoetical, but impracticable. Yet the stars visible to the unaided eye form but a minute fraction of those whose remote rays fail to stir a responsive thrill of consciousness. It has been ascertained that the most piercing vision can discern in both hemispheres barely 6,000; while the number of those perceptible at one time to an observer of average sight scarcely exceeds 2,000. On the other hand, the sum-total of the heavenly host visible with the great telescopes now in use is estimated at the enormous figure of 75,000,000; and in certain parts of the Milky Way the background of the sky is still dim with the commingled radiance of innumerable and indistinguishable orbs. The effect of number in the starry multitude is enhanced by the restlessness of their light, which seems to allow us no leisure to attend to the individuals of which that multitude is composed. It has long been known that the twinkling of the stars results in some way from causes within our own atmosphere; but the recent enquiries of M. Montigny, of the Brussels Observatory, have led to a clearer understanding of the subject than was previously attainable.† Our air, it appears, performs the office of a prism whose refractive power is, in its various strata, subject to continual fluctuations. Thus the image of a star which we perceive is formed by the recomposition of a number of diversely coloured rays previously

* Flammarion, 'L'Univers Sidéral,' 1880, p. 808.
† Secchi, 'Le Stelle,' p. 132.

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separated by the varying amount of refraction undergone by them severally. Each of these rays reaches the eye by a different route, and encounters, so to speak, different adventures by the way—now of increased, now of diminished refraction, sometimes of total interruption or diversion. The result is an incessant change of tint, corresponding to the momentary re-inforcement or subtraction of each component beam, the colour visible being invariably complementary to that withdrawn. This chromatic flickering, or 'twinkling,' is excessively rapid, occurring in white stars as often as seventy times in a second, but with considerably less frequency in those whose light the spectroscope sifts into parti-coloured zones. The fact that an increase of scintillation constitutes a reliable indication of the approach of rain,* is easily understood when we consider that the amount of aqueous vapour present in the air is a main factor in its production. On the tops of high mountains and in equatorial regions the effect is imperceptible, except at very low altitudes, owing to the stillness and homogeneity of the atmosphere.

The opinion that the stars are in any real sense 'fixed' was discarded with the superannuated cosmography of Alexandria. The audacious fancy of Giordano Bruno,† spurning the limits of exact enquiry, was kindled by the glorious harmonies of motion hypothetically performed by these far-off suns; Robert Hooke,‡ less daring and more scientific, tentatively advanced the same view; and Edmund Halley § confirmed their conjecture by pointing out, in 1717, the notable discrepancy between the positions of Aldebaran, Sirius, and Arcturus, as given by Ptolemy, and those ascertained by actual observation. The determination of the amount and direction of stellar proper motions forms at present an important branch of sidereal astronomy, and already indicates conclusions of sublime interest. It is evident, however, that a large element of uncertainty enters into the estimation of movements executed at every imaginable angle to the line of sight, and projected consequently with every possible amount of foreshortening on the surface of the celestial sphere. This apparently insuperable difficulty has been to a great extent removed by an ingenious application of spectrum analysis. No more striking example of the penetrating and versatile character of this

* Bulletins de l'Académie Royale de Belgique, t. xlii. p. 998.
† Cena de le Ceneri, Dial. 4. ‡ Posthumous Works, p. 506.
§ Phil. Trans. vol. xxx. p. 737.

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method of research could be adduced than the discovery we are now about to describe.

The principle upon which it is founded occurred to Doppler in 1841, but was invalidated by a misapprehension. He remarked that the colours of stars must be affected by their motion to or from the earth, precisely in the same manner that the pitch of a vibrating tuning-fork is alternately raised and lowered when it is caused to approach and recede rapidly from the ear. The same fact is familiar in the shrilling and sinking of the steam-whistle when a train happens to pass at full speed. Now it is undoubtedly true that, since the perception of colour depends upon the number of luminous vibrations striking the retina in a given time, if the source of those vibrations be in motion towards or from the eye, that number will be increased or diminished, and the resulting tint proportionately elevated or degraded in the chromatic scale. An important circumstance was, however, neglected in these speculations. The visible part of the spectrum alone was taken into account, while it was forgotten that at either extremity lay an invisible set of waves, which would, equally with the luminous beams, be altered by the motion in question. Hence the only effect of translation in the line of sight would be a shifting of the entire spectrum, some rays previously visible sinking into obscurity, and as many previously invisible being exalted into luminosity, but the net result remaining to the eye absolutely unchanged. Now it is precisely this shifting of the spectrum which prismatic analysis, by observation of the corresponding displacement of the well-known Fraunhofer lines, affords the means of detecting and measuring, thus lending, after a quarter of a century of unfruitfulness, unexpected validity to Doppler's abortive proposal.

It is to Dr. Huggins that science is indebted for the successful employment of this new mode of investigation. Father Secchi, it is true, turned his attention about the same time in the same direction, but failed, owing to the deficiencies of his instruments, to achieve any trustworthy results, and indeed ended his life unconvinced of their attainability. The delicacy of the observations required may be estimated from the fact that to produce a displacement equal to the interval separating the components of the double line of sodium (which can be divided only by a spectroscope of considerable dispersive power), would demand a rate of approach or recession of 196 miles per second. But this velocity is more than ten times that of the earth in its orbit, and the average real motions of the stars are almost certainly inferior even to this compara-

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tively slow pace. The assertion that a quantity so minute as the ensuing displacement of the spectral lines is susceptible of exact measurement, might well provoke a smile of incredulity in those unfamiliar with the extraordinary refinement of modern instrumental means; yet it is impossible to doubt that the conclusions arrived at are, within certain limits of possible error, entirely reliable.

The results of Dr. Huggins's first experiments in this branch were communicated to the Royal Society in April, 1868, and were confirmed, although in some cases slightly modified, by subsequent investigations. The method pursued was as follows. A line was selected in the spectrum of the star to be examined, which, from its character and companions, was unmistakeably derived from some particular substance. Any deviation from its normal position which could then be detected was attributed—and, beyond question, rightly attributed—to motion in the line of sight. In the case of Sirius, the first star experimented upon, the chosen test was the F line of hydrogen, which, by a series of careful measurements, was shown to be slightly displaced towards the red end of the spectrum. In other words, its refrangibility was lowered by an increase in the corresponding wave-length, caused by a movement of recession estimated at more than twenty-six and less than thirty-five miles per second. Deduction having been made of the earth's orbital velocity—then directed *from* the star—there remained about twenty miles per second to be divided, in undetermined proportions, between Sirius and the sun. It is no novelty to our readers to be informed that the entire solar system is advancing through space towards a point situated in the constellation Hercules. Of the rate of this motion we are, however, ignorant, since the calculation of Otto Struve, making it little more than four miles a second, was undoubtedly based upon unsound assumptions. There remains, then, this source of uncertainty in estimating stellar movements. Among the stars which, like Sirius, are increasing their distance from us at rates varying from twelve to twenty-eight miles each second, are Betelgeux, Rigel, Castor, and Regulus; Vega, Arcturus, Pollux, and Deneb in the tail of the Swan, are, on the other hand, diminishing it even more rapidly. Of the seven conspicuous stars in the Great Bear forming the figure recognised from the earliest times as the Wain or Plough, the most brilliant (being the 'pointer' nearest the pole) is found to be approaching the earth; the next five are swiftly receding from it; while the movement of the seventh has the same direction, but a greatly inferior velocity. And this brings us to a very remarkable subject of enquiry.

It has been long remarked that the distribution of stars in the heavens betrays the existence of relations, the precise nature of which it is difficult to imagine, and impossible to define. More than a hundred years ago, the Rev. John Michell, a thinker of considerable originality, was able to show that the chances against the occurrence of such a group as that formed by the six bright Pleiades, on the supposition of a random sprinkling of stars through space, were about half a million to one; * and the same reasoning applies with equal or greater force to innumerable other stellar aggregations. Indeed, the more closely the face of the sky is studied, the more clear becomes the evidence of law and order inscribed upon it. This species of probable persuasion, however, needs the support of more positive proof, now forthcoming, and likely to accumulate. The orbital motions of double stars, announced by Sir William Herschel in 1803, offered the first examples of the connexion, by a physical tie, of separate members of the sidereal universe. The number of such systems—some of them containing as many as five members—now known to astronomers is no less than 10,300.† Association on a larger scale, however, had long been suspected, and may now be said to be ascertained. This result is largely due to the industry of Mr. Proctor, who, with the express purpose of demonstrating the reality of what he has termed 'star-drift,' undertook the labour of charting the proper motions of over 1,500 stars. Extensive community of movement was thus rendered, it might be said, evident to the eye. Whole battalions of stars were perceived to be marching across the sky in an identical direction, and doubtless under the compulsion of an identical force. Thus, seventy or eighty orbs, forming the constellations Gemini and Cancer, are sweeping together towards the zone of the Milky Way; while in Taurus is visible that singular unanimity of motion which led Mädler to fix upon Alcyone in the Pleiades as the central sun of the entire sidereal system.‡ But the instance of 'drift' most striking to the imagination is that presented by the stars of the Plough. The observation that five of these seven lucid

* Phil. Trans. vol. lvii. p. 246 (1767). Also Proctor, 'Universe of Stars,' p. 21.

† A Catalogue of 10,300 Multiple and Double Stars, vol. xi. of 'Memoirs of R. Astr. Society.'

‡ Proctor, 'Universe of Stars,' p. 120.

orbs (excluding the first 'pointer' and the third 'horse') possessed a seemingly identical proper motion, led Mr. Proctor, in a paper read before the Royal Society, January 20, 1870, to signalise them as in all probability forming a physically connected system, and he accordingly invited the application of Dr. Huggins's new method as a sure criterion of the correctness of his surmise. The response of the spectroscope was conclusive. All five were (as already mentioned) discovered to be receding at the same rate from the earth, while the independence of their two companions, presumed from the difference of their apparent motions, was, by the non-concordance of their real motions, conclusively demonstrated.

We see then here five mighty suns (besides two smaller attendants) associated into a system the vastness of which staggers thought. At the lowest estimate of their distance (for none of them possess any sensible parallax), a single second of arc would represent an actual linear extension of a thousand millions of miles, and may represent an amount indefinitely greater. But the extreme members of the group are separated by an apparent interval of no less than nineteen degrees of the celestial sphere, or 68,400 seconds! Again, the revolution round one of these stars (Mizar, the middle 'horse' of the Wain) of a satellite-sun named Alcor, barely distinguishable from it with the naked eye, occupies, according to the calculation of Mädler, a period of 7,659 years. How vast, then, must be the cycle in which these majestic luminaries (all of them probably far exceeding our sun in size and brilliancy) execute their harmonious orbits round some inconceivably remote centre! Our earth itself, with its long ages of geological transformation, is but as an ephemeris in the tract of time thus stretched out before the baffled imagination.

It is a circumstance to be carefully noted that all the five stars thus singularly united belong to the same optical category, exhibiting spectra of the purest Sirian type. We are not indeed thereby justified in assuming that a similar agreement prevails amongst the members of all analogous systems; but it is undeniable that, in certain regions of the sky, certain spectroscopic classes predominantly obtain. Thus, white stars are most numerous in the great constellations of Taurus and Ursa Major; in Hydra and Eridanus the solar type dominates; while the majority of the stars grouped together in Orion partake of the characters of both orders, displaying a peculiar greenish tinge as if from a suffusion of faint nebulous light.*

* Secchi, 'Le Stelle,' pp. 121, 178.

It is besides common to find red stars surrounded by a *cortége* of smaller ones of the same colour. From these evidences of natural grouping we should rather infer that spectroscopic distinctions correspond to inherent differences in stellar constitution, than that they represent successive stages of development. But on this subject it is premature to speculate.

We have already seen that the colours of stars depend mainly, if not entirely, on the nature of their atmospheres—or, to put it otherwise, that the light emitted by all is (approximately) the same, while the absorption suffered by that light, in its transmission to outer space, is different. Thus the beautiful complementary tints—the purple and gold, orange and azure, rose-pink and apple-green—visible in many double stars, find an explanation in what we may call complementary bands of darkness in their several spectra. As to the nature of the physical influence producing these singular correspondences, we are indeed in ignorance; but some dim indications of its mode of action may be discovered in the recent observation of M. Niesten, that the colours of double stars are conditioned by the form of their orbits, and vary with their mutual positions.* The fact is also full of significance that blue or green stars of a decided hue are never known to be solitary in their habits, but are either dependent or gregarious; so that Milton's firmament of 'living sapphires' collapses at the touch of literal truth, none but telescopic stars supporting a comparison with that brilliant gem.

A vast and imposing subject still confronts us; but here we can do little more than indicate the conclusions towards which modern researches tend. The elder Herschel set before his mind at an early stage of his career the sublime object of attaining to a knowledge of the structure of the heavens. But his long life, joined to unwearied industry and rare genius, sufficed only to demonstrate the extraordinary complexity of the problem. Most of, if not all, his original assumptions have been overthrown by the progress of enquiry; but many truths, grasped by his vigorous intelligence in its successive approximations to the realities of the cosmical scheme, have been confirmed, and will, without doubt, yet bear abundant fruit. What has been called the 'grindstone 'theory' of the universe, originated by Thomas Wright of Durham,† extended by Kant,‡ adopted and elaborated by

* Bulletins de l'Académie Royale de Belgique, 1879. See 'Nature,' vol. xx. p. 331.

† An Original Theory or New Hypothesis of the Universe, 1750.

‡ Allgemeine Naturgeschichte, 1755.

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Lambert and Michell, statistically investigated by both Herschels, is now discredited, if not definitively abandoned. The irresistible logic of facts no longer permits us to regard the Milky Way as a cloven disc of evenly distributed suns, apparently minute because indefinitely distant. Nor is it now possible to see in the nebular host an array of 'island-'universes' studding the great ocean of space, similar to our galaxy in structure, and perhaps superior to it in splendour and extent. But it is easier to perceive the fallaciousness of the reasoning on which these views are founded, than to substitute for them a theory which shall at once accord with ascertained facts and appease our symmetrical instinct. It must, however, be remembered that the very completeness of a scheme argues its insufficiency, since the true creative plan can never be wholly divested of the difficulties and obscurities which beset a finite mind labouring in the track of an infinite idea. We shall then content ourselves with laying down a few broad lines on which, it may confidently be asserted, our conception of the universe will henceforth be based, leaving details to the practical, and conjectures to the speculative in astronomy.

The first point clearly discernible is that the heavenly host are not constituted on a democratic principle of equality, but form a hierarchy, exhibiting infinite gradations of power, beauty, and splendour. This is demonstrably true of double and multiple stars, and is hardly less conspicuously evident in the case of groups united in a concurrence of motion. Such systems usually comprise individuals of every variety of apparent magnitude; but since their distances from each other almost certainly bear but a small proportion to their distance from us, we inevitably conclude (unless where the spectroscope shows unequal absorption) that their disparity in lustre is due to difference in size. Evidence of other kinds tends in the same direction. The movements of the stars must, on an average, appear greater for those that are nearer to the earth than for those that are more remote, both in so far as such seeming displacement is a perspective effect of the sun's progress through space, and in so far as it is caused by an actual translation of the stars themselves. But it is not found, on the whole, that the most brilliant orbs are the most mobile. On the contrary, many imposing luminaries, such as Canopus, Rigel, and Antares, are observed to be extremely sluggish in shifting their positions, while some insignificant stars dart through space with a velocity not only exceptional, but unaccountable.* The inference that brilliancy forms not even an approximate criterion of distance is confirmed by parallactic observations. As a general rule, the stars have no appreciable parallax—a statement implying the astounding fact that, seen from their remote stations, the enormous expanse of the terrestrial orbit shrinks to a point and vanishes from sight. In a few cases, however, a small annual displacement has been detected, and more or less reliably measured. It is true that a star of the first magnitude, *a* Centauri, heads the list by a large interval, and is hence regarded as our nearest neighbour in sidereal space, but the correspondence between vicinity and splendour goes no farther. Of the twenty-one stars believed to show some trace of parallactic displacement, eight only exceed the fourth, while thirteen range between the fourth and the eighth magnitudes.† Thus, 61 Cygni, a small star of the fifth magnitude, is considerably nearer the earth than Sirius, Vega, or Arcturus, and indefinitely nearer than Aldebaran, Regulus, or Spica. According to approved calculations, Sirius must (if his intrinsic splendour be the same) surpass our sun in volume from two to three thousand times; while 61 Cygni is unquestionably of far less size than the central orb of our system. Nor is there any reason to suppose Sirius one of the largest, or 61 Cygni one of the smallest, of the suns in space.

Until recently it was confidently held, in accordance with the view first proposed by Kant, that the galaxy with its myriads of suns formed but a subordinate member of the nebular system. We are now compelled to believe that nebulæ, in all their varieties, have their place and play their part within, not without, the galactic scheme. Of some of the arguments used on this subject by Mr. Proctor (whose collected essays on this and kindred subjects we have quoted at the head of this article) we now avail ourselves. These are concerned principally with the peculiarities of nebular distribution. If these bodies form an independent system or series of systems, their position in space must evidently be wholly irrespective of the internal architecture of the sidereal habitations If, on the other hand, we perceive evident signs of such a connexion, we are justified in assuming a fundamental unity of plan. Now it is impossible to avoid observing the existence

* The small star known as 1830 Groombridge has a velocity (estimated at not less than 200 miles a second) considerably greater than could be impressed upon it under the known conditions of the sidereal universe. Newcomb, Popular Astronomy, p. 505, *note.*

† Flammarion, Comptes Rendus, t. lxxxv. p. 783.

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of a marked relation, both of association and avoidance, between nebular and stellar aggregations. The great mass of the unresolved nebulæ (being four-fifths of the entire) congregate about the poles of the galactic zone, while a corresponding tract of almost total destitution runs parallel with that vast star-girdle both on its northern and on its southern sides. Two classes, however, of closely allied cosmical bodies obey a law of a totally opposite character. Gaseous nebulæ, or those giving a spectrum of bright lines, are found almost exclusively in the Milky Way and its immediate neighbourhood, the same region concentrating in itself the immense majority of those swarms of lucid points usually described as 'star-clusters.' Between these and unresolved nebulæ showing a stellar spectrum, it is not easy to draw an intelligible distinction. We can hardly escape the conclusion that differences, either of distance or of aggregation, alone distinguish them. Whether or not the external attraction exercised upon those found within the span of the Milky Way, constitutes in itself the physical cause of their more open formation and consequent resolvability (as Mr. Proctor inclines to think),* the fact is patent that the influence of that zone largely affects the distribution of all classes of nebulæ.

Still more convincing proof of the systemic unity of the stellar and nebular orders is, however, offered by a closer examination of the nebulæ themselves. We have not only the argument of continuity (which indeed may and often does prove delusive), urging the impossibility of separating by any clear line of demarcation groups obviously stellar from patches of unresolved luminosity, and the inconsistency of admitting one class of objects within the bounds of our firmament, while excluding the other; but also a visible intimate association of undoubted members of the sidereal system with the structure and position of nebulæ. Thus, the sinuosities and convolutions of several of the 'irregular' kind are followed with such unmistakeable fidelity by knots and trains of minute stellar bodies projected on them as a background, that, in some cases, it seems as if the pattern, so to speak, of the nebula were pricked out with stars. We see, moreover, in the Magellanic Clouds—the wonder and the ornament of southern skies—a 'glaring instance' of the truth we desire to enforce. The greater 'Nubecula,' or 'White Ox,' of Abdurrahman Sufi,† seems expressly designed to exhibit the union into a single

* Monthly Notices, vol. xxix. p. 343.
† Cosmos, vol. iii. p. 122.

confederation of all orders of the visible universe. This cosmical 'happy family' (if we may be allowed the expression) contains within its capacious bosom (extending over forty-two square degrees) 291 nebulæ, gaseous and stellar, forty-six star-clusters of every degree of condensation, besides nearly 600 individual stars of the seventh and eighth magnitudes.* It is entirely impossible to believe that this amazing assemblage is the result of accidental projection on the surface of the sky, and we have no alternative but to accept the conclusion that stars and nebulæ coexist in the same region of space, and form inseparable components of one vast system.

What then should be our general conception of that portion of the created world which we are permitted to contemplate? We find it stamped with the two great characters of unity and complexity—unity of design, bewildering and unfathomable complexity of detail. From the scattered 'star-dust' just stippling with light the dark telescopic field, and the 'star-'seed,' or 'star-food' (in whichever aspect we choose to regard it), revealing in the spectroscope its surprising bright lines, to the royal procession of the Ursine orbs, and the solitary state of Arcturus and Vega, all that we see from pole to pole is bound together by mutual dependence, and unites to execute a single majestic scheme. Of the inner intricacies of that scheme we can form but a distant and inadequate idea. The galaxy, in its larger outlines, may be described as a congeries of stellar groups of every imaginable variety, arranged in an annular form. Our sun, with about 400 stars, from the first to the seventh magnitudes, is believed to form an outlying cluster situated not in the circumference of the ring, but considerably removed from it towards the centre. Seen from some planet circling round a sun belonging to another similar firmament, the whole of these radiant orbs, separated from each other by distances entirely inconceivable to our minds, would appear but as one of the more prominent of the luminous nodosities that roughen the surface of the Milky Way.

All these separate systems—these starry commonwealths—are doubtless united in one grand federation, whose all but infinitely remote boundaries our imagination may indeed transcend, but our knowledge can most probably never pass. And as each terrestrial body politic is separated, by nature or by choice, into numberless associations, distinct in their aims and in their courses, so the nations of the sky are divided and organised into tribes, families, and households, various in their polity, harmonious in their action, united in their end. What

* Flammarion, 'L'Univers Sidéral,' p. 818.

may be the nature of the laws governing the relations, internal and external, of such systems, it would, in the present state of our knowledge, be the height of presumptuous folly to attempt even to surmise. We know, indeed, from the observed revolutions of binary stars, that gravitation acts in the same manner in sidereal regions as at the surface of the earth; but we do not know but that, at enormously increased intervals of space, it may be superseded by some higher and wider law, ruling higher and wider relations, just as gravity itself is replaced, at minute distances, by the action of molecular forces.

We must now pause. What we have said is indeed little and inadequate, but it is enough to show that the natural awe and delight with which we regard the stately pageant of the spheres are amply justified in the sublime realities represented by it. A scene is disclosed to our enquiries instinct with life, motion, and variety. Law, the evidence and the instrument of design, sits enthroned there, but presides over no dull or monotonous succession of events. Unexpected activities from time to time manifest themselves, and tremendous catastrophes disturb the serenity of the heavens. Some one of the obscure bodies which, for aught we know, may be as numerous as the lucid ones, suddenly assumes a vesture of light, and sends us, across an interval which costs its swift messenger perhaps a thousand years of travel, the first tidings of its existence. Luminous bodies, on the other hand, sink into obscurity and apparent annihilation. Nebular worlds, far surpassing in extent the entire ambit of the solar system, grow dim and vanish, like a pencil-mark rubbed with a touch from a sheet of paper, again as capriciously to reappear. Suns fade, century by century, like a field-flower held in a child's hand, while other suns grow and brighten, like rose-buds unfolding on their stems. Terrific conflagrations, involving perhaps in destruction whole dependent schemes with their myriad possible inhabitants, desolate fore-doomed orbs; while a large class of luminaries seem, by their periodical outbursts of volcanic fury, to be rendered unfit to act as the beneficent centres of planetary households. On all sides we see traces of activity and change; everywhere we find evidence of development and decay—decay, possibly a prelude to renovation, which again leads round to decay. For many and strange are the vicissitudes comprised within that stupendous cycle which bounds the existence of the heavens themselves, destined on the expiration of their appointed term, like the 'frail and fading sphere' of the dew-drop to which Shelley compares them,

'To tremble, gleam, and disappear.'