MODERN COSMOGONIES

'The world's a prophecy of worlds to come.'—YOUNG

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PREFACE

Of the sixteen chapters constituting this little work, thirteen have been published as a series, begun in *Knowledge* and continued in *Knowledge and Illustrated Scientific News*, and to the proprietors of those journals, for their courteous permission to reprint them, I offer my sincere thanks. Three additional chapters, equivalent to, though not identical with, those that now appear, formed an integral part of the original plan of the book, now presented to the public in the hope that it will enable general readers to follow, with the profound interest it should inspire, the course of modern inquiries regarding the origin of the world. Their advance is by no means smooth or facile. Many difficulties and perplexities are encountered in the attempt to get back towards the beginning of things. Some of the old tracks, too, have been torn up by the pioneers of twentieth-century science, and the process of constructing new ones, which shall lead further into the unknown foretime, is slow and laborious. But the rail-head in the desert is a peculiarly suggestive place of pilgrimage, and several such outlying posts and temporary halting-places are more or less vaguely localized in the following pages.

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CHAPTER I

FROM THALES TO KANT

VERY few even of the most savage tribes are content to take the world just as it is without speculating as to how it came to be. For time has three dimensions—past, present, and future—and we can no more restrict our thoughts within one of them than we can exist corporeally in Flatland. We are, indeed, told that the Abipones and Esquimaux refuse to trouble themselves with questions of origin, on the ground that the hard facts of life leave no room for otiose discussions; but even they feel obliged to justify their incuriosity. In easier circumstances they, too, would claim the entirely human privilege of 'looking before and after,' as their forgotten progenitors may have done. It is, indeed, difficult to think at all about the framework of nature without attempting to divine, were it only by a crude surmise, the process of its construction. We are instinctively convinced that there is no such thing as fixity of condition. So far, Heracleitus was in the right.

Experience tells us of continual change in ourselves and whatever surrounds us. Reason teaches us that its minute momentary effects, if pursued backward for an indefinite time, must sum up to a prodigious total. No limit, that is to say, can be put to the difference between what is and what was. Yet the machinery of modification must somehow have been set going. An initial state is prescribed by logical necessity. And the start was made on certain terms—it was 'conditioned.' But the conditioned implies the absolute; ordinances, an enactive power. The inevitableness of the connection has been more or less obscurely perceived wherever men have tried to establish some kind of accord between phenomena and intuition, with results legible in the wavering outlines of many primitive cosmogonies. Only, however, in the Hebrew Scriptures has the idea of Creation been realized in all its fulness and freedom; elsewhere the gods invoked to bring the world into existence themselves demanded a birth-history, a theogony being the usual and necessary prelude to a cosmogony.

Nevertheless 'picture-thoughts' (it has been well said),* and nothing more, were represented by these prefatory genealogies. Night and darkness loomed into personal shape, and from the obscurity of their union the creatures of light radiantly sprang, and proceeded, according to a predetermined law of order, to sort out the elements of chaos and dispose them into cosmical harmony.

This mythical phase of thought terminated in Greece with the rise of the Ionian School of Philosophy. Immemorial legends, discredited by the advent of a new wisdom, took out a fresh lease of life under the guise of folk-lore; Orphic fables were left to the poets and the people; and the sage of Miletus set on foot a speculative tradition, maintained by a long succession of metaphysicians down to the very threshold of the recent scientific epoch. All

* Zeller, *History of Greek Philosophy*, translated by S. F. Alleyne, vol. i., p. 86.

were what we should call evolutionists—Thales of Miletus no less than Descartes and Swedenborg ; their main object, in other words, was to find a practicable mode of evoking a systematic arrangement of related parts from the monotony of undifferentiated confusion. Now, in essaying this enterprise they encountered two distinct problems. One was concerned with the nature of the primeval world-stuff ; the other with the operations to which it had been submitted. Modern theorists have made it their primary object to expound the mechanism of cosmic growth—the play of forces involved in it, the transformations and progressive redistribution of energy attending it. But questions of this kind could only in the scantiest measure be formulated by early thinkers, who accordingly devoted their chief attention to selecting an appropriate material for the exercise of their constructive ingenuity.

Thales asserted all things to have been derived from water, and water is still among unsophisticated tribes the favourite 'Urstoff.' Anaximenes substituted air. Heracleitus gave the preference to the mobile and vital element (as he thought it) of fire. Anaximander, on the other hand, might put forward a colourable claim to priority over Sir William Crookes in the invention of 'protyle.' He imagined as the matrix of the world a boundless expanse of generalized matter, containing potentially all the chemical species, which, separating out by degrees through the affinity of like for like, formed, by their contrasts and conjunctions, the infinitely varied sum of things. The successors of Anaximander had recourse to spontaneously arising condensations and rarefactions as the mainspring of development; but all these vague principles were quickly crowded into oblivion by the definite and intelligible doctrine of the 'four elements' enunciated by Empedocles, which, guaranteed by the imprimatur of Plato, took a place unchallenged for nearly two millenniums among the fundamentals of science. Erroneous and misleading though it was, it yet served as a means of regulating appearances and guiding vagrant ideas—it was a track to follow in the absence of any better method of orientation.

Leucippus and his more famous disciples, Democritus and Epicurus, were the first who ventured to trace the mechanical history of the cosmos. Their primordial atoms were endowed with weight, and it was weight or gravity which ultimately determined their spacial arrangement and mutual relations. Rectilinear in the first draft of the scheme, their movements were somewhat arbitrarily deflected by Epicurus; and the gyrations thence ensuing eventually became, so to speak, authentic and precise in the Cartesian vortices and in Swedenborg's solar maelstrom. Kant's *Natural History* of the universe was another, though an entirely separate branch of the atomistic stock. The Democritean atoms, however, and in a lesser degree the Kantian atoms, differed essentially from the ultimates of chemical analysis postulated by Dalton. They were a scratch lot — an incongruous assortment of fragments, rather than of elementary portions of matter, indefinitely various in size, shape, and mass.

Nor was this diversity created as a mere play of fancy. It was strictly necessary to the plan of action adopted. For, apart from heterogeneity, there could obviously be no development. Absolute uniformity involves absolute permanence. Change can originate only through inequality. There must be a tilt of level before the current will begin to flow; some cause of predominance is needed to set it going in a given direction. Here, of a surety, is the initial crux of all cosmogonists. They usually surmount it by assuming the occurrence of casual condensations, secure against disproof, while incapable of verification. The expedient thus begs the question.

Theories of world-history made an integral part of antique philosophy. Each founder of a school aimed at establishing a complete system of knowledge, co-extensive with phenomena, embracing all things, from the *primum mobile* overhead to the blade of grass underfoot, and rationalizing the past, present, and future of the comprehensive whole. Modern science is less ambitious. Aspiring to no such vast synthesis, it is content to make laborious acquaintance with the facts of nature, to ponder their implications, and, if possible, to reconstruct on the basis supplied by them the condition of things in the 'dim backward' of unmeasured time. By no such means, it is true, can their beginning in any real sense be arrived at; the weapons of induction become blunted long before they strike home to the heart of that mystery ; yet the recognition of their inadequacy brings compensation in a fuller mastery over their properly adapted use. Science, so called, was, indeed, down to the Baconian era, a turbid mixture of physics with metaphysics. The solution, it might be said, was attempted of an insoluble material which refused to dissolve and was hindered from precipitating.

The Greek view of nature was essentially pantheistic. The Ionian speculators appear to have presumed without expressly insisting upon its self-regulating power. Aristotle alone emphatically rejected the doctrine of cosmic vitality or sub-conscious tendencies. But Plato accepted and magnified the Oriental tradition ; the conception of a 'World-Soul' owed to him its vague splendour and perennial fascination. The function of the Platonic vice-creator (for such the World-Soul must be accounted) was that of moulding brute matter into conformity with the archetypal ideas of the Divine mind ; this was not, however, accomplished once for all, but by a progressive spiritualizing of what in its nature was dead and inanimate. The spiritual agent, becoming incorporated with the universal frame, lent to it a semblance of life, an obscure sensitiveness, and even some kind of latent intelligence; and so the *anima mundi* was shaped into existence, and continued century by century to be the subject and source of imaginings beyond measure wild and fantastic.

One great thought—that of the unity of nature—lay behind them, but its significance was lost amid the phantasmagoria of Neo-Platonist exaltations. Hence the Bacchic fervours of Giordano Bruno took their inspiration; here was the groundwork of Spinoza's pantheism. Shelley's Demiorgon, felt as 'a living spirit,' seen as 'a mighty darkness,' descended lineally from that strange essence—formless, inarticulate, devoid of individual self-consciousness—which animated the submerged philosophy of Neo-Pagan times with the barren ardours of mysticism. The doctrine, in its original and more sober version, obtained memorable expression in Virgil's melodious hexameters:

'Principio cœlum, ac terras, camposque liquentes,
Lucentemque globum lunæ, Titaniaque astra,

Spiritus intus alit, totamque infusa per artus
Mens agitat molem, et magno se corpore miscet.'

In Conington's rhymed version they run as follows:

'Know first, the heaven, the earth, the main,
The moon's pale orb, the starry train,
Are nourished by a soul,
A bright intelligence, whose flame
Glows in each member of the frame,
And stirs the mighty whole.'

Kepler was no cosmogonist, but he aspired to found a 'physical astronomy,' and in his gropings for a mechanical power that might suffice to regulate the movements of the heavenly bodies, he stumbled upon a mode of action highly appropriate for the explanation of their growth. His ignorance of the laws of motion precluded him from the conception of velocities persistent in themselves, and merely deflected from straight into curved paths by a constant central pull. Hence he was driven to the twofold expedient of creating a whirling medium for maintaining the revolutions of the planets, and of supposing the sun to exercise a 'magnetic influence,' by which they were drawn into closed orbits. Here, then, central forces made a definitive entry on the astronomical stage, although with scarcely a discernible promise of their brilliant future. But it was otherwise with the clumsy machinery they helped to animate. Kepler's simple *modus operandi*, adopted, or more probably reinvented by Descartes, was published as an epoch-making discovery in his *Principia Philosophica* (1644), and sprang under its new aspect into swift notoriety. The wide acceptance of the theory of vortices was at least in part due to the impressive largeness of its framework. Descartes left nothing out. The spacious scope of his speculations embraced all that was knowable—nature, animate and inanimate, life and time:

> 'Planets and the pale populace of heaven,
> The mind of man, and all that's made to soar.'

A philosophy, a metaphysic, and a cosmogony were linked together in a single plan. Its author distinguished in matter three gradations of fineness. The coarsest kind was that composing the earth and other opaque bodies; the more sublimated materials of the sun and stars came next; finally, there was the ethereal substance of the skies, so delicately constituted as to be luminous or luminiferous.

This last variety was regarded as of subordinate origin. It represented, in fact, a kind of celestial detritus. Interstellar space had gradually become filled with intangible dust, the product of molecular attrition among originally angular solar and stellar particles. Ether was thus supposed to bear to the subtlest description of ordinary matter very much the same sort of relationship that ions presumably do to atoms.

Enough has been said to show that the Cartesian universe was based on crude atomism. Its mode of construction, moreover, evinced a total disregard of mechanical principles. Yet some acquaintance with the laws of motion was by that time easily within reach. The first of the three, at any rate, had been unmistakably enounced by Galileo in 1632, and Descartes himself strongly championed its validity. Yet he thought it necessary, in order to keep the planets moving, to immerse them in one great self-gyrating vortex centred on the sun, each being further provided with a similar subordinate whirlpool for the maintenance of its domestic system. Comets were left in a singularly anomalous position. They circulated freely on the whole, their exemption from planetary restrictions being tacitly recognized; nevertheless, they took advantage of every encountered swirl to help themselves on towards their destination.

Among the fables of pseudo-science Delambre declared that, had the choice been offered to him, he would have preferred the solid spheres of Aristotle to the *tourbillons* of Descartes. 'The spheres,' he added,* 'have proved helpful both for the construction of planetariums representing in a general way the celestial movements, and for their calculation by approximate rules deduced from them; but the system of vortices has never served any purpose whatsoever, whether mechanical or computative.'

Its vogue had, nevertheless, been brilliant and sustained. Advanced thinkers in the time of Louis Quatorze piqued themselves upon being Cartesians. The vortical hypothesis was novel—it seemed daring; and though it might not be true, it had plausibility enough for fashionable currency. Nor did it deserve the unmitigated contempt with which it was

* Quoted by R. Wolf, *Handbuch der Astronomie*, Bd. II., p. 593.

treated by Delambre. A glance at the skies makes us pause before condemning it to scornful oblivion. Just two centuries after its promulgation the first spiral nebula was identified in Canes Venatici. That the heavens swarm with analogous objects is certain, and their status as partially developed systems is visible in every line of their conformation. Our own planetary world may, or may not, have traversed the stage they so copiously illustrate ; but in any case they prove beyond question that vortices variously conditioned are prevalent among the forms assumed by cosmic masses advancing towards an orderly arrangement.

Mystical cosmogonies belong to the period of ethnic infancy. They have not ceased to be current. World-fables must be invented wherever the obscure wonder of savage communities is excited by the mysterious spectacle of Nature's apparently designed operations and irresistible power. But they were superseded among peoples in the van of progress by philosophic cosmogonies at the epoch when Thales began to diffuse throughout Ionia the wisdom of the Egyptians and Chaldeans.

Schemes, however, such as he and his successors elaborated result from the discourse of reason unfettered by any close attention to facts. They have been mostly wrought out by men who, in Delambre's words, 'Dissertaient à perte de vue, sans jamais rien observer, et sans jamais rien calculer.'

The insubstantial fabrics reared by them were then fatally discredited by Baconian methods and the Newtonian reign of law; they survived—forms of thought die slowly—but insecurely, with noticeably undermined foundations. Swedenborg was the last eminent reactionary, and his restoration in 1734 of the Cartesian gyrating medium as the motive power of the solar machine was a palpable failure. It could not be otherwise, since its inceptive idea had grown superannuated. The modern era of scientific cosmogony was at hand.

It was preceded by some remarkable attempts at sidereal generalization. Cosmology is the elder sister of cosmogony. What *is* must be studied before what *was* can be inferred. Precedent states remain visionary unless they can be closely linked to actual and observable conditions. Now about the middle of the eighteenth century an intelligible plan of the stellar universe, so far as the telescope had then disclosed it, began to be a desideratum. And the enterprise of supplying the need was undertaken independently by two men of obscure origin and imperfect education—one English, the other German.

Thomas Wright, of Durham, was the son of a carpenter at Byer's Green, where he was born September 22, 1711. His life was one of many vicissitudes, but ended happily. Having struggled hard for a livelihood—now at sea, then again on shore as a clock and almanac maker, a teacher and lecturer—he finally attained, somewhat unaccountably, to distinction and affluence, built himself a handsome house hard by his native shanty, and prosperously and reputably inhabited it during a quarter of a century. He died February 25, 1786, just one year after Herschel had described to the Royal Society the outcome of his first experiments in 'star gauging.' As the originator of the 'cloven disc' theory of the Milky Way, Wright is still deservedly remembered, for although that majestic structure is assuredly otherwise designed, it was no mean achievement to have initiated the science of its architecture.

Heinrich Lambert was a still more adventurous speculator than his unknown English rival. His father was a poor tailor at Mühlhausen, then in Swiss territory, and he worked as his apprentice. But his irrepressible talents brought him into notice, and he died, in 1777, through the favour of the second Frederick, a Berlin Academician. His *Cosmological Letters*, published in 1761, were entirely original; they were composed in ignorance of what Wright and Kant had already written. In some respects he overtopped them both. He had splendid intuitions, and just touched the confines of greatness. And if his performances fell short of the very highest, it may have been rather through abridgment of opportunity than through lack of capacity. The Milky Way marked, to his apprehension, a sidereal ecliptic, and he coincided with Wright in regarding it as a disc of aggregated stars, but with breaches and gaps indicating a multiplicity of systems circulating, he thought, round a common centre. Nor did he doubt the existence of other Milky Ways—numberless, remote, unseen—grouped into a combination of a higher order; while beyond, and still beyond, stretched further hierarchies of systems on an ascending scale of magnitude and grandeur.

Our knowledge of the structural facts of the universe can never be made exhaustive; in the middle of the eighteenth century, before Herschel had opened his sidereal campaign, it was barely elementary. Wright and Lambert were accordingly on a stint of material—they had to make bricks with very little straw. Yet they did their best with what was at hand. Both paid profound attention to the stellar heavens; they earnestly sought the true interpretation of the appearances presented by them, holding it possible, as we, despite accumulating difficulties, still do, to harmonize countless detached phenomena in one vast synthetic plan.

It was this purpose of fidelity to Nature which gave value to their work, and made it a new thing in cosmological history. This alone lent it impulsive force, and caused the meditations of two lonely thinkers to become effective in stimulating fresh attempts, favoured by improved conditions, to comprehend what actually exists, and to infer thence, with rational confidence, its sources in the vague but undeniable past.

CHAPTER II

THE NEBULAR HYPOTHESIS

IMMANUEL KANT was, in 1751, still in the plastic stage. His period of 'pure reason' was remote, and might have appeared improbable. Such as they were, his distinctions had been won in the field of concrete science, and the world of phenomena invited his speculations more seductively than the subtleties of logic. A seed was accordingly thrown into fertile soil by his reading of Thomas Wright's *New Theory of the Universe,* as summarized in a Hamburg journal. It set him thinking, and his thoughts proved to be of the dynamic order. Wright regarded the heavens under a merely statical aspect. He laid down the first definite plan of their construction, showing that the stars were not scattered at random, but aggregated by method; and this was much for one necessitous human being to have accomplished unaided.

But the young professor of Königsberg could not rest satisfied with the idle contemplation of any subsisting arrangement. His mind was incapable of acquiescing in things simply as they presented themselves; it craved to know further how they came to stand to each other in just such mutual relations. He was, moreover, permeated with Epicurean doctrines. Not in any reprehensible sense. He could not be reproached either as a hedonist or as an atheist. His pleasures were intellectual, his morals austere, his convictions orthodox. Behind the veil of material existence he divined its supreme immaterial Originator, and his perception of the activity in Nature of an ordering First Cause remained equally vivid, whether its disclosures were taken to be by immediate creation or through tedious processes of modification and growth. His large and luminous view embraced besides the ethical significance which such processes adumbrate. The following sentence shows an appreciation of the place of man in Nature truer and more profound than was attained perhaps by any other of his philosophical contemporaries: 'The cosmic evolution of Nature,' he wrote in memorable words, 'is continued in the historic development of humanity, and completed in the moral perfection of the individual.'*

Nevertheless, he owned to a community of ideas with Democritus as to the origin of the universe. Lucretius had cast over him the spell of his lofty diction, and captured his scientific adhesion by the stately imagery of his verse. With reservations, however. Docile discipleship was not in his line. He availed, then, of the Democritean atoms, but by no means admitted their concourse to be fortuitous. Chaos itself, as he conceived it, half concealed, half revealed the rough draft of a 'perfect plan.' His postulates were few. He demanded only a limitless waste of primordial matter, animated by no forces save those of gravitation and molecular repulsion, and undertook to produce from it a workable solar system. The attempt was no more than partially successful. Retrogressive investiga-

* Quoted by Dr. Hastie in the preface to his translation of Kant's *Cosmogony*, Glasgow, 1900.

tions lead at the best to precarious results, and this one, in particular, was vitiated by a fundamental error of principle. Its author clearly perceived that planetary circulation must be the outcome of a vortical swirl in the nebulous matrix; but he failed to see that no interaction of its constituent particles could have set this swirl going.

Systems cannot of themselves add to their 'moment of momentum.' No changes of internal configuration avail to increase or diminish the sum of the products obtained by multiplying the mass of each of the connected bodies into its areal velocity projected on a common plane. The sum is of the algebraic kind. Equal and opposite motions cancel each other, the total representing only the aggregate excess of speed in either direction. A system with all its parts in rapid motion might then conceivably be devoid of moment of momentum. And if this were its state to begin with, it should be its state to the end of time, unless external force were applied to alter it. But the possibility may be dismissed as ideal. The establishment of so nice a balance as it would require is not practically feasible. In the actual world one side of the velocity account would be sure to exceed the other, albeit very slightly, and the smallest predominance would suffice to set on foot an eventual rotation of the system.

Had Kant been better acquainted with mechanical principles, he might then have safely trusted to the minute beginnings supplied by aboriginal inequalities of movement and dissymmetry of arrangement for the development in his colossal dust-cloud of the wheeling movement necessary for his purpose; and he would thus have escaped stumbling at the threshold of his daring inquiry. Rightly averse to employing arbitrary expedients, he piqued himself on the simplicity of his postulates, and was thus misled into substituting an imaginary for a real cause. The hypothesis adopted by him was that the particles forming the initial inchoate mass fell together by gravity, but were deviated from rectilinear courses through the effects of unequal resistance. And he derived from the combination of these multitudinous encounters a common axial rotation for the entire agglomeration. The futility of this mode of procedure was adverted to by M. Faye in 1885.* The deviations in question would, in fact, exactly balance one another, there being no reason why movement in one sense should prevail over movement in the opposite; consequently a general rotatory movement could not even begin to affect the seething mass, which would condense in sterile rigidity. Kant should then, as Laplace did when his turn came, have assumed the gyration indispensable to his purpose. He asked too little from Nature on one side, and too much on the other, with the result of arresting the machinery he designed to set going.

Kant made the germ of the future sun to consist in an aggregation of atoms at the core of the nebula, which, growing by successive innumerable accessions, provided the motive power for the machinery of planetary construction. For it was, as we have seen, the jostling of the particles drawn towards the gradually preponderating centre of attraction which set on foot, it was supposed, the whirl eventually transformed into the tangential velocities of the sun's attendant bodies. They

* *Sur l'Origine du Monde*, 3e éd., p. 136.

were formed, like the sun, by the perpetuation and increase of subordinate nuclei sure to arise in the elemental tumult. They were formed, not under the guidance of a definite law, but just where chance—or what seemed like chance—favoured an accretion.

The progressive increase of planetary distances noted by Titius and Bode could never have arisen in the Kantian system. Nor could the Kantian planets have had a direct rotation.* Under the given conditions retrograde systems should have originated. This would have necessarily ensued from the incoherence of their materials. Particles revolving independently one of the other have smaller velocities the more remote they are from the focus of movement. Should they agglomerate into a globe, the inner flights must, as being the swiftest, determine the direction of its rotation, which will consequently reverse the direction of its orbital revolution. Hence, it depends upon the nature of their generating stuff no less than upon the advance of central condensation whether planets, in their domestic

* This also was pointed out by M. Faye, *loc. cit.*, p. 150.

arrangements, contravene or obey the larger law of circulation prevailing in the system to which they belong, and Kant's nebula was undoubtedly such as to involve its contravention.

Yet his scheme, with all its deficiencies, bore the authentic stamp of genius—of genius imperfectly equipped with knowledge, but original, penetrative, divinatory. The very entitling of the work, *A Natural History of the Heavens* was an audacity implying a radical change of conception. It was in this remarkable treatise that 'island universes' made their definitive appearance. Wright, it is true, had, five years previously (in 1750), thrown out the idea that 'cloudy spots' might represent 'external creations,' but as a mere vagary of the scientific imagination. Kant unhesitatingly laid hold of it, classed nebulæ as so many separate galaxies, and regarded them as combining with our own into a revolving system on a surpassing scale of grandeur. Kant was also the first to take into account the effects on their development of the plasticity of the heavenly bodies. He published in 1754, in a Königsberg paper, by way of preliminary to his forthcoming *Natural History*, an outline of the workings of tidal friction in the earth-moon system. He saw clearly that it had acted in the past to reduce our satellite's rotation to its present minimum rate, and that it even now, by very slow degrees, tended to retard the spinning of the earth. This brilliant forecast remained unnoticed for well-nigh a century.

The assertion, however, that Kant's cosmogony was an anticipatory 'Meteoritic Hypothesis' lacks foundation. It is only true in the sense that his building materials were pulverulent, not 'fluid.' Laplace's primitive nebula was a coherent mass. It rotated as a whole; it divided only under considerable strain; its separated parts had individual unity—they held together with, so to speak, a purpose of concentration. Kant's elemental matter, on the contrary, was a loose aggregate of independent particles, each pursuing its way, disturbed, indeed, by its neighbours, but essentially isolated from them. They were, in short, genuine Lucretian atoms, intended to stand for the irreducible minima of Nature. The chaos that they formed was in nowise a 'meteoritic plenum,' unless the phrase be emptied of all distinctive meaning. Meteorites, so far from being primordial units, have the show and semblance of advanced cosmical products. They raise special questions in chemistry, mineralogy, geology, and physics, claiming to be dealt with by experts in each branch. Before serving for explanatory purposes, in fact, they themselves need to be explained.

Laplace enounced his hypothesis in 1796, and republished it with supplementary details in 1808. Herschel had meanwhile ascertained the retrograde movement of the Uranian satellite-system, a circumstance highly damaging to the validity of the adopted line of reasoning; yet its author was content to leave it in jeopardy. He must, to be sure, have regretted that Nature had seen fit to mar the admirable symmetry indicative of her presumed plan of action, running counter thereby to the plainest teachings of the doctrine of probabilities. But he kept his own counsel on the subject, preferring that it should be discussed, as it has been in full detail, by posterity; and posterity has, at any rate, learned that the seeming caprices of Nature are often more instructive than her most harmonious regularity, and has derived a warning from her frequent breaches of continuity against the undue extension of apparently well-grounded inferences.

Nevertheless, the constructive scheme handed on by the eighteenth to the nineteenth century has not, up to the present, been consigned to the limbo of vanities. It accorded too profoundly with undoubted realities to be thus summarily disposed of. No one then living had studied the mechanism of the solar system so attentively, or was so intimately acquainted with its workings, as Pierre Simon Laplace. None knew better how admirable, yet how far from inevitable, were the adjustments by which its stability was secured. Long meditation upon their poise and plan persuaded him that the subsisting congruities of arrangement must have had their source in a community of origin. He thus acquired the settled conviction that the sun engendered his cortège, or was together with it engendered from one parent-mass. And this virtually new truth (for Kant's speculation had attracted a negligible amount of notice) was set forth by him with a directness and lucidity which won for it an immediate place among the permanent acquisitions of the human intellect. Few, perhaps, any longer believe that planetary formation took the precise course laid down for it in the *Système du Monde*, but fewer still doubt that the entire ambit of the solar system was once occupied by an inchoate sun, and that its component bodies came into being incidentally to that sun's progressive contraction.

In favour of this view Laplace could allege no clinching argument; it recommended itself to him solely through its inherent probability. Unexpected confirmation has, none the less, been afforded to it by the modern theorem of the conservation of energy, applied by Helmholtz with widely illuminative effect to solve the problem of the maintenance of solar heat. Laplace assumed an enormously high initial temperature. It was the only way open to him, and he took it. But a transcendentally hot nebula is not easily conceivable; an exalted thermal state seems, and probably is, incompatible with a high degree of attenuation. The key to the enigma was given by the demonstration that a diffuse mass, although actually cold, might contain vast stores of potential heat. There was then no need to postulate a primitive 'fire-mist'; the surrendered energy of position amply sufficed to meet the requirements of the case. The temperature of the nebula necessarily rose as it contracted through gravitational stress; shrinkage and heat-evolution proceeded together; and they in all likelihood proceed together still. Our existence depends in part, or wholly, upon the collapse of the sun. If its particles ceased to descend, their incandescence would become less intense, and terrestrial vitality would be seriously compromised.

Their number, however, being finite, the store of energy they can supply in falling even from an infinite distance is also finite. The process of solar sustentation is then terminable; it had a beginning, and it will assuredly come to an end. Now the *terminus ad quem* is of a calculable remoteness: it can be located (unless shifted by radio-active processes) within certain limits of time. But the *terminus a quo* depends upon too many conditions to be satisfactorily defined. It is only certain that the sun is to-day slightly more condensed than it was a year ago. It might a few millenniums back have been measurably larger, had modern micrometrical methods been available in the Stone Age; while, looking into the geological past, we discern a continually more diffuse globe, filling the orbit of Mercury when the earth was perhaps still red-hot, then successively ampler spheres, out to, and beyond, that of Neptune. And just such a vastly diffused sun realizes the nebula of Laplace. The state of things he imagined can be reached accordingly, either by tracing forward the development of a tenuous rotating mass, or by pursuing backward the surely indicated, unceasing, and inevitable distension of the sun. Hence, no sooner was it acknowledged that energy may be transformed, but cannot be destroyed, than the nebular cosmogony assumed a new and authoritative aspect.

But here a *caveat* has been entered by the latest inquirers—a *caveat* not to be ignored, though based upon modes of action still exceedingly obscure. Radio-activity is a fledgling science; its capabilities, though immense, are vaguely outlined. Until they more fully approve themselves, it would be unwise to admit conclusions which they may eventually enforce. Subversive ideas are in the air; the theory of atomic dissociation goes to the very root of things, and it insistently claims assent. Its verification, by disclosing the presence in the universe of a measureless store of unsuspected energy, would overthrow all the calculations of cosmic time heretofore attempted, and might protract indefinitely the radiative span of the sun.

Mr. W. E. Wilson pointed out in 1903* that its entire thermal output could be supplied by the spontaneous liberation of energy from 3·6 grammes of radium in each cubic metre of its volume; and although we have no evidence of the actual existence of radium in the sun, the possibility that chromospheric helium represents the decay of solar radio-active elements† must be taken into consideration. The ground here is undermined with pitfalls. We can only see that although Helmholtz's gravitational rationale of the sun's long life-history remains

* *Nature*, July 9, 1903.

† Rutherford, *Radio-activity*, p. 342.

true, the results derived from it may be profoundly modified by co-ordinate processes, variously efficacious according to circumstances, perhaps knowable, but as yet unknown.

The scope of the nebular hypothesis had widened prodigiously by the time Helmholtz took it in hand. Five years before its promulgation at Paris, Herschel gave at Slough the first hint of a corresponding scheme of sidereal evolution. The discovery of a nebulous star in Taurus (N.G.C. 1514) set him pondering; and he found himself, as the upshot of his meditations, reduced to the dilemma either of concluding nucleus and *chevelure* to be alike stellar, though composed of stars differing enormously in real magnitude, or of admitting the possession by the star of a voluminous appendage constituted of a peculiar and unknown 'shining fluid.' He chose the latter alternative, adding the pregnant remark: 'The shining fluid might exist independently of stars,' and 'seems more fit to produce a star by its condensation than to depend on the star for its existence.'*

Thus tentatively, and under the compulsion

* *Philosophical Transactions*, vol. lxxxi., p. 85.

of phenomena rather than by the deliberate choice of its inventor, the universal theory of the genesis of stars from nebulæ took its rise. Herschel shaped it definitively in 1811 and 1814 into a formal plan for the interpretation of celestial appearances, but in a large and general way. He made no attempt to realize the particularities of a *modus operandi* vaguely conceived of as involving growth by absorption or assimilation. He and Laplace thought out their separate schemes quite irrespectively one of the other. There is no evidence of their having exchanged views personally or by correspondence, nor does their mutual influence appear to have been appreciable.* Yet Laplace needed as the raw material for his solar system precisely the 'shining fluid' elaborated, one might say, by Herschel, partly through the revelations of his telescopes, partly as the outcome of his reasonings concerning the *chevelure* of the star in Taurus. Halley, it is

* Herschel met Laplace during a visit to Paris in July, 1801, but what passed between them is unrecorded. In the sixth edition, however, of the *Exposition du Système du Monde*, Laplace referred to Herschel's observations of nebulæ as confirmatory of his own genetic scheme.

true, had, by a sagacious intuition, surmised the composition of nebulæ out of a 'lucid medium.' But the ineffectual phrase remained stranded in the pages of the *Philosophical Transactions*, and has only of late been set floating on the stream of scientific literature.

Down to the end of the eighteenth century world-building had been a purely speculative undertaking. It lacked actuality; it was concerned with operations thought of as belonging exclusively to a past order of things, now over and done with, and lying wholly outside the range of experience. Through Herschel's synthesis, however, those dimly apprehended operations were brought into view as variously progressing even now in different parts of the cosmos, as incipient in some regions, far advanced in others, the rubbish of the workshop here half masking the rising edifice, while elsewhere signs of decay and exhaustion give legible presage of an appointed end. And this stupendous vision of a forming universe has not vanished on critical scrutiny. It is no dream-tissue; it cannot dissolve into airy nothingness; it is based upon a firm substratum of reality. The immeasurable purposes of creative wisdom are still only in part fulfilled. It has become the strange privilege of humanity to contemplate from its little shoal of time the oceanic flow of their development. Thus, in the swing of the ages, Laplace's thought was caught up and vitalized. He himself was scarcely sensible of their movement. He recognised very imperfectly, if at all, his obligations to Herschel's nebulous star. His means were inadequate; his field of view narrow; his knowledge, though co-extensive with that of his time, fell short of what his boundless task demanded. In some respects his mode of procedure was faulty; his forecasts have been belied; the behaviour imputed by him to a nebula such as he devised is questionable, if not impossible. But with the instinct of consummate intelligence he hit off the 'psychological moment,' and, divining the genetic import of harmonies of construction obvious to perception, but arduous of interpretation, he laid down with masterly simplicity the ground-plan of a structure likely to maintain its substantial integrity despite innumerable additions and rectifications.

CHAPTER III

CRITICISMS OF THE NEBULAR HYPOTHESIS

LAPLACE'S theory was a perfectly definite conception. In this lay its distinctive merit; in this also its special susceptibility to attack. Here was no question of condensation round nuclei arising at discretion amid the large possibilities of boundless elemental confusion; but of an orderly succession of occurrences, rendered inevitable by the steady operation of mechanical laws, and harmonizing, in their outcome, with the array of ascertained phenomena visible in the planetary system. These accordingly ceased to be regarded as arbitrary or casual; they became linked together in the present, and with the past, as joint products of one grand scheme of development. The mode of origin of the bodies exhibiting them accounted, its inventor claimed to have shown, simply and entirely for them all; and at least the fundamental propositions laid down by him could not be gainsaid.

Clearly, the unanimity of planetary movements is no result of chance; it represents quite obviously a survival of the general swirl of an inchoate mass, occupying primitively the whole recognised sphere of solar influence. Ambiguities set in only when details come to be considered. The engendering nebula devised by Laplace was provided with a vast endowment of heat and a slow movement of rotation; hence cooling, contraction, and acceleration advanced *pari passu*, the last as a consequence of the mechanical law by which the algebraic sum of the areas described by any number of bodies round a given axis, multiplied by their several masses and projected upon a single plane, remains constant to the end of time. In other words, to repeat what has been stated a few pages back, the moment of momentum of a congeries of particles can neither increase nor diminish through the effects of their mutual interactions, however varied and prolonged.

The nebula then quickened its pace until a stage was reached at which centrifugal speed could no longer be controlled by gravity; separation became inevitable, and an equatorial ring was abandoned, which thenceforward revolved on its own account in the period conformed to by the undivided mass at the epoch of its secession. This was the first of many subsequent crises of instability, each eventuating in the detachment of a nebulous ring. These rings, however, were regarded as merely transitional forms. They survived, just for illustrative purposes, in the Saturnian system; elsewhere they broke up into fragments, which ultimately coalesced into globes, and the globes were embryo planets. There was, indeed, a hitch in the line of argument which did not escape the acumen of the French geometer. The direction of the axial movement imparted to the members of the solar family depended essentially upon the relative velocities of the portions of matter brought together for their construction. If the inner sections of the self-shaping mass moved faster than the outer, the resulting rotation should have been retrograde; if slower, direct rotation would have ensued. Now, in a ring like that of Saturn, composed of discrete particles, linear speed decreases continuously outward, each of its minutest constituents obeying independently Kepler's law of periods and distances. Such a formation, since it would necessarily have yielded backward-spinning planets, would have been unfit for the purpose in view, and Laplace accordingly substituted an annulus endowed with a considerable amount of cohesion, and capable of rotating, like a solid, in a single period. It is true that such unanimity of movement was incompatible with the other postulated conditions; but the anomaly escaped notice for above half a century.

Professor Darwin has moreover pointed out* that a ring of matter distributed with any approach to uniformity must concentrate, if at all, round its own centre of gravity. It should accordingly collapse upon, and become re-absorbed by, the parent body. If markedly unsymmetrical and ill-balanced, its materials might certainly collect at an interior point more or less remote from the centre; but in

* Presidential Address to the British Association, Johannesburg, August 30, 1905.

no case could the focus of condensation be situated in any part of the annular circumference, where it was located by Laplace.

Whether workable or not, the genetic plan traced out by him was a strictly regulated one; its steps were marked with characteristic precision. Yet by this very determinateness it gave hostages to the future. It challenged the application of tests which designs more vaguely sketched might have evaded. The primary criterion of its truth was the prevalence of concordant motion throughout the solar domain. Counter-currents were formally excluded; their possibility was not even contemplated. Hence, the discovery of the retrograde systems of Uranus and Neptune flatly contravened its pretensions to unconditional acceptance. With less evidence, but equal certainty, Laplace's hypothesis, strictly interpreted, involves the consequence that each planet circulates in the identical time occupied by the rotation of the undivided nebula just before instability toppled over into separation. Each of the planetary periods should accordingly bear a certain ratio, prescribed by inexorable mechanical law, to the actual period of the sun's rotation. In point of fact, however, the periods in question are much shorter than comports with the necessity for the conservation from age to age of the system's moment of momentum. The discrepancy was adverted to nearly half a century ago by M. Babinet.* He showed in March, 1861, that the axial movement of the solar mass, when distended to fill the sphere of Neptune, should have been, by the law of areas, so excessively slow that more than 27,000 centuries would have been needed for the completion of a single rotation; while the period, even when the shrinking nebula had come to be bounded by the terrestrial orbit, must still have been protracted to 3,181 years. Under these circumstances, centrifugal force would never have overbalanced central attraction; no rings could have separated, and no planets could have been formed.

Quite recently, Mr. F. R. Moulton, of Chicago,† has reconsidered the subject in the course of a careful and candid discussion of the difficulties besetting the nebular cosmogony as viewed from the standpoint of modern

* *Comptes Rendus*, tom. lii., p. 481.

† *Astrophysical Journal*, vol. xi., p. 103.

science, and he comes to essentially the same conclusion. His calculations, though founded on data expressly chosen so as to give the classic theory the benefit of every doubt, made it perfectly clear that the moment of momentum of the embryo planetary system should have exceeded its present value no less than 213 times if, when it extended to the distance of Neptune, it rotated in what is now the period of Neptune. But moment of momentum is a constant. The lapse of millions of years makes no difference to it; it is not, like energy, subject to 'dissipation'; it can neither have gained nor lost value since the sky was first flecked with the 'breath-stain' appointed to condense into our sun, which, in this respect at least, must at every stage of its subsequent evolution have maintained immutability. On the other hand, this being so, its primeval wheeling motion would have been much too leisurely to permit the occurrence of accesses of instability. Gravity would have steadily kept its supremacy over the forces tending to disruption until the nebula had contracted to less than the compass of the Mercurian sphere, and its overthrow at that epoch would have been too late for the origination of any of the sister orbs of the earth. These results, it is true, depend in part upon the mode of variation in density ascribed to the progressively shrinking nebula; but the law adopted by Mr. Moulton has a consensus of authorities in its favour. Nor could its deviation from exactitude—if it be inexact—possibly suffice to account for the enormous discrepancies which calculations based upon it have brought to light.

The nebular hypothesis stipulates further that satellites must revolve more slowly than their primaries rotate. The reason is patent. In the periodic time of a body detached by centrifugal acceleration the rate of gyration of the original mass is, if the theory be valid, perpetuated. Subsequent contraction tends to quicken, and very greatly to quicken, the rotation of the planet, while the period of the satellite survives unaltered as a standing record of what the joint period was. This relation may indeed be modified by the effects of tidal friction, but it is more than doubtful whether it can ever be reversed. It is, then, a characteristic feature of the mode of evolution described by Laplace that no month—so to call it—can be shorter than the corresponding day. And the rule is conformed to in nearly every part of the solar system. Nevertheless, two flagrant violations of it have lately obtruded themselves upon notice, and can scarcely be explained away by supplementary hypotheses. The first ascertained anomaly of the kind was met with in the swift circulation of Phobos, the inner satellite of Mars, which completes three revolutions and enters upon a fourth while the planet attended by it wheels once on its axis. The fact is most perplexing, and the confident persuasion that solar tidal friction would avail to remove the difficulty has not proved well grounded. Solar tidal friction, it may be remarked, acts as an external force upon subordinate systems submitted to its influence. Within their precincts moment of momentum may be destroyed by it; it tends, so far, to abrogate the law of conservation; and the supposition was hence feasible that the rotation of Mars had, in the course of ages, greatly slackened through the retarding effect of sun-raised tides. But the agency was demonstrably inadequate to the task assigned to it.

The reduction of the rotational moment of Mars to about one twenty-fifth its primitive amount* would have brought other consequences in its train, at least one of which did clearly not ensue. At an early stage of the process Phobos should have been re-engulfed in the mass of its primary.† For the pull of the small tidal wave raised by it on the surface of that body would have been backward from the instant that the balance of periods became inclined, through solar compulsion, in a direction contrary to that it would have naturally taken; and the ensuing loss of velocity must have entailed the descent of the little satellite along a spiral path towards an inevitable doom. Its continued existence, then, closes this way of escape from the difficulty raised by the shortness of its period. M. Wolf had recourse to a different explanatory subterfuge.‡ He believed that Phobos might have owed its origin to one of Roche's 'elliptic sheddings' of nebulous matter dropped downward from near the polar regions of the distended Martian

* Moulton, *Astrophysical Journal*, vol. xi., p. 110.

† Nolan, *Nature*, vol. xxxiv., p. 287.

‡ *Bulletin Astronomique*, tom. ii., p. 223.

spheroid, and rotating, owing to its low rate of linear speed, in the immediate vicinity of the cooling planet. The explanation, though ingenious, is too recondite to be satisfactory. The mind takes no grip of it; it evades distinct apprehension.

The Saturnian system exhibits a case of the same kind, but still more perplexing to speculative prepossessions. Saturn's ring-system has always appealed to thinkers as a striking object-lesson in nebular development. It forcibly arrested Kant's attention, and he sketched its birth-history on lines anticipatory of those adopted by Laplace for the solar system in its entirety. Laplace himself regarded the formation as the one surviving relic of the annular stage of planet-building—as a witness from the dim past to a condition of things elsewhere transitory. Yet the witness has turned king's evidence, and betrayed the whole situation. The innermost Saturnian ring has a period far too short to be compatible with the requirements of theory. For its meteoric constituents, known on spectroscopic testimony to revolve each on its own account, complete their circuits in between five and six hours, while the planet needs just ten hours and a half for its axial rotation. Moreover, tidal friction is here far less available than on Mars; yet no other retarding agency has been invented. The deadlock appears final and hopeless.

An objection quite as formidable, and even more fundamental, was raised by Kirkwood in 1869. The nebulous material of the uncondensed sun must have been, at the outset, of the utmost tenuity. Atmospheric air is, by comparison, a dense and massive substance. Yet no reasonable person could ascribe to aerial matter the least power of resisting strain. We know perfectly that a rotating globe of air, and, *à fortiori*, a globe of matter thousands of times less compact than air, would unintermittently disintegrate at the surface with the progress of acceleration. The disturbance and restoration of equilibrium would be virtually simultaneous. There could be no accumulation of internal stress, and consequently no definitely separated epochs of instability. At the first solicitation, at the first instant that centrifugal velocity gained the upper hand over gravity, nebulous wisps would have become detached, and their detachment would have gone on without pause. Space would have been strewn with the débris of the condensing nebula, and there should have resulted a vast cloud of cosmic dust, not a majestic array of revolving spheres.

Further, the possibility of their emergence from pre-existent annuli is by no means assured. Even if the nebulous material had possessed the fabulous cohesion indispensable for its division into voluminous rings with wide intervening empty gaps, their ultimate agglomeration into planetary globes would probably never have been effectually accomplished. Kirkwood long ago questioned the feasibility of the process. Mr. Moulton has gone far towards demonstrating that it must have had an abortive outcome. Professor Darwin pronounces its very inception, apart from very special conditions, to be impracticable.

Another grave objection to Laplace's scheme is founded on the marked deviations visible in the solar system, from conformity to a fundamental plane of motion. Unless acted on by influences difficult to imagine or explain, all the planets should circulate along the level of the sun's equator, and rotate on axes perpendicular to it. How far this is from being realized in nature we have only to look around us to perceive. We owe the changes of our seasons to the tilted fashion of the earth's spinning. Yet it is by no means easy to understand how the pole of its equator comes to be situated in the tail of Ursa Minor, while the pole of the ecliptic is involved in the folds of Draco. They should have coincided if the simple rules of the nebular prescription had been followed in the making and modelling of the planets. Nor are the terrestrial arrangements exceptional. The Saturnian equator and the Saturnian rings have a still higher inclination; while in the systems of Uranus and Neptune—if we may thus interpret their retrograde revolutions—the angle exceeds the limit of a quadrant. These and other similar discrepancies prove the solar mechanism to have originated by a more complex method than that imagined by Laplace, and an hypothesis which invokes the aid of a multitude of auxiliary devices for its extrication from accumulating embarrassments falls thereby under the suspicion of not being worth the trouble of extricating. It forfeits, at any rate, all claim to commendation for directness and simplicity.

The cosmogony turned out at Paris has thus proved vulnerable on a number of points; but all the blows aimed at it have not told with such deadly effect as those just referred to. Some have fallen harmlessly, or glanced aside. One hostile argument in particular, which for a time seemed irresistible, has been completely overthrown by the logic of facts, and deserves mention only as a historical curiosity. Towards the middle of the nineteenth century the progress of sidereal astronomy seemed to take the direction of showing all nebulæ indiscriminately to be of stellar composition. With Lord Rosse's great reflectors a good many such objects were genuinely, and some besides were deceptively, resolved into stars, the illusory effects being confirmed by Bond's observations with the deservedly celebrated 15-inch refractor then recently built by Merz for Harvard College. Hence the rash inference was drawn that resolution was wholly a question of optical power, and that no real distinction existed between the stellar and the nebular realms. Herschel's 'shining fluid' assumed a mythical air; 'island-universes' came into popular vogue; and all but a few careful thinkers held nebulæ and clusters to be differentiated merely by degrees of remoteness. But if space contained only full-grown stars and no stars in the making—no star-spawn, no star-protoplasm—then the imagined evolutionary history of our system was left in the air, destitute of even the most fragile prop of observed fact.

From this precarious position it was rescued, partly by the cogent reasonings of Whewell and Herbert Spencer, finally and triumphantly by Sir William Huggins's spectroscopic discovery of the cosmic gas 'nebulium.' Since August, 1864, there has been no possibility of denying that the heavens contain ample stores of just the kind of material Laplace wanted, though whether it played just the part he assigned to it in the manner that he supposed is a question to be answered with profound and growing reserve.

An objection of late urged against the nebular theory from the standpoint of the kinetic doctrine of gaseous constitution is of much speculative interest. A gaseous nebula equal in mass to the sun and planets, and distended sufficiently to fill the orbit of Neptune, would have been, supposing the prevalent opinion correct, subject to a rapid leakage into space of its lighter ingredients. Of hydrogen and helium, we are told, it should infallibly have become depleted; yet there is no lack of either in the sun of the twentieth century. Their retention, it must be admitted, is, on the hypothetical conditions, difficult to account for. The 'critical velocity' at the limiting surface of the supposed nebula would have been 4·8 miles a second. This is, in fact, at the distance of Neptune, parabolic speed. The planet itself, if it could attain to it, would break the bonds that bind it to the sun, and seek its fortunes under some different allegiance. Similarly, any particle of the primitive nebula thus accelerated should have become an irreclaimable vagrant.

Now, the velocity of hydrogen molecules at the zero of Centigrade is, in the mean, about $1\frac{1}{6}$ miles a second, but attains in the extreme to above seven miles. Hydrogen could not then have been permanently retained by the solar nebula, and the escape of helium would have more slowly ensued. Yet these results, though seemingly inevitable, did not actually come to pass, either because the generating body was differently constituted from what has been supposed, or because countervailing influences were brought to bear. It is, for instance, amply possible that the dynamical condition of gases may be essentially modified by rarefaction carried to a degree transcending the range of experimental enquiries. The progress of science affords many warnings against trusting implicitly to the rule of continuity. Curves of change seldom preserve indefinitely a uniform character. Their unexplored sections may include quite unlooked-for peculiarities of flexure, and the possibility seriously undermines confidence in inferences depending upon 'extrapolation.' The presence of hydrogen and helium in our system cannot, then, be ranked among facts incontestably contradictory of the nebular hypothesis.

The concerted advance of mathematical astronomy during the eighteenth century was effected with the confident serenity of irresistible power. One after another the obstacles barring its path went down before repeated and skilful onslaughts, the unbroken succession of which lends a certain exultant sameness to the story of the heroic age of analysis. The *Mécanique Céleste* attested 'victory all along the line.' There were no more worlds to conquer that Laplace knew of; the reign of gravitational law was firmly established throughout the solar dominions; menaced revolts had been appeased; anomalies removed; no extant observations any longer impaired the perfect harmony between what was and what had been foreseen. Nature for the moment submitted readily to the trammels put upon her by human thought; her intricacies had apparently ceased to defy unravelment; her modes of procedure looked straightforward and intelligible. As they were judged to be in the present, so they might be presumed to have been in the past; and the temptation was irresistible to adventure backward speculation, inferring initial conditions from the elaborated product laid open to scrutiny.

It was an epoch of peremptory renewals. The formula of equality promised to regenerate society; a political panacea had been found by the creation of a republic 'one and indivisible'; and the success of the guillotine in securing its supremacy was almost outdone by the triumphs of the calculus in vindicating the unimpeded sway of gravitation.

Humanity had made a fresh start; science should do likewise. The sanguine spirit of a rejuvenated world animated all forms of human endeavour. It has long since evaporated. The buoyant hopes of a century back have been crushed; the future of civilization looks dim; and its uncertainty compromises the future of knowledge. But we, at any rate, no longer delude ourselves with the idea that he who runs may read the secrets of the universe. We have learned by convincing experience how much, and how variously, 'the subtlety of nature transcends the subtlety of sense and intellect'; we are vividly aware that there is no single and simple recipe for the 'cosmification' of chaos.

That devised by Laplace has ceased to be satisfactory. Its simplicity, at first sight so seductive, leaves it at a disadvantage compared with the intricacy of the effects it was designed to elicit. The relations claiming explanation have multiplied with the progress of research. Those of the dynamical order were alone attended to by the geometers of the eighteenth century, and even they have grown recalcitrant; while those of a physical and chemical kind have proved wholly unmanageable. It has, indeed, become abundantly clear that the series of operations described by Laplace could scarcely, under the most favourable circumstances, have been accomplished, and in a thin nebulous medium would have been entirely impossible. The nebular cosmogony has not, then, stood 'Foursquare to all the winds that blew.'

Its towers and battlements have crumbled before the storms of adverse criticism. It survives only as a wreck, its distinctive features obliterated, although with the old flag still flying on the keep. In the next chapter we shall attempt a survey of the works set on foot for its reconstruction.

CHAPTER IV

THE NEBULAR HYPOTHESIS VARIED AND IMPROVED

'RESTORATIONS' often go very far. Things may be improved beyond recognition, nay, out of existence. So it has happened to the nebular hypothesis. *Stat nominis umbra.* The name survives, but with connotations indefinitely diversified. The original theme is barely recalled by many of the variations played upon it. Entire license of treatment prevails. The strict and simple lines of evolution laid down by Laplace are obliterated or submerged. Some of the schemes proposed by modern cosmogonists are substantially reversions to Kant's *Natural History of the Heavens;* the long-discarded and despised Cartesian vortices reappear, with the éclat of virtual novelty, in others; nor are there wanting theories or speculations reminiscent even of Buffon's cometary impacts. Moreover, the misleading fashion has come into vogue of bracketing Kant with Laplace as co-inventor of the majestic and orderly plan of growth commonly designated the 'nebular hypothesis.' This has been, and is, the source of much hurtful confusion. Save the one fundamental idea—and that by no means their exclusive property—of ascribing unity of origin to the planetary system, Kant's and Laplace's evolutionary methods had little in common. Their postulates were very far from being identical; they employed radically different kinds of 'world-stuff'; and the 'world-stuff' was subjected, in each case, to totally dissimilar processes.

Yet it is often tacitly assumed that to defend or refurbish one scheme is to rehabilitate the other. Under cover of the intellectual vagueness thus fostered, a backward drift of thought is, indeed, discernible towards the view-point of the Königsberg philosopher. It is recommended, not so much by the favourable verdict of science as by the wide freedom of the prospect which it affords. The imperative guidance of Laplace, reassuring at first, led to subsequent revolts. But Kant is highly accommodating; one can deviate widely from, without finally quitting, the track of his conceptions; they are capacious and indefinite enough to comport with much novelty both of imagination and experience, and hence lend themselves with facility to the changing requirements of progress.

A noteworthy attempt was made, in 1873, by the late Édouard Roche of Montpellier to reconstruct, without subverting, Laplace's hypothesis. This remarkable man lived and died a provincial. Only a few scattered students have made acquaintance at first hand with his works; his fame, always dim, now already begins to seem remote. Yet a score of years ago he was still lecturing at the Lycée of his native town. The waters of oblivion have grown, perhaps, more turbid than of yore. Anyhow, Roche of Montpellier is only vaguely remembered, and that by a specially educated section of the public, as having fixed a limit within which a satellite cannot revolve intact.* Nearer to the ruling planet than

* *Mémoires de l'Académie de Montpellier*, tom. i.

2·44 of its mean radii, it could not—setting aside improbable conditions of density—maintain a substantive globular status under the disruptive strain of tidal forces. In point of fact, all the moons so far discovered in the solar system circulate outside 'Roche's limit'; and Saturn's rings, which lie within it, owe to that circumstance, it may plausibly be asserted, their pulverulent condition. Professor Darwin accordingly regards knowledge of that condition as dating from 1848, the year in which Roche published the law involving it as a corollary.*

Roche was the precursor of Poincaré and Darwin in those profound investigations of the figures of equilibrium of rotating fluid bodies which have opened up new paths and disclosed untried possibilities in evolutionary astronomy. His researches, moreover, into the origin of the solar system† constituted a reinforcement of first-rate importance to the strength of Laplace's position. He was perhaps its most effective and timely defender; he came to the rescue just when its safety was

* *The Tides*, p. 327.

† *Mémoires de l'Académie de Montpellier*, tom. viii.

seriously compromised, repaired its breaches, and threw up skilfully constructed outworks. Adopting the same premisses, he drew virtually the same conclusions as Laplace, ingeniously modifying them, however, so as to evade certain objections, and temporarily to silence the less obstinate cavillers. His results were, indeed, almost as difficult to disprove as they had been to attain. They were arrived at laboriously, legitimately, by long-drawn analytical operations; and the reasonings survive in full credit, even although the initial conditions they started from now wear an aspect of unreality. Thus, the invention of *trainées elliptiques* not only usefully met an argumentative emergency, but still remains as a supplementary adjunct to cosmic processes. Undeniably, polar annulation may have played a part in planetary formation; the possibility cannot be gainsaid.

The 'ellipsoidal trains' investigated at Montpellier were huge nebulous strata detached from the polar regions of the primitive spheroid, which, bringing with them the low rotational velocity proper to that situation, tended, some to constitute interior equatorial rings, others to become agglomerated with the central mass. But their incorporation should have had as its consequence—since the 'law of areas' is inviolable—a quickening of angular rotation throughout the nebula. The 'law of areas,' it may be explained, is merely a short title for the 'law of conservation of moment of momentum,' which prescribes—as we know—that the sum total of the areas described in a given time on a given plane by the members or constituent particles of a rotating system, multiplied by their several masses, remains constant under all conceivable circumstances of re-arrangement or mutual disturbance. Hence, approach towards the centre, because it narrows the circle, must quicken the speed of rotation. A short line having to sweep over the same space as one of greater length, its moving end must proportionately hurry its pace. An engulfment, accordingly, by the embryo sun of one of Roche's 'elliptic trains' would have occasioned an immediate shortening of the period of revolution of both nucleus and atmosphere, an accession of centrifugal force producing sudden instability, and, as a consequence, the separation of an equatorial ring.

By this subtly devised expedient Roche sought to explain away the difficulty connected with the wide intervals between the planets. For they originated, he conceived, not in the regular course of condensation, but through complications arising abruptly and exceptionally. What he called the 'limiting surface' of the nebula might also be described as the atmospheric limit. It corresponds to the widest possible extension of a true atmosphere. Its boundaries are fixed at the distance just outside of which a satellite could freely circulate in the axial period of its primary. Now the limiting surface, if contraction had proceeded equably, should have retreated continuously, as axial movement quickened, its withdrawal being attended by the shedding of slender rivulets of superfluous matter. But by the introduction of 'elliptic trains,' stability, artificially maintained (so to speak) throughout long spells of time, was overthrown only by catastrophic downrushes from the shoulders of the nebulous spheroid, when, with the prompt abridgment of the axial period, the limiting surface as promptly shrank inward, and there was left, outstanding and self-subsistent, the tenuous ring destined to coalesce into a planet. A singular and unexplained felicity of Roche's analysis consisted in the symmetry of time-relations established by it. The successive births of his planets followed each other at equal intervals. A species of translation of Bode's law of distances (extended by him to satellite-systems) in terms of the nebular hypothesis thus appeared to be rendered feasible.*

That hypothesis, in its original form, as explained in the last chapter, produced planets with retrograde rotation—that is, spinning in an opposite sense to that of their circulation. For the purpose of abolishing the anomaly, Kirkwood, in 1864,† had recourse to solar tidal friction, and he was followed, doubtless independently, by Roche, and by Roche's interpreter, C. Wolf of Paris. Objections to any particular mode of planetary formation, on the ground that its outcome must have been inverted axial movement, lost their validity,

* C. Wolf, *Bulletin Astronomique*, tom. i., p. 596.
† *American Journal of Science*, vol. xxxviii., p. 3.

they remarked, through the consideration that solar tidal friction would have availed to redress the incongruity. For its retarding action would have ceased only when synchronism with the revolutionary period was attained—that is, when the planet wheeled in its orbit, as Mercury seems to do, turning always the same face inward; and then already direct rotation would have set in, and, becoming accelerated by contraction, should permanently retain the direction impressed upon it by the friction of sun-raised tides. A certain air of plausibility is given to this view by the fact that the only two retrograde planetary systems are situated entirely beyond the possible range of any such manner of influence, and may accordingly be supposed to have preserved unaltered their primitive fashion of gyration.

The late M. Faye was less loyal to tradition than the savant of Montpellier. The appearance in 1884 of his work, *Sur l'Origine du Monde*, gave the signal for renewed activity and a larger license in cosmological speculation. Conservative opinions on the subject are now rarely held; the old groove has been by most definitively quitted; inquiry becomes continually more individual and less constrained by tradition. Faye's reform, however, was not avowedly of a revolutionary character. He did not make a clean sweep of the work of his great predecessor, by way of preliminary to setting forth his own more perfect plan. Yet his emendations of it went very deep.

Laplace's nebula was of a gaseous consistence, and it stood in a genuine atmospheric relation to the central condensation—that is to say, its strata gravitated one upon the other; they were subject to hydrostatic pressure. Faye ruled things otherwise. The nebulous matrix which he postulated was a vast congeries of independently moving particles, forming a system governed by a single period, in which both gravity and velocity increased in the direct ratio of the distance from the centre. Now, globes formed by the method of annulation (admitting its practicability) out of materials thus conditioned, should have possessed, *ab initio*, a direct rotation; their axial spinning would have been in the same sense as their orbital circulation. And this it was which recommended to Faye the adoption of a meteoric structure for the inchoate solar system. But the simple law of force regulating it at first would, by degrees, have undergone essential alteration. That of inverse squares, familiarized to ourselves by long habits of thought, would have begun to supersede it so soon as a sun, properly so called, could be said to exist. The retrograde planets, Uranus and Neptune, must, however, by Faye's supposition have taken shape under the modern regimen; they were formed subsequently to the earth and all the rest of her sister orbs. This unexpected inversion of the recognised order of planetary age involved the further consequence that the ante-natal offspring of the sun—thus paradoxically to designate them—must have drawn closer to him as his attractive power developed, Uranus and Neptune alone among the entire cortège preserving the original span of their orbits.

Faye's scheme, if it did not meet all the arduous requirements of the problem it confronted, served, at any rate, to illustrate very forcibly the devious variety of tracks by which nebular evolution might advance towards its goal. The particular one chosen was certainly not clear of impediments. In his preoccupation with the removal from Laplace's hypothesis of the flaw relating to planetary rotation, M. Faye had discarded its cardinal merit of explaining secessions of material by the growth of centrifugal force. He alleged no sufficient reason, and none could be alleged why the remodelled nebula should have separated into rings.* The process implies definite and special conditions; it testifies to a rhythmically acting cause. Laplace brought such a cause into play. Faye abolished it, and his annuli, accordingly, wear a fictitious aspect. It is, indeed, true that an annular structure is commonly visible in nebulæ, but it is begging a most arduous question to assume that nebular spires have anything in common with planet-forming rings.

These would probably never have been heard of save for the Saturnian example. A pattern is easily copied; an idea palpably feasible is tempting to adopt; a demonstration on the *solvitur ambulando* principle cannot but prove convincing. But how if the rings

* G. H. Darwin, *Nature*, vol. xxxi., p. 506.

cannot be made to coalesce into globes? And the difficulty of the transformation becomes more apparent the more clearly its details are sought to be realized. Reversed in direction, it might better find a place in the order of Nature. 'Analysis seems to indicate,' Kirkwood wrote in 1884,* 'that planets and comets have not been formed from rings, but rings from planets and comets.' Nor is this mode of procedure merely possible according to theory; it is also vividly illustrated by facts. Meteoric swarms can be observed, decade by decade, to disperse under the scattering influence of the sun and planets, and unmistakably tend to become more or less uniformly distributed along the entire round of their orbits. Their advance is directed, not towards condensation, but towards disaggregation; and they pursue it with surprising rapidity.

Faye's theory was disfigured by a still more glaring incongruity. Nothing in the planetary economy seems more evident than that the zone of asteroids marks a division

* *Proceedings of the American Philosophical Society*, vol. xxii., p. 109.

between two strongly dissimilar states of the solar nebula. It is a visible halting-place. One series of events came to an end, and there was an interlude before the next began. During that interlude, during the partial suspension of activity which ensued upon the production of the Ajax among the planets, the crowd of planetoids were launched to fill the blank space. Here, if anywhere, Nature changed her hand and tried a fresh method. Faye's shifting of the scene of change to trans-Saturnian regions is then, as M. Wolf justly perceived, non-natural, and undermines the credit of a plan to which the device is essential.

On the other hand, it had the merit of being elastic enough to include the great cometary family. Kant had also, although in an unsatisfactory manner, made room for them; but Laplace had no choice save to regard them as casual intruders from space, the admission of which as natives of his well-ordered domain would have led to the subversion of all its harmonious regulations. Modern inquiries, however, prove comets decisively to be no such stray visitors as Laplace supposed, but to be of the same lineage—however remotely traceable—with the planets, and to own the same allegiance. Drifting with the sun, they form part of its escort on the long, irrevocable voyage it is engaged upon, and cannot, save by accidents of perturbation, be driven finally to part from its company. The problems of planetary and cometary origin are then inseparable; the two classes of body are fellow-citizens of one kingdom. Comets become only by compulsion cosmopolitan wanderers from star to star.

There was yet another motive and semblance of justification for Faye's reform of the nebular hypothesis. The discovery of the conservation of energy supplemented, as we have seen, very happily the mechanics of a condensing nebula by satisfactorily solving the enigma of solar radiation. Helmholtz was thus able, in 1871, to sketch cosmic development as, in its essence, a thermodynamic process on the grandest scale. Yet the alliance entered into, fruitful and fortifying though it was, had an attendant embarrassment. Time had now to be reckoned with. In the cosmogonies of Kant, Herschel, and Laplace the allowance of æons was unstinted. Because the rate of change was indeterminate, they might be permitted to elapse *ad libitum*. But it was otherwise when the driving-power came to be defined. 'Conservation of force' implies the measurableness of force. Equivalence cannot be ascertained where no limits are determinable. Knowledge, accordingly, regarding the source of the sun's heat brought with it the certainty that the source was by no means inexhaustible. The stock of energy rendered available by shrinkage from a primitively diffuse to its present compact state was enormous, but not boundless. The task then became incumbent upon cosmogonists of proving its sufficiency, or of eking out its shortcomings.

The problem is both retrospective and prospective. We look back towards the birth of the sun, we look forward to its demise; and each event has, if possible, to be located on our time-scale. Helmholtz assigned terms of twenty-two millions of years in the past and seventeen millions in the future for the shining of our luminary with its actual intensity. Geologists and biologists, however, claimed a much more extended leisure for the succession of phenomena on this globe, and efforts on the part of physicists to meet their demands barely availed to tone down without removing the discrepancy. M. Faye then came to the rescue. His suggestion that the earth took separate form while the sun was still nebulous was designed to conciliate the demands of those who needed all but eternity for the slow accumulation into specific differences of infinitesimal variations. In this way a start was gained upon the sun; the preparations for vitality on our planet were going forward long before the lavish radiative expenditure designed to nurture its development had begun. The earth, in fact, was shaping itself for its destiny in advance of the epoch when time began to count for the sun.

This supposed relation of precedence cannot, indeed, be insisted upon; it was imagined to save a difficult situation, and intimates a design more or less academic. Yet the expedient was significant as regards the effect of the introduction into modern thought of the principle of the conservation of energy. It gave definiteness and a kind of solidity to speculation by widening the basis upon which it was made to rest. At the same time it necessitated adjustments between the exigencies of the various sciences, and brought into prominent view apparent incompatibilities only to be removed by prolonged investigations of wide scope and intricate bearings. Modern cosmogony, in short, while disposing of enlarged means, has to meet multiplied requirements. Quite lately, nevertheless, some authoritative exponents of geological and biological science manifest a satisfactory disposition to 'hurry up their phenomena,' quite independently of the inadequate age of the sun.* On neither side, accordingly, are the irreconcilable claims of the past any longer insisted upon, and a compromise has become easily possible.

A theory of planetary evolution marked by some novel features was ably expounded by M. du Ligondès in 1897.† Designed to improve, by simplifying, Faye's plan, it reduced

* De Vries, *Die Mutationstheorie*, Bd. II., p. 714.

† *Formation Mécanique du Système du Monde.* See also *Le Problème Solaire*, by the Abbé Th. Moreux, p. 63 *et seq.*

postulates to a minimum, and left the freest possible play to 'original indetermination.'* The embryo world of M. du Ligondès was a tumultuous mêlée of particles moving anyhow. Their jostlings, however, did not, and could not, exactly balance, and the inequality, small though it might be, sufficed to afford a basis for harmonious growth. Motion became regularized by collisions; counter-currents of velocity were gradually eliminated; and the particles pursuing eccentric or retrograde courses, brought sooner or later to a stand, fell towards the centre and accumulated into the sun, while the remnant that travelled in the prevalent direction along circular paths finally constituted the planets. They were formed, not at haphazard, but through the medium of zones of maximum density, due to the variations of gravity within the disc towards which the primitive spheroid finally collapsed; and each, as it took shape, became a source of perturbative influence on its subsequently developed neighbours, by which the inclinations of their orbital planes and of their axes of rotation were in various ways altered. The

* *Revue des Questions Scientifiques*, January, 1904.

planetary zones, too, contracted with the advance of condensation, so that the matured planets occupied positions much nearer to the sun than those assigned to their inchoate materials. The *modus operandi* employed, in short, adapted itself with praiseworthy readiness to the diversities of nature.

Sir Robert Ball is at one with M. du Ligondès in regarding the origin of the solar system chiefly under its mechanical aspect. Like Helmholtz and Faye, he chooses pulverulent materials to work with; his nebula is a 'white nebula.' But looking still further back, he discerns as its parent an irregular 'green' nebula, the confused movements of which falling into a settled order as the result of encounters, it slowly flattened down into the 'plane of maximum areas'—the fundamental plane conformed to more and more closely as the energy of a system inevitably wastes. He dispenses with the troublesome process of annulation, and starts his planets virtually by Kant's method of accidental nuclear condensation.* A spiral structure, moreover, would be imparted to the entire nebula by the gradual

* *The Earth's Beginnings*, p. 247.

propagation outward of the central acceleration due to contraction.

But would it have contracted? It had, by supposition, reached the stage of approximate unanimity in movement. The great bulk of its constituent bodies circulated in the same direction, in nearly the same plane, and presumably in orbits not deviating much from circularity. Their aggregate condition might then be regarded as permanent and stable. The central mass would, accordingly, no longer be fed by the engulfment of particles brought to rest by their mutual impacts; motion being unimpeded, heat could not be evolved; and the imagined transformation of a disc-like meteoric formation into a sun and planets would fail to come to pass.

What, then, we may ask ourselves, is the upshot of these various efforts at reconstruction? They establish, certainly, the unassailable unity of the solar world; and the solar world must be understood to embrace comets and cometary meteors. The arguments favouring this unity have gained enormously in cogency through modern discoveries. For those depending upon structural coincidences and harmonies of movement have been reinforced by others of a totally different nature, furnished by the doctrine of the conservation of energy and the teachings of spectrum analysis. The sun is hot because it was anciently expanded; the energy of position formerly belonging to its particles incontestably provided a large part, if not the sum total, of its present thermal energy, and this amounts to saying that a sphere indefinitely great was once filled by our inchoate system. The conclusion that it arose from an undivided whole through the gradual differentiation of its parts is further ratified by the identity of solar and terrestrial chemistry. The earth is thus strongly averred to have once made an integral part of the substance of the sun, and what is true of the earth is no less true of its sister planets.

Regarding the mode and manner of cosmic change there is, nevertheless, no consensus of opinion. Faye made a noteworthy effort to elaborate a process that might endure modern tests of feasibility, yet his theory has been well-nigh torn to pieces by adverse criticism. M. du Ligondès escapes some, but not all, of the objections which proved fatal to his predecessor. That there was in the beginning a solar nebula, all are agreed; but whether it was gaseous or pulverulent, whether it shone with interrupted or continuous light, how it became ordered and organized, how it collected into spheres, leaving wide interspaces clear, the wisest are perplexed to decide.

Mr. Moulton concludes, from his careful examination of the subject, that 'the solar nebula was heterogeneous to a degree not heretofore considered as being probable, and that it may have been in a state' resembling that exhibited in recent photographs of spiral nebulæ.* But, even if all the facts do not chime in with this tempting analogy, there can be little reason to dissent from his intimated opinion that 'the Laplacian hypothesis is only partially true, and that we do not yet know the precise mode of the development of the solar system.'

* *Astrophysical Journal*, vol. xi., p. 130.

CHAPTER V

TIDAL FRICTION AS AN AGENT IN COSMOGONY

The effects of tidal friction are of almost infinite complexity. How it will act in each particular case cannot be predicted offhand; it is a matter for detailed inquiry. Mutually countervailing influences have to be taken into account, nor is the balance easy to strike. The manner of its inclination may, indeed, often depend upon qualities and relations of the bodies concerned which lie outside the range of what can be distinctly ascertained. All that may be hoped for, then, is to arrive at estimates neither misleading by their ostensible precision, nor yet so vague as to be wholly uninstructive, of the part played by tidal forces in moulding the history of connected globes.

The assumption that they attract one another as if the mass of each were collected at its centre, is one of those convenient fictions without which the advancing feet of science would be impeded by tangled thickets of illusory refinements and superfluous elaborations. The fiction would correspond with fact only if the globes were truly spherical, and they could be truly spherical only if they were ideally rigid. Cosmic bodies, however—suns and planets alike—are actually plastic spheroids; they can, to be sure, be treated without sensible error as attractive points when their distances are very great relatively to their diameters ; but upon a closer approach inequality of action supervenes. The component parts of the gravitating masses respond, each individually, and in a measure independently, to the graduated pulls exercised upon them, and tidal strains begin variously to take effect.

Their historical significance was in part divined by Kant. His penetration of so recondite a secret is truly astonishing. A struggling young pedagogue in a remote Prussian province, profoundly learned, though no more than half skilled in technical acquirements, saw by intuition what escaped the acumen of all the great geometers of the eighteenth century—namely, that the moon turns one perpetual face towards the earth, because its primitive rotation was stopped by the friction of earth-raised tides. He perceived besides that a reciprocal action of the same kind must affect the earth, and will continue to affect it until the day coincides in length with the month. Nor did he fail to point out that, in a molten state of the globes, the process would advance with comparative rapidity. To one solitary thinker, then, it became apparent, already in 1754,* that oceanic tides are, in cosmogony, of negligible importance compared with bodily tides.

There is no substance in nature that will not change its shape through prolonged stress, and the more readily the nearer it approaches to the fluid condition. The heaping-up of the waters on the earth's surface at the bidding of the moon is thus a differential effect. Continents heave and subside as well as oceans, though not nearly to the same extent. The measurable rise of water serves to gauge the relative mobilities of the solid globe and of its liquid envelope. If the former did not yield

* *Sämmtliche Werke*, Bd. VI., pp. 5-12, 1839.

at all to the pull so readily obeyed by the latter, the tides would, in fact, be greater than they actually are in the proportion of about three to two, the ratio indicating for the earth an effective rigidity at least equal to that of steel.* Were there no discrepancy in rigidity between the various parts of our terraqueous world, tides would fail to be perceptible. The ocean and the bed of the ocean would rise and fall together, and to the same extent. In the far past there *was* no discrepancy. The viscous earth took, as a whole, the form momentarily impressed upon it by the unequal attractions of the sun and moon on its variously distant sections, with the upshot of bringing the year, month, and day into relations so familiar as to appear inevitable.

Tidal friction does not merely act as a check upon rotational speed. One element of motion in a system cannot be altered without some counter-change in the others. They are coupled up together like a train of geared wheels. From the principle of the conservation of moment of momentum, we know with

* G. H. Darwin, *Encyclopædia Britannica*, article on 'Tides.'

certainty that a loss in one direction must be compensated by a gain in some other. Tidal friction had, then, reactive consequences. They were first adverted to by Julius Robert Mayer in 1848,* and were brought prominently into view in the series of investigations begun by Professor Darwin in 1879. The rotational momentum removed from the earth by the drag of a circulating wave of deformation must assuredly have reappeared in some other part of the system. It was restored, all but the percentage wasted as heat, by the widening of the lunar orbit.† Concomitantly with the slackening of the earth's axial rate, the moon retreated from its surface, pulled forward by the tidal crest continually in advance of its position. This redressed the balance by augmenting orbital momentum, while at the same time diminishing the moon's linear velocity. The importance of this secondary frictional effect in the history of the earth-moon system was the virtual discovery of Professor Darwin.

That system occupies a critical situation in

* *Dynamik des Himmels*, p. 49.

† Darwin, *Philosophical Transactions*, vol. clxxii., p. 528.

the solar cortège. The planets interior to it have no satellites; the planets exterior to it (Neptune making probably only an apparent exception to the rule) have two or more. The earth alone is truly binary; and the moon is not only its solitary companion, but it is by far the largest companion-body, relatively to the mass of its primary, to be found within the precincts of the solar domain. These circumstances are certainly not disconnected one from the other, and they obviously depend upon a single cause. Solar tidal friction was here the determining factor. The apportionment of satellites to the various planets was, beyond doubt, in great measure prescribed by the degrees of retarding power exerted on their axial movement through the agency of sun-raised tides in their still plastic bodies. Hence, the disruptive rate of spinning needed for the separation of satellites was never attained by either Mercury or Venus; they remained moonless for all time, and exposed, through the cutting down of their rotational velocity, to uncompensated extremes of temperature. How the earth was to fare in both respects long hung in the balance. Rightly to forecast its destiny would, indeed, have demanded no common perspicuity in an intelligent onlooker from some other sphere. Although the solar brake acted upon terrestrial rotation with no more than one-eleventh the power brought to bear upon that of Venus, it nevertheless sufficed during uncounted ages to hinder acceleration from reaching the pitch involving instability.

Our embryonic planet had long ceased to be nebulous, and had, in fact, shrunk by cooling nearly to its present dimensions before the die was cast. Then, at last, the hurrying effects of contraction prevailed over the slowing down due to tidal resistance, axial speed overbore equilibrium, and the spheroid divided. Now globes thus far advanced in condensation are apt to split less unequally than globes in a more primitive stage; and the moon, because late-born, was of large size. Its mass is $\frac{1}{81}$ that of the earth; the masses of Titan and Saturn are as 1 to 4,600; while Jupiter's third and greatest satellite contains only $\frac{1}{11300}$ part of the matter englobed in the parent-body. Moreover, Professor Darwin has made it clear that the satellites of Jupiter and Saturn revolve now in orbits not widely remote from those at first pursued by them; while the moon, on the contrary, started on its career almost, if not quite, from grazing contact with its primary. Owing to these two exceptional circumstances—its considerable relative mass and its close initial vicinity—the moon wielded over the earth tidal influence incomparably more powerful than that exerted by any of its compeers in the sun's realm.

The lunar-terrestrial system offers, accordingly, an example unique among those in solar subordination of a pair of globes, the mechanical relations of which have been settled on their present basis by the predominating agency of bodily tides. It holds forth, too, the one case in which origin by fission was possible. Professor Darwin's communication to the Royal Society in 1879 occasioned on this point a remarkable diversion of ideas. Saturn's rings were at last, through the reasonings contained in it, perceived to be illustrative of only one among many feasible modes of cosmic growth. It became clear that a single cut-and-dried method would not answer all the infinitely varied purposes of creative design. Annulation might have served its turn, but there were alternatives. A fresh standpoint was virtually attained, and the wide prospect commanded by it begins already to spread out invitingly before the gaze of investigators.

But whether the moon emerged from the earth as a protuberance, or was abandoned by it as an irregular equatorial ring, it was revolving, when our theoretical acquaintance with it begins, in a period of not less than two and not more than four hours, quite close to the earth's surface ; while the nearly isochronous rotation of the earth was conducted with all but disruptive rapidity. The situation is so suggestive that it needs only a short and tolerably safe leap in the dark to reach the conclusion that the two masses had very recently been one. With their division, at an epoch estimated to have been about sixty million years ago, the process began by which the moon was pushed back along a widening spiral course to its present position, the vanished rotational momentum of the earth cropping up again in the augmented orbital momentum of the moon. And the transformation is, at least in theory, still going on.

Tidal friction has further capabilities. The transference of momentum from one part of a system to another is only the most obvious among the crowd of its results. Scarcely an element of movement escapes its influence. It increases, as a rule, orbital eccentricity. The smallest initial deviation from circularity develops, through the inequality of accelerative action thence ensuing, into pronounced ovalness. That of the moon's path can in this way be accounted for. Moreover, its plane was, in all probability, shifted simultaneously and under compulsion of the same power, from its original coincidence with the earth's equatorial plane to the level it now occupies. The obliquity of the ecliptic, too, is partially explicable on the same principle. 'The present motion of the two bodies' (to quote Professor Darwin's words), are 'completely co-ordinated by the theory that tidal friction was the ruling power in their evolution.' Holding this clue, we are enabled to trace them back to the start of their dual existence, and to follow the insensible modifications by which their state was moulded to its actual form.

In no other satellite-system is this possible. No moon besides our own possesses a stock of orbital momentum large enough to intimate for it an analogous history. Planetary attendants elsewhere travel nearly in their original tracks; the fluid ripples raised by them on the surfaces of their primaries lacked power to displace them sensibly. Their own rotation, indeed, seems to have been completely destroyed. Destroyed, that is, relatively to the destroying body. There is a certainty that some, there is the strongest likelihood that all, of the Jovian and Saturnian satellites turn unchangingly the same face towards their primaries. They rotate in the period of their several revolutions, just as our moon does, and as a consequence of the same cause. Tidal friction, however, appears to have been otherwise of subordinate importance in shaping their dynamical relations.

The agency will not, then, serve in all cases for a *deus ex machinâ.* It is not indiscriminately efficacious. The modes of its action have, in each of the systems considered, to be delicately distinguished. The stage of development arrived at by the bodies affected, their degree of viscosity, their comparative mass and bulk, their modes of motion, all avail profoundly, and it may be incalculably, to modify the outcome. The facility of error in estimates of the kind is illustrated by Professor Darwin's remark that the magnitude of the tide-raising force is only one factor of the product.* The other is relative movement. Now, in the case of the moon the former continually augmented retrospectively, while the latter fell off. Tidal generative power varies inversely as the cube of the distance; in antique times, then, when the earth and moon revolved contiguously, the bodily distortions they mutually produced were beyond question on an extremely large scale. Yet, because of the near coincidence of the periods of the globes, they must have been almost inoperative for frictional purposes. The travelling of the piled-up matter over their surfaces was too slow to lend it much power as a friction-brake. The insignificant waves raised by the sun were, we are led to believe, because of their

* *Philosophical Transactions*, vol. clxxi., p. 876.

swift relative motion, more influential at that early epoch in checking terrestrial rotation than the colossal, but nearly stationary waves due to the moon.

Numerical calculations, where they are practicable, afford the only safe guide to this intricate field of inquiry. It does not suffice to show that tidal action would have been of the kind required—would have taken the right direction—for bringing about some apparently anomalous result. Proof must, besides, be forthcoming that the action would have been of adequate power. Plausible guesses on the subject may be entirely fallacious. The machine, even if properly constructed for the end in view, may work too feebly for its attainment. We are, for instance, assured that no difficulty connected with the sense of planetary rotation need impede acceptance of the theory of planetary origin from separated rings, since even if the embryo globes gyrated the wrong way at the outset, solar tidal friction would promptly have reduced them to conformity with the general current of movement. This is true in principle, but will it bear quantitative investigation? Many promising hypotheses have broken down under the weight of figures; whether this particular one is strong enough to survive their application remains to be seen. We are, indeed, sure of its validity as regards Mercury, but the efficacy of tidal friction decreases as the sixth power of increasing distance, and the actual rotation of Venus furnishes an enigma sufficiently perplexing to discourage scrutiny of its dimly discerned antecedent conditions. As regards the earth and the exterior planets, the question could only be answered with the help of information which is not forthcoming.

The unexpected circumstance that the newly-discovered ninth Saturnian moon circulates from east to west can thus be no more than tentatively explained by invoking this agency of change. Admitting (as we seem bound to do) that satellites are the offspring of the planets they attend, there is no evading the conclusion that the small body under discussion was thrown off from a primary endowed with a rotation opposite to that now possessed by it. And the reversal must have been completely brought to pass before the eighth satellite, Japetus, came into existence. The crux is most arduous; there is no other resource for meeting it but to consider the effects on planetary rotation of solar tides, and this Professor W. H. Pickering, the discoverer of Phœbe, has done.* But a cause may be true without being sufficient; and close calculation will be needed to determine, in this instance, how the matter stands.

Professor Darwin's researches were fruitful just because they were definite. They demonstrated, once for all, the diverse faculties of tidal friction as a cosmogonic agency, and indicated clearly the departments of cosmogonic change in which its competence lay. They availed, moreover, to determine for the earth-moon system the amount of work actually done by tidal friction in these several departments, and to prove its large excess over the corresponding output in any other sub-system falling within the sphere of observation. This memorable result suggests that our terrestrial home may be singular, not only in its evolutionary history, but in the innumerable adjustments fitting it to be the abode of life.

The relations of the earth and moon

* *Harvard Annals*, vol. liii., p. 58.

adumbrate, and scarcely more than adumbrate, the physical influences mutually exerted upon each other by numerous twin-globes in stellar space. Tidal friction is of maximum power in systems formed of equal masses; and those of double stars are seldom widely disparate. Most, if not all of them, were, besides, primitively very near neighbours, so that their symmetry must have been marred by conspicuous tidal deformations. The results upon their development have been expounded in detail by Dr. See. One of the most remarkable is the high average eccentricity of their orbits. Visual binaries, with few exceptions, travel in considerably elongated ellipses, while spectroscopic binaries as a rule pursue approximately circular paths. Dr. See's argument that the eccentricity of the more spacious systems was acquired under the influence of tidal friction, during the long course of progressive separation, is well-nigh irresistible.

True, this line of explanation is not wholly clear of obstacles and incongruities. Yet they may probably be described as of a complicating, rather than of a contradictory kind. The theory of tidal friction is not a universal solvent of the difficulties encountered in the study of double stars. That the mode of action it deals with had a contributory share towards regulating their mechanical arrangements may, nevertheless, be regarded as certain, while the potency and perhaps even the manner of its operation varied extensively from system to system. What precisely it effected in each lies beyond our range of determination. For the data available regarding the viscosity, density, and axial movements of embryo star-pairs must always be too scanty and insecure to provide a basis for rigorous computations. The mystery of the fore-time can never be entirely dissipated. Enough if we can look at it through a glass which darkens, without distorting, the objects presented in its field of view.

CHAPTER VI

THE FISSION OF ROTATING GLOBES

Few people need to be told that a rotating fluid mass is shaped very much like an orange. It assumes the form of a compressed sphere. And the reason for its compression is obvious. It is that the power of gravity, being partially neutralized by the centrifugal tendency due to axial speed, decreases progressively from the poles, where that speed has a zero value, to the equator, where it attains a maximum. Here, then, the materials of the rotating body are virtually lighter than elsewhere, and consequently retreat furthest from the centre. The 'figure of equilibrium' thus constituted is a spheroid, a body with two unequal axes. In other words, its meridional contour—that passing through the poles—is an ellipse, while its equator is circular.

Now we know familiarly, not only that a spinning sphere becomes a spheroid, but that the spheroid grows more oblate the faster it spins. The flattened disc of Jupiter, for instance, compared with the round face of Mars, at once suggests a disparity in the rate of gyration. But there must be a limit to the advance of bulging, or the spheroid, accelerated *ad infinitum*, would at last cease to exist in three dimensions. Clearly this unthinkable outcome must be anticipated; at some given point the process of deformation must be interrupted. A breach of continuity intervenes; the train is shunted on to a branch line. Nor is it difficult to divine, in a general way, how this comes to pass. Equilibrium, beyond doubt, breaks down when rotation attains a certain critical velocity, varying according to circumstances, and the spheroid either alters fundamentally in shape or goes to pieces.

So much plain common-sense teaches, yet the precise determination of the course of events is one of the most arduous tasks ever grappled with by mathematicians. M. Poincaré essayed it in 1885;* it was independently

* *Acta Mathematica*, vol. vii., Stockholm, 1885.

undertaken a little later by Professor Darwin;* and the subject has now been prosecuted for eighteen years, chiefly by these two eminent men, with a highly interesting alternation of achievement, one picking up the thread dropped by the other, and each in turn penetrating somewhat further into the labyrinth. The results, nevertheless, are still to some extent inconclusive; they indicate, rather than indite, the genetic history of systems. A strong light is, indeed, thrown upon it; but in following its guidance, the limitations of the inquiry have to be borne in mind. The chief of these are, first, that the assumed spheroid is liquid; secondly, that it is homogeneous. Neither of these conditions, however, is really prevalent in nature, so that inferences based upon them can only be accepted under reserve. They were adopted, not by choice, but through the necessities of the case. There was no possibility of dealing mathematically with bodies in any other than the liquid state. The equilibrium of gaseous globes defies treatment,

* *Proceedings Royal Society*, vols. xlii., lxxi.; *Philosophical Transactions*, vols. cxcviii., cxcix., Series A.

except under arbitrary restrictions.* Nor is it possible to cope with the intricacies of calculation introduced by variations of interior density. Cosmical masses, as they actually exist, are nevertheless strongly heterogeneous, so that at the utmost only an approximation to the genuine course of their evolution can be arrived at by the most skilful analysis. Yet even an approximate solution of such a problem is of profound interest. We can here only attempt briefly to specify its nature.

The course of change by which the equilibrium of a rotating liquid spheroid is finally overthrown has, at any rate, been satisfactorily tracked. When its spinning quickens to a disruptive pitch, it acquires three unequal axes instead of two. The equator becomes elliptical like the meridians. A 'Jacobian ellipsoid' is constituted. To this new form, it would seem, a long spell of stability must be attributed; only its major axis becomes more and more protracted as cooling progresses, and with cooling, contraction, and with con-

* J. H. Jeans, *Philosophical Transactions*, vol. cxcix., Series A, p. 1.

traction the increase of axial velocity. Then at last a crisis once more supervenes; there is a collapse of equilibrium, and its re-establishment involves the sacrifice of the last vestige of symmetry. An 'apioid,' or pear-shaped body, replaces the antecedent ellipsoid; and its apparent incipient duality suggested to M. Poincaré that the furrow unequally dividing it might deepen, with still accelerated gyration, into a cleft, splitting the primitively single mass into a planet and satellite. But this eventuality, he was careful to note, had no direct bearing on Laplace's hypothesis, which dealt with a nebula condensed towards the centre, while the fissured apioid was liquid and homogeneous.*

Professor Darwin followed out the conditions of this remarkable pear-shaped body to a closer degree of approximation than its original investigator had done, and succeeded in virtually demonstrating its conditional stability. But his analysis tended to smooth away the characteristic peculiarities of its shape, and, so far, to diminish the probability of its ultimate disruption. Mr. Jeans, on the other hand,

* *Figures d'Équilibre d'une Masse Fluide*, p. 172.

from an elaborate study of a series of cigar-shaped figures which in theory follow a parallel course of development to that pursued by ellipsoids, derived, by strict mathematical reasoning, the actual separation of a satellite from one end of a parent-cylinder. The representative figures reminded Professor Darwin 'of some such phenomenon as the protrusion of a filament of protoplasm from a mass of living matter.' 'In this almost life-like process' he saw 'a counterpart to at least one form of the birth of double stars, planets, and satellites.'*

But the resemblance, when examined dispassionately, seems shadowy and evasive, especially when we confront it with the case of double stars. Here, indeed, an entirely different set of conditions comes into play from that postulated by Poincaré and Darwin, since stars are certainly not liquid bodies.† They are most likely gaseous to the core, though the indefinite diffusiveness incident to gaseity is restricted by their condensed photospheric surfaces. This circumstance intimates the

* *Proceedings Royal Society*, vol. lxxi., p. 183.

† J. H. Jeans, *Astrophysical Journ.*, vol. xxii., p. 93.

possibility that the results arrived at for liquid globes by mathematical analysis may, with qualifications, be extended to stars; but the necessary qualifications, unfortunately, are vague and large; for too little is known regarding the physical condition of stellar spheres to warrant assumptions that might provide a secure basis for research.

The evolution of binary stars can then only be treated of inferentially, not rigorously; and we must, at the outset, discard the idea that it is illustrated by the phenomena of double nebulæ. Many such objects thought to supply clinching visual arguments for the actual effectiveness of slow cosmic fission proved, on the application to them of the late Professor Keeler's searching photographic methods, to be knots on spiral formations. Their mutual relations are then entirely different from what had been supposed by telescopic observers; they are, in fact, still structurally connected, and the mode of their origin, however inviting to conjecture, scarcely comes within the scope of definitely conducted inquiries. Their future destiny is no more accessible to it than their past history, and only by a daring flight of imagination can we see in spiral nebulæ the prototypes of double stars.

Questions as to the mode of genesis of these latter systems have, in recent years, acquired extraordinary interest. Conclusive answers cannot, indeed, at present be given to them, because the terms in which they are couched lack distinctness, owing to our lack of knowledge; but probable answers may legitimately supply their place, at least *ad interim*, above all when their probability is heightened almost to certainty by the accumulation of circumstantial evidence.

Observations and investigations of stellar eclipses have created a new department of astrophysics, and have vastly widened the domain of cosmogony. They have brought to notice a number of systems, not merely in a primitive, but seemingly in an inchoate stage of development. The periods of occulting stars are nearly all of them less than seven days, although one extending to thirty-one has lately been recognised; and the comparative length of the intervals of obscuration shows them to be produced by the circulation in narrow orbits of distended globes. These are characteristic symptoms of juvenility, for, as we have seen, orbits widen and periods lengthen with the efflux of time through the frictional power of bodily tides.

Now the class of stars which obviously and certainly undergo eclipses has some outlying members of a still dubious nature. And their marginal position serves greatly to enhance the present, the prospective, and the retrospective interest attaching to them. These remarkable objects vary in light continuously. Their phases are not, like those of Algol, mere interruptions to a regular course of steady shining. They progress without a moment's sensible pause; they are represented graphically by a smoothly-flowing, symmetrical curve. The eclipses by which they are occasioned—if they are so occasioned—must, accordingly, succeed each other in a strictly unbroken series. No sooner has one terminated than the next commences. One star passes first behind, then in front of its companion, and their combined brightness is seen undimmed only during the few moments of actual maximum. This means that they revolve in contact; they are separated by no sensible gap of space.

Goodricke's variable, β Lyræ, is held to be thus constituted. The possibility, at least, of employing the 'satellite-theory' to account for its changes was demonstrated some years ago by Mr. G. W. Myers, of Indiana.* He found the system to be composed of two barely separated ellipsoids, circulating in the visual plane, and producing, by their successive transits, two unequal eclipses in the course of each period of 12·91 days. The joint mass of the pair is just thirty times that of our sun, but their mean density has the almost incredibly small value of $\frac{1}{1200}$ that of water. Their real existence is conditional upon the possibility that masses much more tenuous than atmospheric air should radiate with the intensity of true suns. Spectroscopic observations are not wholly unfavourable to Mr. Myers's hypothesis, but their interpretation is hampered by discrepancies so numerous and perplexing that no secure inference can be derived from them. Moreover, the star supposed to be alone presented to view at the principal minimum is that giving the bright-line spectrum; yet it is compulsorily assumed, in order

* *Astrophysical Journal,* vol. vii., p. 1.

to meet the exigencies of the situation, to be much more massive, while much less intrinsically bright, than its companion. This is disquieting, but nearly everything connected with β Lyræ *is* more or less disquieting.

A variable of the same type, but much fainter, was made the subject of a similar inquiry by Mr. Myers in 1898.* U Pegasi never attains ninth magnitude; hence, spectroscopic complications equally with spectroscopic verification remain at present out of sight. The star, nevertheless, excites keen interest, and claims sustained attention. Its light-curve has been laid down with exquisite accuracy at Harvard College, and shows two slightly unequal minima to be comprised within a period of nine hours, signifying, on the adopted theory, the occurrence of alternating eclipses at intervals of four and a half hours. The distance from centre to centre of the occulting stars, the smaller of which is of about eight-tenths the brightness of the larger, 'does not materially differ,' Mr. Myers tells us, 'from the sum of their radii, suggesting the probable existence of the "apioidal" form of Poincaré.' If they do not actually

* *Astrophysical Journal*, vol. viii., p. 163.

coalesce, the component bodies revolve in contact, and rotate synchronously. Thus, it is hard to say whether U Pegasi should be accounted as a single pear-shaped mass spinning in the time of light-change, or as a close couple circulating freely in that identical period. The mean density of the system appears to lie between one-third and one-fourth that of the sun.

Another specimen of the 'dumb-bell' system is possibly met with in R^2 Centauri. The narrow range of its variation makes it a delicate object to observe; but Mr. A. W. Roberts, who first noticed its peculiarity in 1896, has since accumulated an extensive series of wonderfully accurate visual determinations of its fluctuating brightness, and has besides rendered them the basis of an able and exhaustive theoretical discussion.* The double period of R^2 Centauri is restricted to fourteen hours thirty-two minutes. Within this brief span quadruple phases are included—that is to say, two evenly balanced maxima and two slightly disparate minima. These result, Mr. Roberts concludes, from the mutual eclipses of interpenetrating ellipsoids,

* *Monthly Notices*, vol. lxiii., p. 627.

one somewhat more luminous than the other, revolving—if they can properly be said to revolve—in an orbit inclined 32° to the visual plane. They are of just one-third the solar density, and the forms satisfying photometric requirements by the varying areas of luminous surface presented to sight in different sections of their path show a surprising agreement with the bi-prolate figure given by Professor Darwin's analysis as the shape of a body on the verge of disruption through accelerated rotatory movement. The inference is, then, almost irresistible that R^2 Centauri really exemplifies the nascent stage of binary stars. To establish this completely, however, spectroscopic data are needed; and they are difficult to procure for a star below the seventh magnitude.

No such obstacle impedes the investigation of the analogous, but much brighter object, V Puppis. Detected as a spectroscopic binary by Professor Pickering in 1895, this star traverses so wide an orbit in the short period of thirty-five hours as to imply—if the published details are correct—that the pair possess no less than 348 times the gravitational power of the sun. They are, nevertheless, according to Mr. Roberts, fifty times more tenuous, and each globe should have a diameter of about 16½ million miles; yet nothing of all this is incredible. The light-curve of V Puppis, as traced by Mr. Roberts, is closely modelled upon that of U Pegasi. And he postulates similar conditions of eclipse. It rests with the spectroscope to determine whether those conditions are realized or not.

Probably all short-period variables are binaries, with coincident orbital- and light-cycles. But all are not occulting binaries. There are some—we are still ignorant of their proportionate numbers—which undergo a course of light-change, apparently compatible with an occulting hypothesis, yet certainly escape eclipse. Professor Campbell has made it unmistakably clear that ζ Geminorum is thus constituted.* Two stars are present, but their plane of motion is inclined at an unknown angle to the line of sight; it does not approximate to coincidence with it. Now the possibility

* *Astrophysical Journal*, vol. xiii., p. 90; *Science*, July 27, 1900.

is not excluded that V Puppis belongs to the same class. Mr. Roberts's assumptions are, indeed, in themselves plausible, and they may at any moment be proved, by a few well-timed spectrograms, to be undeniably true.

The one conclusive test of their truth is the cessation of radial movement at epochs of minimum. Evidently, if the diminution in lustre be due to an eclipse, the eclipsing and eclipsed bodies must be crossing the line of sight just when the obscuration is deepest. There is no evading this geometrical requirement, and it must be rigorously complied with in the circular orbits traversed by bodies revolving in contact. Before, then, Mr. Roberts's theory of V Puppis can be accepted with implicit confidence, it has to be ascertained whether a zero of radial speed is reached concurrently with the photometric minima. If so, these may be unhesitatingly set down as eclipse-phenomena; if, on the contrary, the decline in brightness prove to be unrelated to a slackening of speed, then the supposition that it accompanies and indicates a transit must be peremptorily discarded. Moreover, the spectroscopic verdict as regards V Puppis can safely be applied to stars with similar light-curves, especially to R^2 Centauri and U Pegasi, and may serve to clear away some of the intricacies connected with the exceptional system of β Lyræ. The measurement of a single spectrographic plate might thus, by deciding the test-case of the binary in the poop of Argo, be made essentially to supply the lack of desirable, but at present unattainable determinations as regards a considerable number of analogous objects.

The existence of stellar systems of the 'dumb-bell' type would violate no mechanical law. 'Roche's limit' does not apply to globes comparable in size. The range of disparity within which it holds good has not, indeed, been theoretically established; but it may be said, in general terms, to concern the relations of planets and satellites (to use a purposely vague phrase), not those of double stars. What the law asserts is that a subordinate small body cannot revolve intact at a less distance than 2·44 radii of its primary from that primary's centre, if their mean density be the same. For satellites of slighter consistence the limit should be extended. Our own moon, for instance, could never have circulated, without being rent in pieces by tidal strains, in an orbit less than 22,000 miles in diameter.*

Bodies of co-ordinate mass are, however, exempted from the prohibitive rule against mutual approach. No analytical veto is imposed upon the origin by fission of double stars, or upon the subsistence of stellar Siamese twins. The inequalities of their mutual attractions avail to distort, not to disrupt, such embryo globes. Their individuality, therefore, once created, is in a manner indestructible. It tends, in fact, to become more pronounced as the orbital span gradually widens through the reactive effects of tidal friction. The 'dumb-bell' condition may then be regarded as in a manner transitory. Nor can we be assured of its actuality otherwise than by the peculiar nature of the eclipses attending upon it, taken in connection with correlated spectroscopic observations proving eclipses of the kind veritably to take place. The disclosure, by such means, of systems so strangely

* G. H. Darwin, *The Tides*, p. 327.

conditioned promises to afford a deeper insight than would else have been possible into the cosmical order, and fills a blank page in the marvellous history of sidereal birth and growth.

CHAPTER VII

WORLD BUILDING OUT OF METEORITES

The idea is seductive that we see in every meteoric fire-streak a remnant of the process by which our world, and other worlds like or unlike it, were formed. It is not a new idea. Chladni entertained it in 1794; and it has since from time to time been revived and rehabilitated with the aid of improved theoretical knowledge and a larger array of facts. Survivals are tempting to thought. It costs less effort to realize differences in degree than differences of kind. The enhanced activity of familiar operations is readily imagined, while perplexity is apt to shroud the results of modes of working strange to experience. Hence the presumption in favour of continuity; nor can it be said, even apart from our own mental inadequacy, that the presumption is other than legitimate. Nature is chary of her plans, lavish of her materials. Her aims are characterized by a majestic unity, but she takes little account (that we can see) of surplusage or wreckage. Now, it seems likely that meteorites represent one or the other of these two forms of waste stuff. They are analogous, apparently, either to the chips from shaped blocks, or to the dust and rubbish of their destruction. Let us consider what it is that we really know about them.

It cannot be said that the sources of our information are scanty. Fully one hundred millions are daily appropriated by the earth as she peacefully spins through the ether. Their absorption leaves her unaffected. It produces no perceptible change in her internal economy, and makes no sensible addition to her mass. The hundred millions of small bodies taken up have, nevertheless, in Professor Langley's opinion, an aggregate weight of more than one hundred tons.* And this increment is always going on. Yet its accumulated effect is evanescent by comparison with the enormous mass of our globe. That it was more considerable

* *The New Astronomy*, p. 197.

in past ages than it is at present might be plausibly conjectured, but cannot reasonably be maintained. Geological deposits contain—unless by some rare exception—no recognisable meteoric ingredients. There is nothing to show that the earth was subject to a heavier bombardment from space during the Silurian era than in the twentieth century. Nor could the whole of its constituents have been, in any case, thus provided. Out of kiln-dried fragments, like the Mazapil iron or the 'thunder-stones' of Adare, a terraqueous planet could not have been formed. This objection, urged by Mr. O. Fisher,* is seemingly irrefutable.

Meteorites signify their existence to us, in general, only by the bale-fires of their ruin; but in a few cases their tangible relics come to hand. Those substantial enough to escape total disintegration through atmospheric resistance to their swift movements plunge into the sea or bury themselves in the earth, and in a certain proportion of cases find their way to museums and laboratories, where they are subjected to the searching investigation

* *American Journal of Science,* vol. xi., p. 421, June, 1901.

demanded by their exotic origin. Its results are scarcely what might have been expected. Aerolites—as these samples from space are distinctively called—are not chemically peculiar; they consist exclusively of the same elementary substances composing the crust of the earth; but their mineralogy is strongly characteristic. They are extremely complex structures, formed apparently in the absence of water, and with a short supply of oxygen; the further condition of powerful pressure is indicated with some probability, nay, with virtual certainty for those including small diamonds,* while prolonged vicissitudes of fracture and re-agglomeration are possibly recorded by the brecciated texture of many of these rocky *trouvailles.* Their aspect is thus anything but primitive; each fragment tacitly lays claim to an eventful history; they suggest a cataclysm, of which

* Carbon does not liquefy under ordinary conditions. In the production of his artificial diamonds M. Moissan employed tremendous pressure and great heat; and, although the genuineness of his products has been denied (Combes, *Moniteur Scientifique*, November, 1903), his methods at least seem to have approximated to those by which Nature fabricates her most authentic crystals.

we behold in them the shattered outcome. The nature of such cataclysms is scarcely open to conjecture ; only a hint regarding it may be gathered from the circumstance that the most profound terrestrial formations are those which approximate most closely to the mineralogical peculiarities of meteorites.

Nevertheless, the only ascertained relationships of meteorites are with comets. In every system of shooting stars the primary body most probably is, or at any rate was, a comet. Each appears to be the offspring of a cometary parent, and develops *pari passu* with its decay. The view has hence been adopted, and not without justification, that comets in their primitive integrity are simply 'meteor-swarms.' Assent may be given to it with some qualifications which we need not here stop to discuss. What immediately concerns us is the interesting question as to the constitution of meteor-swarms. What is the real meaning of the term ? What does it convey to our minds ? A meteor-swarm may be defined as a rudely globular aggregation of small cosmical masses, revolving under the influence of their mutual attraction, round their common centre of gravity. Each must revolve on its own account, though all have the same period; and their orbits may be inclined at all possible angles to a given plane, and may be traversed indifferently in either direction. From this tumultuous mode of circulation collisions should frequently ensue, but they would be of a mild character. They could not be otherwise in a system of insignificant mass and correspondingly sluggish motion. We are considering, it must be remembered, only cometary swarms, as being the only collections of the sort that come, even remotely, within our ken; and comets include the minimum of matter. This we are entitled to infer from the fact that none of those hitherto observed, whether conspicuous or obscure, newly arrived from space, or obviously effete, have occasioned the slightest gravitational disturbance to any member of our system.

A cometary swarm, if left to itself, might eventually shape itself into a reduced model of the 'Saturn' planetary nebula. Colliding particles should, owing to their loss of velocity, subside towards the centre, and accrete into a globular mass. A predominant current of movement would, through their elimination, gain more and more completely the upper hand; and it would finally, with the inevitable diminution of energy,* be restricted almost wholly to the principal plane of a system, composed essentially of a rotating nucleus encompassed by a wide zone of independently circulating meteorites. But this mode of evolution is not even distantly followed by comets. It would be possible only if they were isolated in space, and, in point of fact, their revolutions round the sun are of overwhelming importance to their destinies. The sun's repulsive energy causes them to waste and diffuse with expansion of splendid plumage. Under the sun's unequal attraction at close quarters they are subject to disruption, and the upshot of the tidal stresses acting upon them is the dispersal of their constituent particles along the wide ambit of their oval tracks.

We are, nevertheless, invited to look further afield. Cometary meteor-swarms may be only miniature specimens of the contents of space. Why should not remote sidereal regions be thronged with similar assemblages, colossal

* Sir R. Ball, *The Earth's Beginnings*, p. 243.

in their proportions, countless in number? And may they not supply the long-sought desideratum of a suitable 'world-stuff' for the construction of suns and planets? From some such initial considerations as these Sir Norman Lockyer developed, in 1887, a universal meteoritic hypothesis, designed on the widest possible lines, based on promising evidence, and professing to supply a key to the baffling enigma of cosmical growth and diversification. The meteoric affinities of comets formed its starting-point; comets were assimilated to nebulæ; and from nebulæ were derived, by gradual processes of change, all the species of suns accessible to observation. The view was of far-reaching import and magnificent generality, but its value avowedly rested on a body of facts of a special kind. In this it differed from the crowd of ambitious speculations regarding the origin of things by which it had been preceded. In this it attained an immeasurable superiority over them, if only the testimony appealed to could be established as valid. Indeed, it is scarcely too much to say that, whether it were valid or not, the mere circumstance of having called the spectroscope as a witness in the high court of cosmogony constituted an innovation both meritorious and significant.

The spectrum of the nebulæ was a standing puzzle. A theory which set out by making its meaning plain secured at once a privileged position. This was seemingly accomplished by Sir Norman Lockyer through the means of some simple laboratory experiments on the spectra of meteorites. Certain 'low temperature' lines of magnesium given out by the vapours of stony aerolitic fragments were shown to fall suspiciously close to the chief nebular lines previously classed as 'unknown.' The coincidences, it is true, were determined with low dispersion, and were published for what they were worth, but they looked hopeful. Their substantiation, had it been feasible, would have marked the beginning of a new stadium of progress. Nature, however, proved recalcitrant. The suggested agreements avowed themselves, on closer inquiry, as approximate only; magnesium light makes no part of the nebular glow, and nebulium, its main source, evades terrestrial recognition. The light of cosmic clouds is *sui generis*—it includes no metallic emissions; while the fundamental constituents of meteorites are metals variously assorted and combined.

The decipherment of the nebular hieroglyphics was the crucial test; its failure to meet it left the hypothesis seriously discredited; for coincidences between spectral rays, common to nearly all the heavenly bodies, naturally counted for nothing. Yet the investigation had its uses. The energy with which it was prosecuted, the ingenuity and resource with which it was directed, told for progress. There has been a clash of arms and a reorganization of forces. Thought was stirred, observation and experiment received a strong stimulus, fresh affluents to the great stream of science began to be navigated. Efforts to prove what had been asserted were fruitful in some directions, and the work of refutation had inestimable value in defining what was admissible, and establishing unmistakable landmarks in astrophysics.

The discussion, it must be admitted, threw very little light on the part played by meteorites in cosmogony. Their world-building function remains largely speculative. Doubts of many kinds qualify its possibility, and lend it a fantastic air of unreality. But this may in part be due to a defect of imaginative power with which the universe was not concerned. Waiving, then, preliminary objections, we find ourselves confronted with the fundamental question: Given a meteor-swarm of the requisite mass and dimensions, is there any chance of its condensing into a planetary system? Sir Norman Lockyer set aside this branch of his subject. His hypothesis was, in fact, 'pre-nebular.' He assumed that the small solid bodies with which it started would, in course of time, become completely volatilized by the heat of their mutual impacts, and that the resulting gaseous mass would thenceforward comport itself after the fashion imagined by Laplace. Professor Darwin regarded the matter otherwise. It seemed to him possible to combine the postulates of the meteoric and nebular theories in a system planned on an original principle. For this purpose it was necessary to excogitate a means of rendering the kinetic theory of gases available for a meteor-swarm. 'The very essence,' he wrote,*

* *Proceedings of the Royal Society*, vol. xlv., p. 4.

'of the nebular hypothesis is the conception of fluid pressure, since without it the idea of a figure of equilibrium becomes inapplicable.'

M. Faye abandoned this idea; he built up his planets out of incoherent materials, thereby avoiding the incongruities, but forfeiting the logical precision of Laplace's stricter procedure. Professor Darwin consented to forfeit nothing; he stood forward as a syncretist, his object being to 'point out that by a certain interpretation of the meteoric theory we may obtain a reconciliation of these two orders of ideas, and may hold that the origin of stellar and planetary systems is meteoric, whilst retaining the conception of fluid pressure.' For the compassing of this end he adopted a bold expedient. Fluid pressure in a gas is 'the average result of the impacts of molecules.' Fluid pressure in a meteor-swarm might, he conceived, be the net product of innumerable collisions between bodies to be regarded as molecules on an enormously magnified scale. The supposition is, indeed, as Kepler said of the distances of the fixed stars, 'a big pill to swallow.' Between molecules and meteorites lies a wide unbridged gap. The machinery of gaseous impacts is obscure. It can be set in motion only by ascribing to the particles concerned properties of a most enigmatical character. These particles are, however, unthinkably minute; and in sub-sensible regions of research the responsibilities of reason somehow become relaxed. We are far more critical as to the behaviour of gross, palpable matter, because experience can there be consulted, and is not unlikely to interpose its veto.

Meteorites are, doubtless, totally dissimilar from molecules, however many million-fold enlarged; and they would infallibly be shattered by collisions which only serve to elicit from molecules their distinctive vibrations. Moreover, the advance of the shattering process would admittedly end the prevalence of fluid pressure. So that the desired condition, even if initially attained, would be transitory. There is, besides, a radical difference between a group of bodies in orbital circulation and a congeries of particles moving at haphazard, unconstrained by any predominant law of force. A meteoric swarm belongs to the first category; it is a community swayed in some degree by a central power; while the gaseous contents of a retort or a balloon obey purely individual impulses. The analogy looked for by Professor Darwin can then scarcely be said to exist, and his paper stands out as a monument of ingenious mathematical treatment applied to an ideal state of things.

An aggregation of revolving meteorites has no figure of equilibrium, and it is through the consequences necessarily resulting from this property that mathematicians are enabled to trace the progressive changes of a rotating fluid mass. In the absence of any such direct means of attack, their position regarding the problem presented by an assemblage of flying stones is not much better than that occupied by Kant, face to face with an evolving universe. It seems, nevertheless, clear that a meteor-swarm can be impelled to condense no otherwise than through the effects of collisions among its constituents. When the irregularities of movement upon which their occurrence depends are got rid of, the system must remain *in statu quo*. Order makes for permanence; a tumultuary condition is transient. The eventual state of the system can, however, be no more than partially foreseen.

Bodies arrested in their flight should fall inward, hence a central mass would form and grow; but the production of planets would seem to be conditional upon the existence of primitive inequalities of density in the swarm. These might serve as nuclei of attraction for meteoric infalls, not yet completely exhausted, but plying with harmless fire one at least of the globes they helped to shape.

There could, indeed, on this showing, have been no such harmonious succession of events as constituted the predominant charm of Laplace's scheme. The planets should be supposed to have issued pell-mell out of a chaos; or, rather, the chaos should have contained from the beginning the seeds of a predestined cosmos. Its evolution would have been like that of the oak from the acorn, an unfolding of what was already essentially there. And it may be that at this stage of penetration into the past, the unaided human intellect meets its *ne plus ultra*. There is a vital heart of things which we cannot hope to reach. Thought instinctively pauses before the vision of the symbolical brooding dove.

To resume. Meteoric cosmogony has a

rational basis. The modes of action it demands are still operative. Enfeebled almost to evanescence compared with the vigour they must have needed to be efficacious in world-building, they continue to make play in our nocturnal skies. They make play, it is true, with a very small quantity of material; but it may even now be distributed elsewhere in relatively enormous profusion, and in the solar system itself it presumably was much more abundant formerly than it now is. The earth has been raking up meteoric granules by hundreds of millions daily during untold ages, and her zone of space is still very far from being swept clean. The persistence of the supply, however, may be occasioned by the continual arrival of reinforcements from interstellar realms.

Comets appertain to, and travel with, the sun's cortège, and this is also inevitably true of comet-born meteors. But a multitude besides circulate independently of comets, and with much higher velocities. Their orbits are, then, hyperbolic; they belong to the category of 'irrevocable travellers,' and by their capture we are privileged to possess genuine shreds of sidereal matter. Universal space contains probably a vast stock of them, yet there is nothing to prove their collection into swarms. The spectroscope supplies no assurance to that effect; it has given its verdict against the meteoric constitution of nebulæ and temporary stars. And if we admit, through the persuasion of mineralogical testimony, that the aerolites so strangely landed on terrestrial soil are really the débris of ruined worlds, we can see for them no chance of restoration. Solitary they are, even if they occasionally pursue one another along an identical track, and solitary they must remain. Bodies do not of themselves initiate mutual circulation. Planetary or stellar outcasts cannot become re-associated into a gravitational system. Of a cosmic swarm, as of a poet, it may be said, *Nascitur, non fit*; and their birth-secret is undivulged.

CHAPTER VIII

COSMOGONY IN THE TWENTIETH CENTURY

Prospective and retrospective inquiries into physical conditions stand very much on the same footing. The same degree of uncertainty attaches to results of both kinds; the same qualifications need to be applied to them; a similar reserve is understood to accompany our admission of them. The reserve grows more marked as science unfolds to our surprised apprehension the multiplex possibilities of Nature. The time has gone by when 'men of light and leading' could draw cheques for unlimited amounts on the bank of public credulity. Not that the balance has diminished, but that it is reserved for other uses. Most of us in these days, have learnt to 'look before and after' for ourselves, and we instinctively mix the proverbial grain of salt with what is told to us, even on the highest authority. Ideas are on the move; dim vistas are opening out; much that lies beyond the verge of actual experience is seen to be possible, and sedate reasoning may at any moment suffer outrage by fantastic discovery. Hence, finality of assertion is out of date.

The secular parallax affecting men's views of the universe is nowhere more strongly apparent than in the trend taken by speculations as to its origin. They have become more subtle, more far-reaching, yet less confident. They have ramified in unexpected directions, but rather tentatively, than with the full assurance of attaining absolute truth. Laplace considered only the solar system, from which he arbitrarily excluded comets. On the vast sidereal world he bestowed barely casual attention. Sir William Herschel, on the other hand, occupied himself exclusively with the growth-processes of nebulæ, relegating the details of planetary evolution to a position of secondary importance. Later, the spectroscope having become available for discriminating generic differences among the suns in space, their relative ages, the order of their succession, their mutual affinities, claimed predominant attention. Just now, however, the flood of speculation is too high to be restrained within separate channels; cosmogonists look far afield; they aim at obtaining a general survey of relations bewildering in their complexity. To some extent they have succeeded; parts are beginning to find their places in a great whole; links are seen to connect phenomena at first sight seemingly isolated; on all sides analogies are springing into view. The unwearied circling of the moon and its imperturbable face remind us how a sun may have been born; the flash of every meteor suggests the mode by which suns die. The filmy traceries of comets intimate the nature of the force acting in nebulæ; the great cosmic law of spirality is remotely hinted at by the antipodal disturbances of the sun. Thus, one set of facts dovetails into the next; none can be properly considered apart from the rest.

The limitations of the human mind impose, nevertheless, restrictions of treatment. Individual efforts cannot grapple with the whole of the known and the knowable, and the larger part of both is included in the scope of modern cosmogony. It deals with all that the skies hold, visibly or invisibly; draws unstintingly on time past and time to come; concerns itself equally with gradual transformations and sudden catastrophes, with the dissipation and concentration of energy, with the subtle interplay of matter and force, with physical and ultra-physical, chemical and electrical modes of action. But let us consider a little more particularly how things actually stand, so as to collect some definite ideas regarding the lines of advance practicable and promising for the immediate future.

To begin with our domestic circle. The insecure state to which Laplace's scheme has been reduced by the assaults of numerous objectors has found compensation in the development of the tidal theory. Much light has thereby been thrown upon planetary pre-history. The relations of planets to the sun, and of satellites to planets, have been rendered comparatively intelligible. Noticeable above all is the discovery thence ensuing of the earth's suggestive position, just outside the boundary of the region where planetary rotation was destroyed by sun-raised tides, and with it the prospects of planetary vitality.

Moreover, the dubious state of the inchoate terrestrial spheroid, consequent upon its intermediate situation, accounts for the peculiar mode of birth of the moon, and the distinctively binary character of the earth-moon system; while the variety perceptible in the circumstances of the different planets precludes the employment of any single recipe for their development from a primal vortex. The forces concerned, we can now see, acted in a far more complex manner than could formerly have been supposed, and their balance was proportionately more delicate. To which side it would have inclined in a given case must then often be incalculable, or calculable only with the guidance of the known result. The strict bonds of reasoning have thus become somewhat relaxed, and difficulties that looked formidable have, in the long run, proved not to be insuperable. But conviction has also grown faint. The old, imposing façade of theory remains erect; the building behind it has been, for the most part, pulled to pieces, and the architect has yet to be found who can reconstruct it to our satisfaction.

On one point we have, nevertheless, acquired certainty. It is now known that comets with their dependent trains of meteors are aboriginal in the solar system. They are no unlicensed intruders, but collateral relations of the planetary family. Possibly they represent waste scraps of world-stuff which escaped the action of the formative machinery; and if so, they exemplify its primitive texture. Not that their composition need be, on this supposition, identical with that of the planets. A sifting of elements would have been likely to accompany the processes of cooling and contraction. Comets were, perhaps, made (to speak illustratively) of the white of the nebulous egg, planets of its yolk. But in any case we may safely regard the glimmering fabrics of acetylene and cyanogen that occasionally illuminate our skies as shearings from a wide-spreading, fleecy haze, flung aside before 'the starry tides' had as yet begun to 'set towards the centre.' In one respect the quality of these relics is a surprise. They show no chemical affinity with nebulæ. Their spectra are radically different from nebular spectra, gaseous or continuous. They accordingly lend no countenance, although not fatally adverse to the view that the sun was once, in the distinctive sense, a nebulous star.

The grand topic of sidereal succession is no longer abandoned to fruitless surmises. Broad lines have been laid down, along which, so far as we can at present see, progress must inevitably have been conducted. And one fact of overwhelming significance in this connection is entirely of recent discovery. The multitudinous existence of obscure bodies in space had, indeed, been foreseen as a logical necessity long before Bessel founded the 'Astronomy of the Invisible'; but its strong substantiation is almost wholly due to the use of modern spectrographic methods. Decrepit or dusky suns are assuredly no imaginary product, but a potent reality, though it would be too much to assert that all have sunk to extinction by the same road. Nor is it absolutely certain that their present state is uniformly the outcome of prolonged decay. Circumstances connected with many of them suggest rather a congenital incapacity for shining.

We stand, too, on firmer ground than our predecessors in respect to the history of stellar systems. That its course is mainly prescribed by the influence of tidal friction has been ably demonstrated by Dr. See. Telescopic double stars can be led back by the aid of this clue to an initial stage, when they revolved close together, very much like the earth and moon in Professor Darwin's theory; and it was owing to their voluminousness and the unequal attractions it engendered that their orbits became enlarged and elongated to the degree generally observed.

This theoretical inference has been confirmed with singular aptness by the discovery of spectroscopic binaries. Pairs circling in orbits too narrow for visual discernment are the natural complement of pairs just divisible with the telescope; the first class represent the unseen, early stages of the second. The two together form an unbroken sequence of stellar systems, for spectroscopic binaries include couples fully separated, and still separating, as well as others barely divided, and revolving almost in contact. Nay, they include specimens, we are led to believe, of globes conjoined into the apioidal figure theoretically investigated by Darwin and Poincaré, which may be regarded as preparatory to the development by fission of two mutually revolving stars from one primitive rotating mass. Some of these supposed dumb-bell systems are variable in light; and if the eclipse-rationale of their obscurations be confirmed by the spectroscope, there is no gainsaying the inference that each flickering object is composed of two stars actually contiguous, if not confluent.

Now, compound stars are by no means of exceptional occurrence. Their relative abundance has been found to augment rapidly with every advance in our knowledge of the heavens. From the measures of stellar radial velocity lately carried out at the Yerkes Observatory by Professors Frost and Adams, it appears that the proportion of binary to single stars considerably exceeds Professor Campbell's earlier estimate. If those giving helium-spectra are alone considered, there are most probably as many of one kind as of the other. But why the distinction? it may be asked.

The answer is not far to seek. Helium stars are the most primitive, and form the closest and most readily apparent systems. The companions of more fully developed stars would be likely to give less striking spectroscopic signs of their presence. A physically double star must always remain such. There is no law of divorce by which it can put away its companion, although their relations must alter with time. But their alteration tends continually to enhance the difficulty of their detection. For as the members of a pair are pushed asunder by tidal friction their velocity slackens, and the tell-tale swing of their spectral lines diminishes in amplitude, and finally, by its minuteness, evades observation.

And since the majority of spectroscopic satellite-stars are very imperfectly luminous, their eventual telescopic discovery, when far enough away from their primaries to be optically separable from them, would rarely ensue. It must then be concluded that half the stars in the heavens (let us say) broke up into two or more bodies as they condensed. What follows? Well, this. Half the stars in the heavens were, from the first, incapacitated from becoming the centres of planetary systems. To our apprehension, at least, it appears obvious that a binary condition must have inhibited the operations of planetary growth. These innumerable systems are doubtless organized on a totally different principle from that regulating the family of the sun. The nebular hypothesis, even in its most improved form, has no application to them; the meteoritic hypothesis still less. Mathematical theories of fluid equilibrium, combined with a long series of changes due to tidal friction, afford some degree of insight into the mode of their origin and the course of their development. Yet the analogy with the earth-moon couple, which irresistibly suggests itself, is imperfect, and may be misleading, owing to the wide difference in state between plastic globes approaching solidification, and sunlike bodies radiating intensely and probably gaseous to the core.*

The world of nebulæ confronts us with entire cycles of evolutionary problems, which can no longer be treated in the offhand manner perforce adopted by Herschel. The objects in

* *Cf.* Jeans, *Astrophysical Journal*, vol. xxii., p. 93.

question are of bewildering variety; yet we can trace, amid their fantastic irregularities, the underlying uniformity of one constructive thought. Nearly all show, more or less markedly, a spiral conformation, and a spiral conformation intimates the action of known or discoverable laws. Their investigation must, indeed, be slow and toilsome; its progress may long be impeded by the interposition of novel questions, both in physics and mechanics; nevertheless, the lines prescribed for it seem definite enough to give hope of its leading finally to a clear issue. And when at last something has been fairly well ascertained regarding the past and future of nebulous spirals, no contemptible inroad will have been made on the stupendous enigma of sidereal relationships.

Its aspect, if we venture to look at it in its entirety, is vast and formidable. Not now, as in former times, with a mere fragment of creation—a single star and its puny client-globes, one of which happens to be the temporary abode of the human race—but with the undivided, abysmal cosmos, the science of origin and destiny concerns itself. The obscure and immeasurable uncertainties of galactic history invite or compel attention. We know just enough to whet our desire to know a great deal more. The distribution of stars and nebulæ is easily seen to be the outcome of design. By what means, we cannot but ask ourselves, was the design executed? How were things ordered when those means began to be employed? How will they be ordered when all is done? For an ultimate condition has, presumably, not yet been reached. And if not, agencies must be at work for the perfecting of the supreme purpose, which are not, perhaps, too subtle for our apprehension. Meanwhile, facts bearing on sidereal construction are being diligently collected and sifted, and we shall do well to suspend speculation until their larger import is made known.

The inquisitions of science do not cease here. They strive to penetrate a deeper mystery than that of the scattering in space of stars and nebulæ. What are they made of? is the further question that presents itself. What is the nature of the primal world-stuff? Whence did it obtain heat? By what means was motion imparted to it? If it be urged that such-like topics elude the grasp of finite intelligence and belong to the secrets of creative power, we may reply that we are not entitled, nor are we able, to draw an arbitrary line, not to be transgressed by our vagrant thoughts. The world has been, by express decree, thrown wide to their excursions, and it is not for us to restrict their freedom. We need not fear getting too near the heart of the mystery; there is no terminus in the unknown to which we can travel by express; in a sense, we are always starting, and never get nearer to our destination. But that is because it retreats before us. We do, in truth, advance; and as we advance the mists clear, and we see glimpses beyond of imperishable order, of impenetrable splendour. Our inquiries need not then be abandoned in despair at the far-reaching character they have spontaneously assumed.

From the earliest times there has been a tendency to regard varieties of matter as derivative. They have been supposed to be procured by supramundane agency, or by the operation of inherent law, from some universal undifferentiated substance. We moderns call that substance 'protyle,'* and believe ourselves to be in experimental touch with it. The implications of this view we shall consider in the next chapter.

* A term signifying 'first matter,' constructed from corresponding Greek words by Roger Bacon, and revived by Sir William Crookes.

CHAPTER IX

PROTYLE: WHAT IS IT?

The notion of a primordial form of matter meets us at every stage of cosmogonical speculation. It is the outcome of an instinctive persuasion that, if we could only 'lift the painted veil' of phenomena, the real business of the universe would be found to be proceeding in the background, 'without haste or rest,' on a settled plan everywhere the same; that uniformity is fundamental, diversity only incidental; and that the transformations of the one simplified substance might be represented by a single formula, the discovery of which would place in our hands the master-key to the locked secrets of the universe. Among untutored thinkers some familiar kind of matter, idealized and generalized, commonly stood for the typical world-stuff. Water was the first favourite. Thales, the 'wise man' of Miletus, procured his cosmos by precipitation from an aqueous solution, and many savage tribes have devised analogous expedients. Anaximenes regarded air as the universal solvent; Heracleitus replaced it with fire, and set on foot a scheme of what is now often designated 'elemental evolution.' From the perpetual 'flux of things' he conceived that the four substances selected by Empedocles as the bases of nature were not exempt, and a fragment of his scheme survived in Francis Bacon's admission of the mutual convertibility of air and water. In the main, however, the author of the 'Novum Organum' adhered to the Paracelsian doctrine of an elemental triad,* although he regarded the association of salt as a fundamental 'principle' with sulphur and mercury as inept and unnecessary.†

These twilight fancies faded in the growing light of chemical science; yet the mental need that they had temporarily appeased survived,

* First introduced by Basilius Valentinus. See Fowler's edition of the *Novum Organum*, p. 576, note.

† Thus recurring, as Mr. Fowler remarked (*loc. cit.*), to Geber's earlier view.

and had somehow to be satisfied. An 'Ur-Stoff' was still in demand, but the nineteenth century characteristically attempted to supply it by weight and measure. Dalton's combining equivalents afforded the warrant for Prout's hydrogen hypothesis. The problem to be faced was to find a unit-atom by the varied combinations of which all the rest of the chemical atoms might be formed. The condition indispensable to be fulfilled was that their weights should be exact multiples of that of the unit, and it came near to fulfilment by the hydrogen-atom or semi-atom. It was, nevertheless, a case in which approximate agreement was of no avail; the adverse decision of the balance finally became unmistakable; and Prout discreetly fell back, in 1831,* upon the expedient of deriving hydrogen itself from some body lower in the scale. His hypothesis, in short, dissolved into a conjecture. It had only emphasized the stipulation that the 'protyle' of the ancients must be such as would serve not only for the physical unification of the sum of things, but likewise as the substratum of all the chemical species.

* *Dictionary of National Biography*, vol. xlvi., p. 426.

Meanwhile, the theoretical search for it had been carried on in widely different fields of inquiry. Laplace's speculations, no less than Herschel's observations, had led to the conception of some kind of 'fire-mist' as the genuine star-plasm. But its nature and properties remained indefinite, or were assigned at the arbitrary choice of adventurous cosmogonists. So the 'shining fluid' of space was 'everything by turns and nothing long,' until Sir William Huggins, in 1864, gave it spectroscopic individuality. The 'recognition-mark' of nebulium is a vivid green ray, by the emission of which it is known to have a concrete existence. Yet the little that has besides been learned about it discountenances its identification with the *materia informis* of antique philosophy. This we should expect to be the subtlest of all substances. Professor Campbell, however, has gathered indications that nebulium is denser than hydrogen. Its luminosity, at least, which is invariably associated with that of hydrogen, spreads less widely in the same formations; it is confined to a lower level. The nebulium-atom is not, then, the chemical or the cosmical unit.

This evasive entity, or something that curiously simulates it, has proved to be of less recondite origin. Sir William Crookes is amply justified in claiming the venerable designation of protyle for the 'radiant matter' first produced in his vacuum-tubes nearly thirty years ago. The discovery was astonishing and unsought, and its significance has not yet been measured. Matter assumes the 'fourth state,' in which it is neither solid, liquid, nor gaseous,* under the compulsion of an electric discharge in high vacua. At an exhaustion of about one-millionth of an atmosphere the manner of its transit abruptly alters. Conduction gives way to convection. Luminous effects are abolished. The tubes cease to glow with brilliant, parti-coloured striæ; the poles are no longer marked by shimmering halos or brushes; only a green phosphorescence is seen where the glass walls of the receptacle are struck by the stream of projected particles. They come, with half the velocity of light, exclusively from the negative pole, the positive pole remaining inert. Hence the name

* Crookes, *Philosophical Transactions*, vol. clxx., p. 163.

'cathode-rays,' bestowed by Goldstein on the carriers of electricity in highly-exhausted bulbs.

These mysterious, sub-sensible agents possess certain very definite properties. Their paths are deflected in a magnetic field; they can traverse metallic films; and their investigation in the open, thereby rendered feasible, has shown them to possess photographic efficacy, and the faculty of breaking down electrical insulation; moreover, they transport a negative charge of fixed amount, and have a determinate momentum. They are, then, assuredly no mere pulsations of the ether; unless our senses 'both fail and deceive us,' their quality is material. Material, yet not quite with the ordinary connotation of the term. The most essential circumstance about the cathode-rays is that they remain unmodified by the chemical diversities of the originating gases.* A hydrogen tube yields identically the same radiant matter as an oxygen or a nitrogen tube. Here, then, at last we have

* J. J. Thomson, *The Discharge of Electricity through Gases*, p. 195; *Philosophical Magazine*, vol. xliv., p. 311.

within our grasp undifferentiated substance—matter not yet specialized, neither molecular nor atomic, matter destitute of affinities, exempt from the laws of combination—matter in its inchoate, and perhaps ultimate form; in a word, the far-sought protyle.

Already, in 1879, Sir William Crookes conjectured the infinitesimal missiles propelled from the cathode to be the 'foundation-stones of which atoms are composed.'* And in 1886 he pronounced them more decisively to be the raw material of atoms, which, to Sir John Herschel's apprehension, bore the unmistakable stamp of a 'manufactured article.' Nor did his recent commentator refrain from attempting distantly to divine the method of their construction, or from laying his finger on the by-products and residues associated with it,† although he felt compelled to relegate the cosmic factory to the edge of the world, where inconceivable things may happen. All this, indeed, seemed, in the late Victorian era, like mounting the horse of Astolfo for a trip to the

* *Science*, June 26, 1903.

† *Proceedings of the Chemical Society*, March 2 1888.

moon; and sane common-sense pronounced it fantastic enough to 'make Democritus weep and Heracleitus laugh.'* But we have since learned from Nature herself some tolerance of audacities.

Step by step the new order of ideas has irresistibly come to the front. It owed its origin to Sir William Crookes's skill in producing high vacua, and the consequent development in his tubes of radiant effects. Then, in 1879, universal importance was claimed for them, and matter in the 'fourth state,' by a revival of the dreams of the ancients, expanded into a kind of visionary protyle. Philipp Lenard made the next advance towards its actualization by slipping it, in 1894, through an aluminium window, and watching its behaviour towards ordinary matter. Two years later Röntgen rays made their entry on the scene; and before the end of 1896 Becquerel, hurrying along the track of novelties, came upon the momentous discovery of radio-activity.

A revision of ideas has ensued. Some time-honoured assumptions have had to be discarded; so-called laws have been found to

* *Times*, March 30, 1888.

need qualification; the old system of physics is consequently out of gear, and much time and patient labour must be expended upon the adjustment of the new and improved system destined to replace it. The leading and indisputable fact of the actual situation is that a number of hitherto unsuspected modes of energy have been disclosed as widely operative in nature. All are of a 'radiant' character. They travel in straight lines with enormous speed; they start from a material base, and produce their several effects on reaching a material goal. Now, these effects are closely alike, notwithstanding that the rays themselves are radically dissimilar. Those of the cathodic kind are corpuscular. They consist of streaming particles, each, according to Professor J. J. Thomson, of about one-thousandth the mass of the hydrogen atom. Others, the noted 'alpha rays,' are atomic; they are supposed to aggregate into helium. Finally, the Röntgen variety are ethereal; they are composed of light-vibrations reduced in scale, and augmented correspondingly in frequency.

What is most remarkable is that these

various forms of activity give rise, by different means, to very much the same results. They are, in fact, distinguishable only by careful observation. They possess in common, though not to the same degree, the faculties of penetrating opaque matter, of impressing sensitive plates, of evoking fluorescence; while under the impact of cathode and Röntgen rays, as well as of ultra-violet light, insulated electric charges leak away and evanesce. There is, however, one clear note of separation between cathodic and X rays in the sensibility of the former, and the indifference of the latter, to magnetic influence. Thus alone, it would appear, is electrified matter set apart from what we call ether. A magnet acts only upon bodies carrying an electric charge; so that, if flying corpuscles could be obtained in a neutral condition, the only tangible distinction between the various kinds of rays would vanish. But this is evidently impracticable. Indeed, advanced physicists abolish the material substratum of the corpuscle, and assign its attributes to the associated atom of electricity. It is, at any rate, undeniable that the electrical relations of matter become more intimate as our analysis of its constitution goes deeper. Ether, electricity, matter, all seem to merge together in the limit; their differences ultimately evade definition. So animal and vegetable life appear to coalesce in their incipient stages, and strike apart with advance towards a higher perfection.

The various branches of inorganic nature, too, possibly spring from a common stock. Our powers of discrimination fail to separate them as we trace them downward; but that may be because of the inadequacy of the guiding principles at our command. A larger synthesis is demanded for the harmonizing of multitudinous facts, at present grouped incongruously, or left in baffling isolation; and it is rendered increasingly difficult of attainment by the continual growth of specialization. Year by year details accumulate, and the strain of keeping them under mental command becomes heavier; yet what *can* be known *must*, in its essentials, be known as a preliminary to extending the reign of recognised law in Nature.

Sooner or later, nevertheless, the wealth of novel experience recently acquired will doubtless be turned to the fullest account. Just now, we can grasp only tentatively its far-reaching import. That it bears profoundly on the hoary problem of the genesis of visible things is sufficiently obvious. The questions of what matter is, and of how it came to be, have been cleared of some of the metaphysical cobwebs involving them *ab antiquo*, and insistently crave definite treatment by exact methods. We should, indeed, vainly aspire to reach—or to comprehend, even if we could reach—an absolute beginning. To quote Clerk Maxwell's words: 'Science,'* he wrote, 'is incompetent to reason upon the creation of matter itself out of nothing. We have reached the utmost limit of our thinking faculties when we have admitted that, because matter cannot be eternal and self-existent, it must have been created.' The discovery that atoms disintegrate into corpuscles does not, then, bring us any nearer to the heart of the mystery; but it is eminently suggestive as regards secondary processes.

Acquaintance with ultra-atomic matter, begun within the narrow precincts of 'Crookes's tubes,' has advanced rapidly since 'radiology' took its place among the sciences. For, from

* *Encyclopædia Britannica*, article 'Atom.'

the time when Becquerel first saw a plate darkened by the photogenic projectiles of uranium, and Madame Curie sifted radium from the refuse of the mines of Joachimsthal, the lines of proof steadily converged towards the conclusion that chemical atoms are not only divisible, but that their decay progresses spontaneously, irresistibly, in fire, air, earth, and water, as part of the regular economy of Nature.

To explain further. Radio-active bodies are composed—according to Rutherford's plausible hypothesis—of atoms in unstable equilibrium. The gradual changes incidental to their own internal activities suffice to bring about their disruption. And their explosive character is obviously connected with unwieldy size, since uranium, thorium, and radium, the three substances pre-eminent for radio-activity, possess the highest atomic weights known to chemistry. The precarious balance, then, of each of these complex, though infinitesimally small systems is successively overthrown, regardless of external conditions or environment, their constituent parts being hurled abroad with the evolution of an almost incredible amount of energy. Their products include cathode rays;

matter in the 'fourth state,' matter a thousand times finer than hydrogen, is ejected in torrents from the self-pulverized atoms of radium. Moreover, the issuing rays are equivalent to currents of negative electricity. Each corpuscle bears with it an electron, or is itself an electron, for the choice between the alternatives is open. In either case, we are confronted with matter apparently in its ultimate form; and to that form ordinary, substantial bodies tend to become reduced. Electrons may fairly be called ubiquitous. They occur in flames, near all very hot masses, wherever ultra-violet light impinges on a metallic surface;* they are freely generated by Röntgen and cathode rays; they are the agents of electrical transmission in conductors.

Everywhere throughout the universe, atoms are thus in course of degradation into corpuscles. But no information is at hand as to the scene or mode of their reconstitution. The waste and decay are patent; the processes of compensation remain buried in obscurity. Indeed, Sir William Crookes anticipates the

* Fleming, *Proceedings Royal Institution*, vol. xvii., p. 169.

complete submergence, at some indefinitely remote epoch, of material substance in protyle, the 'formless mist' of chaos. He assumes an identity between the past state and the future, leaving, however, the present unexplained. The break-up of matter, in fact, does not render its construction the more intelligible. Running-down is an operation of a different order from winding-up. It is an expenditure of a reserve of force. It needs no effort; it accomplishes itself. But to create the reserve for expenditure demands foresight and deliberate exertion; it implies a designed application of power.

Now each atom is a storehouse of energy, representing the force primitively applied to reduce some thousands of free electrons to the bondage of a harmoniously working system. Its disruption is accompanied by the dissipation of the energy previously accumulated in it; and that atomic systems are not calculated for indefinite endurance is one of the most surprising of modern discoveries. The secret of their original construction is, none the less, impenetrable. That they are composed of protyle—that their clustering members are corpuscles moving under strong mechanical control—is more than probable. And the law of order adumbrated by what are called the 'periodic' relations of the chemical elements shows that their concourse was very far from being fortuitous. But beyond this point there is no holding-ground for distinct thought. We are ignorant, too, whether the process of building matter out of protyle is at present going on, or was completed once for all in the abysmal fore-time, decay being now definitive. Nor is it likely that we shall ever succeed in capturing with recognition a brand-new atom freshly minted for cosmical circulation.

CHAPTER X

UNIVERSAL FORCES

We find it equally impossible to conceive of matter without force, as of force without matter. The two modes of action, or of being, are inseparable. Yet our minds strongly distinguish between them; they impart a dual aspect to the world. Phenomena are not simple manifestations of disembodied energy, if such a thing could be; they have a substantial basis which, nevertheless, eludes apprehension, and seems to slip away into nothingness if we try to empty it of its immaterial contents. Nor do these energize in the void. They and the bodies they animate are knowable only in combination, and exist, to our apprehension, only on the condition of mutual dependence. All we can do towards discriminating them is to fix our attention predominantly on one or the other side of things, and so facilitate thought by drawing ideal lines of demarcation.

Just as there are many forms of matter—all springing, we are led to believe, from an undifferentiated, fundamental world-stuff—so there are various kinds of force, reducible, possibly without exception, to one universal principle. Their correlation, indeed, has been already in large measure demonstrated; heat, light, electricity, and kinetic power are known to be equivalent and interchangeable; but there are outstanding activities, which resist assimilation, and seem to originate under different conditions from the rest. Forces manifest themselves chiefly through attractive and repulsive effects, varying in accordance with their natures and the modification of attendant circumstances. The minute particles of matter, for instance, cohere; they cling together tenaciously; yet no pressure avails to bring them into actual contact; at a certain point of mutual approach, they develop an invincible power of resistance to any further encroachments upon their separate molecular domains. And it is this faculty which gives to matter its distinctive property of hardness. It is rendered tangible to sense just by its recalcitrance to constraint.

Neither the mode of operation nor the nature of the forces by which molecules are organized into masses is known; while the power acting on the masses thus organized, and regulating by its action the mechanism of the universe, is fully as baffling to comprehension. Wonder at its results is blunted by familiarity; presented to us as novelties, they should be pronounced to outrage reason. The relations of gravity are of the utmost simplicity; and they are, on that very account, supremely perplexing. They are governed by one steadfast law, the same everywhere, and under all varieties of conditions within the range of experiment or precise observation. It governs impartially every kind and quality of matter, taking no notice of its states or combinations, ignoring its subjection to chemical, thermal, magnetic, or electrical influences. Gravity is not only indifferent, but inevitable and inexorable; there is no resisting its sway; no screen serves as a shelter against its persuasions; it spreads equably in all directions, becoming enfeebled, like wave-motion, in the strict proportion of its diffusion from a centre over successive spherical surfaces. Its most singular peculiarity, however, is its apparent unconcern with time. The gravitational pull is virtually instantaneous; its transmission—if it be transmitted—takes place millions of times faster than that of light; the finest tests have, so far, failed to elicit symptoms of delay. These would be found in minute discrepancies between calculated and observed perturbational effects in the heavens.

The action of gravity, if propagated with finite velocity, should differ for bodies preserving an invariable distance from its source, and for bodies travelling towards or away from it. Their movement would modify the law of attraction.* Yet, up to the present, it has proved impossible to detect the slightest deviation from the plain rule of inverse squares. Again, the penetrative faculty of this strange force seems absolute and unlimited. We know by ordinary experience that we cannot diminish the weight of an object by

* Lorentz, *Proceedings Amsterdam Academy*, 1900, p. 565.

interposing any kind of shield between it and the earth; and no refinement in experimentation avails to alter this result. That it is so, is a fortunate circumstance for the harmony of the world. We can dimly imagine the riot of confusion that would ensue if a transiting globe could intercept the attraction, as it does the light, of a central governing mass. But from the wonderfully adjusted universal order gravitational eclipses are excluded; nor does the densest body throw even the faintest gravitational shadow.

The nature of a power so singularly conditioned is almost inconceivable; yet attempts have not been wanting to fathom the mystery that surrounds it. Professor Osborne Reynolds, in the Rede Lecture for 1902, claimed to have arrived at 'a complete, quantitative, purely mechanical explanation of the cause of gravitation,' based on the 'dilatancy' of a granular medium in close piling. But his working model of the universe will probably be remembered only as a lesson in the 'inversion of ideas,' showing that with skill and ingenuity a fairly concordant outcome of phenomena may be derived from antagonistic hypotheses. In this author's view matter is equivalent to a deficiency of mass, the spaces where his cosmic grains are relatively few, because their arrangement is out of gear, being driven towards one another by the pressure of the surrounding medium, in which they are compactly stowed, and therefore numerous. Thus, the acting forces in nature are made to depend upon the compression by the denser medium of interspatial tracts of rarer consistence, forming what we call matter. The theory is difficult, if not impossible of acceptance, not because it involves the overthrow of conceptions which may be rooted in habitual modes of thought, rather than in absolute truth, but because of its startling postulates and large vacuities. To be valid, it should be complete; and there are obvious chasms in the vast expanse of ground which it covers with surprising, though only partial success.

The *multa renascentur* of the poet is verified by the revolutions no less of thought than of speech. Flights of minute material particles have served the turn of theorists often, and in more ways than one, and have as frequently been consigned to discredited oblivion; but they are in vogue once more. George Louis Lesage, of Geneva, devoted sixty-three of the seventy-nine years of his life, which came to an end in 1803, to the elaboration of a mechanical rationale of gravity, first given to the world in the *Transactions* of the Berlin Academy of Sciences for 1782, and with details of amplification in his *Traité de Physique Mécanique*, edited by Pierre Prévost in 1818.* The explanation it offered of molar attractions was by the supposed unceasing impacts of 'ultramundane corpuscles,' speeding in countless numbers and at fabulous velocities, from nowhere everywhere, and thus enforcing the mutual approach of masses of gross matter. This involved the supposition of an infinitesimal screening effect, producing a small inequality in the strength of the bombardment on the sheltered and unsheltered sides of the bodies exposed to it. This inequality, in fact, was taken to be the *causa causans* of gravity. Yet its production encountered a difficulty. There was required for it a trifling degree of opacity in every kind

* Sir W. Thomson, *Philosophical Magazine*, vol. xlv., fourth series, 1873. Many hints have been taken, in what is above written, from this valuable paper.

of matter, while perfect gravitational transparency is asserted by the most delicate observations. Lesage, then, reduced the arrests laid upon his particles to a minimum; one in ten thousand, for instance, might at the utmost be intercepted by the terrestrial globe.* Even this insignificant minority, however, would suffice, through the surrender of their momentum to the impeding bodies, to endow them with the noted property of gravitation.

Clerk Maxwell urged the objection that the accompanying loss of kinetic energy by the corpuscles should, if transformed into heat, render all gravitating bodies white-hot. But Professor J. J. Thomson holds that the transferred corpuscular energy might, instead of reappearing in thermal form, be converted into some highly penetrative species of radiation capable of escaping unperceived into surrounding space.† 'A simple calculation,' he adds, 'will show that the amount of kinetic energy transformed per second in each gramme of the gravitating body must be enormously greater than that given out in the same time by one

* Sir W. Thomson (Lord Kelvin), *loc. cit.*, p. 323.

† *Electricity and Matter*, p. 159.

gramme of radium.' This consequence of Lesage's theory takes one's breath away; the 'fables of the Talmud' seem, by comparison, easy of belief; nevertheless, Lord Kelvin* declared it in 1873 to be more complete in the expository sense, and not more arduous in its assumptions, than the kinetic theory of gases.

Its fundamental postulate, at any rate, has been curiously verified in the course of recent researches into the arcana of physics. Entities in some degree corresponding to the ultramundane corpuscles of the Genevese philosopher do actually exist. Electrons are being continually expelled from bodies in all parts of the universe; they issue forth under all conceivable conditions and in unlimited numbers. Space is perhaps thronged with them; no material object can be exempt from their multitudinous buffetings, which are beginning to be taken account of in many cosmical speculations, and cannot certainly be ignored in efforts to solve the most obvious to superficial apprehension, the most intricate on a profound consideration, of all cosmical problems. But

* *Loc. cit.*, p. 331.

there is one fatal objection to an electronic theory of gravitation. The agency appealed to travels too slowly to be available for the required purpose. The velocity of light, there is reason to believe, sets a limit impossible to be surpassed or even attained by the velocity of electrons; yet it is incomparably smaller than the rate of gravitational transmission.

Tisserand estimated at six million times the quickness of luminous travel the minimum speed at which the sun's attraction must be propagated in view of the imperceptibility in planetary observations of effects corresponding to a time-inequality;* and this value may be taken as authentic. So colossal a discrepancy excludes any kind of impact-rationale of the mutual pull of heavy masses; Lesage's corpuscles remain 'ultramundane'; their identification with known atoms or sub-atoms appears to be precluded; no products of ionic disintegration possess the qualities necessarily to be ascribed to them.

We turn, then, inevitably to the menstruum of mysteries, the bank of the insolvent in speculation, to the all-serviceable ether. Ethereal

* *Traité de Mécanique Céleste*, tome. iv., p. 495.

radiations exercise an impulsive power; light-pressure has secured a recognised status among cosmic agencies; and every vibrational system of the luminous type undoubtedly shares the faculty by which light tends to drive minute particles forward along the lines of its propagation. Professor J. J. Thomson, accordingly, considered that but for the drawback of their insufficient velocity, 'very penetrating Röntgen rays' might with advantage be substituted for corpuscular streams as the cause of gravity.* They would, in some slight degree, be absorbed by encountered masses, to which they would impart a proportionate amount of momentum. Two bodies mutually shadowing one another would, under such circumstances, be drawn together with a force varying as the inverse square of distance; and if further they absorbed the impinging rays strictly in the measure of their density (as observation shows to be approximately the case), the attraction would increase in the same ratio as the product of their masses. But Röntgen rays travel with the precise velocity of light; they are, in truth, ultra-invisible light; and they must hence be

* *Electricity and Matter*, p. 160.

regarded as hopelessly incompetent to explain an influence transmitted at least six million times more rapidly.

This was fully admitted by Dr. H. A. Lorentz,* who, five years ago, weighed the vibrational hypothesis of gravity in the balance of rigorous calculation, and found it wanting. His equations yielded the unexpected result that, if its postulates were granted, the noted attractions between massive bodies could subsist only on the terms of an incessant waste of electro-magnetic energy. But this is of course inadmissible. The theory involving such a consequence stands self-condemned, to say nothing of the wholly inadequate rate of propagation afforded by it.

Impulsion hypotheses, whether by corpuscles or rays, being hopelessly discredited, Dr. Lorentz reverted to a half-forgotten speculation by Mosotti, which, though sixty years old, struck him as capable of being adapted to modern requirements. It was of an electrical nature, and, in the novel shape given to it, supposed gravitational action to depend upon

* *Proceedings Amsterdam Academy of Sciences*, 1900, p. 559.

strains of the ether due to the disturbing effects of the positive and negative ions constituting ordinary matter. These 'states' of the medium are distinct in kind; they cannot neutralize one another; and the familiar law of attraction represents their resultant effect. To bring it about much has to be taken for granted; yet the hypothesis can lay claim to one singular prerogative. Although the disturbances invoked by it traverse the ether with no more than the standard speed of light, it appears from Dr. Lorentz's investigation that, owing to certain modifications in the properties of the medium produced by moving matter, the planetary perturbations betraying loss of time in gravitational transmission would, on the electrical theory, be so small as to evade detection. As regards this crucial point, the Dutch physicist has hit upon a felicity of explanation entirely original, and, as it were, unsought.

An 'undulatory theory' of gravity, adumbrated, rather than advanced by Mr. Whittaker in 1902,* excited hopes that the ideal aim of science—a complete unification of the forces of

* *Monthly Notices*, vol. lxii., p. 619; vol. lxiii., p. 258.

Nature—might at last be within reach. Based upon a striking mathematical research, it exhibited the attraction between masses as, in a manner, the integration of innumerable wave disturbances, propagated at a rate not strictly definable, but perhaps immensely surpassing that of gravity. No suggestion was made as to the primary mode or cause of agitation, yet it seemed much to learn that the medium we are cognizant of in space might be capable of transmitting the pull of gravity. Unfortunately, however, the physical foundation of this reassuring congruity proves to be weak or unsound. The mathematical mill works magnificently, but the grist put into it is of dubious quality. Stripping Mr. Whittaker's result of its purely analytical form, Dr. Johnstone Stoney showed that an assumption of extreme improbability lay concealed in his equations, which could not, he concluded, be seriously taken to correspond with the reality of things.*

There would then seem to be no alternative but to accept *ad interim* the electro-dynamical view of the nature of gravity. If not true,

* *Monthly Notices*, vol. lxiii., p. 424.

it is at least not obviously false. Through its subtlety it escapes direct confutation. And the method of exclusions, by eliminating competitors, has left it in virtual possession of the field.

Nothing is more curious in the history of recent science than the continual and irresistible growth which it records in the importance of electrical phenomena. All others tend to become merged in them; the most varied data of experience claim to be translated into electrical terminology. They are not, assuredly, rendered more intelligible by the process, but it at any rate abolishes the confusion incidental to multitudinous points of view. Thus, in the last resort, we find electrical forces (if they may be so designated) swaying the world. What they essentially consist in, we cannot tell; the utmost that may reasonably be hoped for is to arrive at a clear conception of modes of action reduced to antagonistic stresses, by which the play and counterplay of the universe may be kept up. And to this extent we find it possible to understand how electricity works the ethereal machinery. It is strongly dualistic. The nearer we get to the foundations of nature, the more sharply positive and negative charges appear to be differentiated.

The opinion is nevertheless held by some inquirers that negative electricity is the only substantive kind, and that its complement is ordinary matter deprived of some of its negative particles. This, in fact, revives Franklin's 'one fluid theory,' only with the substitution of negative for positive electricity as the active principle.* But we are met by the doubt whether 'ordinary matter' can be said to exist in and by itself. If it do, the mode of its existence becomes more and more baffling to comprehension, as the association of mass with charge makes its way into the foreground of thought.† Moreover, a charge is, or produces, a 'state of the ether' (to use the unsatisfactory current phrase); and the ether being capable of opposite distortions, the effects upon it of opposite charges are contrary and similar, though perhaps not equivalent; whence the 'two fluid theory' obtains a *primâ facie* recommendation as the simplest, though a crude

* J. J. Thomson, *Electricity and Matter*, p. 88.
† *Ibid.*, p. 47.

nterpretation of electrical phenomena. These are ubiquitous; destitute though we are of sense-organs for their perception, we still indirectly recognise their presence on every side. If the unification of the forces in nature be attainable, the unifying formula will doubtless be derived from them. Electricity is the *mot de l'énigme*; yet it is itself the most inscrutable of enigmas.

CHAPTER XI

THE INEVITABLE ETHER

Ether is the fundamental postulate of physics. Its existence, nowise apparent, is in all manner of ways implied. The properties that must be assigned to it are certainly arduous of conception. We need the aid of forced analogies to enable us to realize, even imperfectly and indistinctly, the mode in which it discharges functions obviously somehow discharged. But in the last resort everything is obscure; if our thought-borings go deep enough, they always reach the incomprehensible.

The original ether was the 'quintessence' of the ancients—a kind of matter vaguely imagined as pure and incorruptible enough to serve for the raw material of the heavenly bodies, the four common elements being reserved exclusively for sublunary use. The distinction, however, eventually broke down. All the spheres, from the *primum mobile* to the very surface of our low earth, are pervaded by a subtle mode of action, demanding for its transmission machinery of a finer kind than could be constructed out of gross everyday matter. The phenomena of light, when they came to be attentively studied, imperatively required a medium, universally diffused, evasive to sense, accessible only by processes of reasoning. Hooke and Newton accordingly brought the ether through the Horn Gate of dreamland into a region of reality, where it became a subject of legitimate speculation to men of science. The task, nevertheless, of definitely specifying its qualities was not taken seriously in hand until the beginning of the nineteenth century, when the establishment of the undulatory theory of light supplied tangible holding-ground for ideas regarding the vehicle of propagation, and rendered the ether a fixture of thought.

A great deal is demanded from it. We cannot afford to set up an establishment of ethers; one factotum must suffice. Incongruous offices are devolved upon it. It has to be Atlas and

Mercury in one. It is the universal supporter and the universal messenger. Whatever kind of influence or form of energy can pass from world to world is conveyed by its means. If 'action at a distance' be inadmissible (as Newton himself held it to be), the pull of gravity must be exerted through a medium; and common-sense insists upon its identification with the transmitting medium of light, as well as upon the identification of that with the transmitting medium of electricity. A genuine conformity to these demands of reason is vouched for, not only by Hertz's discovery that an electrical explosion starts an undulatory disturbance indistinguishable, except in scale, from luminous waves; but also by Dr. Lorentz's indicated conclusion that strains of the same ethereal essence bear the all-pervading mandates of gravity. The unity of the medium may, then, be regarded as finally ascertained; the complex interactions of sundry different 'fluids' need no longer be taken into account. To provide one with the capabilities implied by the services we perceive it to render is, indeed, a sufficiently formidable task.

In popular apprehension the ether of space figures as a finer kind of air. No idea could be more misleading. The elasticity by which air transmits the longitudinal waves of sound is totally different from the elasticity by which ether propagates the transversal waves of light. Air yields to pressure; disturbance hence produces in it undulatory condensations due to oscillations of the gaseous molecules along the line in which the audible commotion travels. Ether, on the contrary, appears to be entirely incompressible; it conveys no vibrations directed lengthwise. Now this is extremely perplexing. We have no experience of a kind of matter absolutely rigid to pressure, while yielding, albeit with intense reluctance, to distortional stresses.

A jelly-like solid makes the nearest, though a very distant, approach to fulfilling the indispensable conditions; and a solid ether was accordingly in vogue until long past the middle of the nineteenth century. For a solid it had very peculiar qualities; that, for instance, of offering no resistance to motion. It was, in truth, obviously a mere temporary expedient —a scientific fiction which might pass muster until replaced by something corresponding less distantly with the fundamental fact. At last, on the advent of the electro-magnetic theory of light and the modified conceptions which it brought in its train, the solid ether withdrew behind the scenes. Its properties, though inconsistent and unconvincing, had not been chosen arbitrarily; they were imposed by the necessities of the situation; and when these varied, speculators naturally had recourse to fresh inventions.

The most plausible is that of a medium neither solid, liquid, nor gaseous in the ordinary sense, but in the ideal state of a 'perfect fluid.' Out of such an ether Lord Kelvin, with exquisite ingenuity, constructed his 'vortex-atoms,' which 'had their day and ceased to be.' Other ideas now prevail. 'The present tendency of physical science,' the late Mr. Preston wrote in 1890,* 'is to regard all the phenomena of Nature, and even matter itself, as manifestations of energy stored in the ether.' The more closely we look into the things around us, the more strongly the persuasion is forced upon us that what we call ether,

* *Theory of Light*, second edition, p. 28.

electricity, and matter are really varied forms of one primal substance.

Two comprehensive schemes of molecular physics, resting upon the basis of this unifying thought, have lately been elaborated—one by Dr. Larmor, the other by Professor Osborne Reynolds. They have nothing in common beyond the largeness of their synthesis. In every respect they are radically unlike, save in regarding the intangible ether as the one material reality. Dr. Larmor, however, is not quite confidently explanatory. He presents no cut-and-dried theory of the universe; its haunting mysteries are not ignored in his efforts to rationalize them. He is vividly aware of the difficulties besetting the endowment of the ether with the type of elasticity which it is recognised to possess. He can only surmise that it results from particular modes of motion—from 'kinetic stability' ensuing upon a special dynamical state. The medium may thus be thought of as pervaded by 'a structure of tangled or interlaced vortex filaments, which might resist deformation by forming a stable configuration.'* But the

* *Encyclopædia Britannica*, vol. xxv., p. 106.

details of any such scheme of action are evidently far too intricate to be easily unravelled; what concerns us here is to point out that no simple structureless fluid can avail to maintain cosmical communications.

Reduced to its lowest terms, Dr. Larmor's conception of the ether is that of a 'rotationally elastic medium.'* In other words, it resists being turned round an axis. The forces continually acting upon it are nevertheless of a gyratory nature; and hence arise strains, betrayed to our apprehension by electrical manifestations. Each 'electron' is held to be the nucleus of some kind of distortion or displacement,† and carries with it, as it moves, a field of force. Out of these 'point charges' material atoms are variously built up. They are 'structures in the ether,' encompassed by 'atmospheres of ethereal strain,' not—as they were formerly taken to be—'small bodies exerting direct action at a distance on other atoms according to extraneous laws of force.'‡ Obviously the new view brings to the front

* *Report of the British Association*, 1900, p. 626.
† *Æther and Matter*, p. 26.
‡ *Nature*, vol. xlii., p. 453.

extremely subtle questions regarding the nature of 'dynamical transmission'*—what the propagation of energy essentially consists in, and by what mechanism it is effected; and they are, for the present, unanswerable. Electricity is, on the theory we are attempting to sketch, positive or negative according to the direction of the originating strain. A positive electron might be imagined to resemble a spiral nebula of the right-handed sort, a negative one a left-handed spiral, or *vice versâ.* The analogy is, perhaps, fanciful; yet it helps towards obtaining a mental picture of objects which, insignificant and elusive though they appear, may be the initials and ultimates of this strange world.

The forces, at any rate, by which it is at present kept going are evoked *ad libitum* by the pioneers of modern research from the ethereal plenum. The actualities of matter are potentialities in the ether. 'All mass,' in Professor J. J. Thomson's opinion, 'is mass of the ether, all momentum, momentum of the ether, and all kinetic energy, kinetic energy of the ether.† Only if this be so,' he adds, 'the

* Larmor, *Report British Association*, 1900, p. 625.

† *Electricity and Matter*, p. 51.

density of the ether must be immensely greater than that of any known substance.'

The condition is startling, but in dealing with such subjects we must be prepared to meet with anomalies. They come, as the ghosts appeared to Odysseus in Hades, at first one by one, then in an awe-inspiring swarm. Yet, in spite of the perplexities they occasion, we can discern, with growing sureness of insight, the amazing reality of the universal medium. It is, in a manner, the only reality. For what is manifest to sense is subject to change. We can conceive that the visible framework of material existence might crumble and dissolve, like 'the baseless fabric of a vision,' into seeming nothingness. But a substance that is inapprehensible is, to our limited ideas, imperishable. The ether is assuredly the seat of intense activities, which lie at the root, most likely, of all the processes in Nature. An absolutely uniform medium, however, can scarcely be imagined to energize or react. Some kind of heterogeneity it must possess; and the heterogeneity produced, in Dr. Larmor's view, by strains, is associated, in Professor Reynolds's theory, with intrinsic texture.

The 'Sub-Mechanics of the Universe' are here made to depend upon the fitting together of ineffably small, ideally rigid grains. A misfit gives rise to matter, which might hence be defined as 'ether out of joint'; and the misfit can be propagated endlessly from one range of granules to the next. This propagation through the ether of an abnormal arrangement of its constituent particles, without any transference of the particles themselves, explains the phenomena of matter in motion. A concrete existence belongs to the ether alone. It is composed of round aboriginal atoms, the diameters of which measure the *seven hundred thousand millionth part* of the wave-length of violet light.* They are packed closely together, yet not so closely but that free paths are left to them averaging in length the *four hundred thousand millionth part* of their diameters.

This inconceivably small relative motion suffices, nevertheless, to render the medium elastic; is, indeed, 'the only cause of elasticity in the universe, and hence is the prime cause of the elasticity of matter.' The medium so

* *The Structure of the Universe*, Rede Lecture, June 10, 1902, p. 14.

formed is ten thousand times denser than water; it exerts a mean pressure of 750,000 tons on the square inch; the coefficient of its transverse elasticity is $9+10^{24}$ (in C.G.S. units); which gives a velocity of transmission identical with that of light for vibrations of the same type, while longitudinal waves are propagated 2·4 times more rapidly. The scheme further includes a plausible rationale of gravity and of electrical effects; so that there is much to warrant the claim of its author to have excogitated 'the one and only conceivable purely mechanical system capable of accounting for all the physical evidence, as we know it, in the universe.'

The machine, to be sure, lacks motive power; but that is a want which no human ingenuity can supply. Its source is obscured in the primal mystery of creation. And as regards the preliminary assumptions required for the constitution of an atomic ether, inclined though we might be to cavil at them, we should, perhaps, act more wisely in following Dr. Larmor's advice by abstaining from attempts to explain 'the simple group of relations which have been found to define the activity of the ether. We should rather rest satisfied,' he tells us, 'with having attained to their exact dynamical correlation, just as geometry explores or correlates, without explaining, the descriptive and metric properties of space.'* Yet one cannot help remarking that the properties of space are not ordinarily modified to suit the needs of demonstration, while those of the ethereal medium are varied at the arbitrary discretion of rival cosmogonists. In the future, when they come to be more clearly ascertained, they will, perhaps, form the basis of a genuine new science. Already, the study of ethereal physics excites profound interest and attention. Nor is it possible to ignore the gathering indications that it will impose qualifications upon principles consecrated by authority and hitherto regarded as fundamental.

The grand modern tenet of the conservation of energy, for example, may need a gloss; it may prove to be admissible only with certain restrictions. The second bulwark of the scientific edifice is even more seriously undermined. For the 'strain theory' of atomic constitution necessarily includes the conception

* *Nature*, June, vol. lxii., p. 451.

of opposite distortions corresponding to positive and negative electricity. And the further inference lies close at hand that these, by combining, may neutralize one another. The coalescence, then, of a positive and negative electron should result in the smoothing out of the complementary strains they stand for; and there would ensue the annihilation of a pair of the supposed ultimates of matter. The event might be called the statical equivalent of the destruction of light through interference. That its possibility should be contemplated even by the most adventurous thinkers is a circumstance fraught with meaning as to the subversive tendencies of recent research.

Already, in May, 1902, Professor J. A. Fleming* pointed out that 'if the electron is a strain-centre in the ether, then corresponding to every negative electron there must be a positive one. In other words, electrons must exist in pairs of such kind that their simultaneous presence at one point would result in the annihilation of both of them.' The consequence thus viewed in the abstract finds

* *Proceedings of the Royal Institution*, vol. xvii., p. 177.

concrete realization, if Mr. Jeans's suggestion be adopted,* in the processes of radio-activity, which possibly consist 'in an increase of material energy at the expense of the destruction of a certain amount of matter. There would, therefore, be conservation neither of mass nor of material energy.'

No longer ago than at the opening of the present century such notions would have been scouted as extravagant and paradoxical; now there is no escape from giving them grave and respectful consideration. Scientific reason has ceased to be outraged by hypotheses regarding the disappearance of mass and the development of energy. Mass and energy may, after all, be interchangeable; they are, at any rate, kept less rigidly apart in our meditations than used formerly to be the case. Nor can we assert with any confidence that partial subsidences into or emergences from the surrounding medium are for either a sheer impossibility; the universal framework, on the contrary, presents itself to us in the guise of an iridescent fountain leaping upward from, and falling back towards, the ethereal reservoir.

* *Nature*, vol. lxx., p. 101.

To the very brink of that mysterious ocean the science of the twentieth century has brought us; and it is with a thrill of wondering awe that we stand at its verge and survey its illimitable expanse. The glory of the heavens is transitory, but the impalpable, invisible ether inconceivably remains. Such as it is to-day, it already was when the *Fiat Lux* was spoken; its beginning must have been coeval with that of time. Nothing or everything, according to the manner in which it is accounted of, it is evasive of common notice, while obtrusive to delicate scrutiny. Its negative qualities are numerous and baffling. It has no effect in impeding motion; it does not perceptibly arrest, absorb, or scatter light; it pervades, and may even share in the displacements of gross matter; yet its motion (if it do move), is without effect on the velocity of light.

Looking, however, below the surface of things, we find the semi-fabulous quintessence to be unobtrusively doing all the world's work. It embodies the energies of motion; is, perhaps, in a very real sense, the true *primum mobile;* the potencies of matter are rooted in it; the substance of matter is latent in it; universal intercourse is maintained by means of the ether; cosmic influences can be exerted only through its aid; unfelt, it is the source of solidity; unseen, it is the vehicle of light; itself non-phenomenal, it is the indispensable originator of phenomena. A contradiction in terms, it points the perennial moral that what eludes the senses is likely to be more permanently and intensely actual than what strikes them.

CHAPTER XII

THE FORMS OF NEBULÆ

SIR WILLIAM HERSCHEL'S celestial surveys first made the classification of nebulæ practicable. Until he began grinding specula at Bath very few such objects were known, and those too imperfectly for the effectual discrimination of their differences. Arrangement presupposes comparison, and comparison some variety of specimens to be compared, which became available only through Herschel's scrutiny. The rapidity and penetrative power of his observations in this field almost passes belief. He detected with discernment. Discovery and enrolment did not satisfy him ; he was, besides, keen to note analogies and contrasts, likenesses and dissimilitudes. He could not see without at the same time setting in order what he saw; and the law of order that commended itself to him was founded on an evolutionary principle. The contents of the heavens seemed to fall spontaneously, as he regarded them, into genetic sequences; and the nebulæ with particular facility. The criterion adopted was that of progressive condensation. Development must clearly, he judged, be attended by contraction and local brightening. Diffused milky tracts represented cosmic formations in their most rudimentary form; they assumed, through the unremitting action of gravity in drawing their particles together, a more compact texture, more definite shapes, and a heightened lustre.

But things have changed somewhat in aspect during the last hundred years. Herschel's simple regulative plan, although of unquestioned validity, needs to be supplemented and controlled. Much auxiliary knowledge has been acquired since it was formulated. In attempting to estimate the comparative antiquity of nebulæ, we no longer depend exclusively upon one set of indications. The conclusions drawn from their immediate inspection can at least be checked by the study of their spectra and distribution.

The Milky Way might be figuratively described as the nursery-garden from which the parterres of the universe are stocked. A primitive condition is usually assigned, not without good reason, to any class of objects markedly tending to collect in its plane. And this is the case with gaseous or 'green' nebulæ. Moreover, their materials appear to be in a highly elementary state (if it be permissible to speak of one kind of matter as more elementary than another); their spectra including no rays due to metallic incandescence, but mainly those of nebulium, hydrogen, and helium. These substances, inconceivably attenuated, constitute the vast irregular formations placed by Herschel at, or near, the start of cosmical development. And so far he has been justified by the outcome of modern research. But he has not been justified in his description of planetary nebulæ as 'very aged, and drawing on towards a period of change or dissolution.' For, despite their determinate shape and definite boundaries, they do not appreciably differ in composition from nebulæ of the irregular class, and must be reckoned as, in a manner, coeval with them.

There is, on the whole, a concurrence of evidence that gaseous nebulæ are at a very early stage of growth. They are the least elaborated of sidereal objects; they seem, many of them, barely to have crossed the threshold of creation. Yet their mutual relations in time are by no means obvious. They cannot easily be disposed in any kind of rational sequence. Each of the great nebulæ, at any rate, exhibits features and occupies a position shared by none of its fellows. The most discerning cosmologist cannot pretend to say that the Argo nebula, say, is of greater or less antiquity than the Orion or the 'America' nebula. They are individual growths, simultaneous, not successive. The line of development suggested by their relationships is rather towards the formation of star-clusters than of diverse nebular species. Thus, the Pleiades illustrate not improbably the future condition of the Orion nebula, the contained stars having gained predominance over their misty envelopments, though fragmentary swaddling-bands, later, presumably, to be shaken off, still adhere to many of them.

Planetary nebulæ have much more in

common than irregular nebulæ, and their minor varieties might, with some plausibility, be associated with differences in relative age. They are marked chiefly by the character ot the nuclear star which, in nearly all such objects, appears to act as the pivot of the surrounding vaporous structure. The supposition lies close at hand that it is designed as a provision for the nourishment of the star—that the star gains in mass and light at the expense of the nebula, which it is eventually destined wholly to absorb and supersede. On this view, planetaries like the green glow-lamp at the pole of the ecliptic (N.G.C. 6,543) should be regarded as the most advanced, while Webb's planetary in Cygnus (N.G.C. 7,027) would exemplify an inchoate condition. In the former the central star is of 9·6 magnitude, and sharply stellar; in the latter it is double and diffuse,* perhaps a wide binary system in embryo.

The question is, however, still open as to the real nature of the connection between planetaries and their central stars. The pabulum theory is a promising conjecture; but no facts

* Keeler, *Lick Publications*, vol. iii., p. 214.

with which we are acquainted stringently enforce it. Ideas on the subject will need complete revision if the traces of spirality noted from time to time in some of these peculiar objects prove to be of radical significance. The *oculi*, distinctive of the 'Owl nebula' (N.G.C. 3,587), as originally shown by the Parsonstown reflector, consisted of luminous traceries coiled round *two* interior stars,* but the appearance was either due to illusion, or became effaced by change, since the camera has refused to endorse it as genuine. The 'helical' planetary in Draco† is doubtless essentially a spiral conformation;‡ and Professor Schaeberle, by means of exposures with a 13-inch reflector of 20 inches focus, has compelled, not only the Ring nebula in Lyra,§ but the Dumb-bell in Vulpecula, to betray the surprising secret of their whorled structure. Both these nebulæ give a spectrum of bright lines, and inventive-

* Rosse, *Transactions Royal Dublin Society*, vol. ii., p. 93.

† First detected as such by Holden and Schaeberle in 1888, *Monthly Notices*, vol. xlviii., p. 388.

‡ Deslandres, *Bulletin Astronomique*, February, 1900.

§ *Astronomical Journal*, Nos. 539, 547.

ness is at a loss to devise means for building up gaseous materials into edifices of strongly characterized architectural forms. The materials, indeed, may not be wholly gaseous;* or we possibly see (as Professor Darwin long ago suggested) merely illuminated stream-lines of motion furrowing an obscure mass. But if this be indeed so, there is the further question to be asked: What direction does the motion take? Do the tides set inward or outward?

Our spontaneous impressions are all in favour of concentrative tendencies. We cannot easily shake off centripetal prejudices. Our lives are passed under a regimen of central attraction, and we naturally incline to universalize our experience. Herschel's scheme of sidereal evolution invites accordingly at first sight ready acceptance. Stars seem as if they could not act otherwise than as foci of condensation in nebulæ; the lucid stuff involving them must, apparently, with the lapse of ages, settle down towards their surfaces, and become absorbed into their substance. Such processes, indeed, belong, unless counteracted by different

* Maunder, *Knowledge*, vol. xix., p. 39.

modes of action, to the inevitable order of nature; but these may, and probably do, exist. From sundry quarters the conviction is pressed upon us that cosmic bodies can drive out matter as well as draw it in. Repulsive forces insist upon recognition, and their effects become more palpable the more attentively they are considered. Under certain conditions they get the better of gravity; and stars may possibly, like cocoon-spinning insects, expend their organic energies in weaving themselves faintly lucent envelopes, the products of subtle and unaccountable activities.

The example of Nova Persei is fresh in every mind, but we make no pretension to decide the controversy it raised. A dogmatic pronouncement is unadvisable where the unknown elements of the question obscure and outweigh those that are known. A less slippery foundation for reasoning is afforded by the permanently visible spiral nebulæ, and features charged with an emphatic meaning have been revealed in them by photographic means.

Looking at the entire contents of the nebular heavens, we find the spiral type very largely predominant. It claims more specimens, and emerges more distinctly with each development of delineative power. Its chief prevalence is among 'white' nebulæ, showing continuous spectra.

They are vastly numerous. Gaseous nebulæ are reckoned by the score, white nebulæ by tens of thousands. Moreover, they collect near the poles of the Milky Way,* while the gaseous variety crowd towards its plane, both branches of the family thus manifesting galactic relationships, though of an opposite character. Now, these facts of distribution have some bearing on the question of relative age. There is, as already remarked, a consensus of opinion that objects showing a marked preference for the Milky Way are in a more primitive state than those withdrawn from it, and the inference is supported by the circumstance that nebulæ situated in high galactic latitudes shine with continuous light, those near the galactic equator with vivid lines. Yet it would be rash to assume that any individual nebula

* Dr. Max Wolf places the point of nebular concentration in R.A. $12^h\ 53^m$, D. $+61°\ 20'$, that assigned to the galactic pole being in R.A. $12^h\ 49^m$, D. $+62°$. *Königstuhl Publ.*, Bd. I., p. 174.

traverses these successive stages. The series would be satisfactorily established only if we could point to a number of intermediate instances, which seem to be almost wholly lacking. We cannot trace in nebular as we can in stellar growth the insensible gradations of progressive change. They are perhaps complicated in nebulæ by influences of a different kind from those which have gained the ascendancy in stars. Diffusive effects may in them be more conspicuous than concentrative effects;* or a balance may be temporarily struck between antagonistic tendencies.

Spiral conformation is the real crux of nebular cosmogony. The conditions from which it arises are met with only in the sidereal heavens, but are there widely prevalent. Though remote from our experience, they are fundamental in the realms of space. If we could define and comprehend them, we should be in a better position for determining the cosmical status of nebulæ.

The choice is open between two rival theories of nebulous spirals. The first is the more

* T. J. J. See, 'Repulsive Forces in Nature,' *Popular Astronomy*, No. 100, December, 1902.

obvious, and readily falls in with admitted mechanical principles. Sir Robert Ball has adopted and ingeniously advocated this view.

A globular collection of promiscuously revolving particles inclines, if left to itself, to flatten down into a disc. The reason is this: In a system of the kind moment of momentum is invariable, while energy constantly diminishes. To render the contrast intelligible we have only to consider that moment of momentum is the algebraic sum of all the products of mass and motion in the aggregation, reduced to, or projected upon, its 'principal plane,' while energy is independent of the varied directions of velocity. Collisions consequently involve no diminution of moment of momentum, but combine with radiative waste to produce a steady loss of energy. Inevitably, then, the system will assume the form in which it possesses the minimum of energy that is consistent with the maintenance of its original momentum; and it is that of a disc extended in the principal plane. Retrograde movements will by the time this shape is definitively arrived at have become eliminated; the constituent particles circulate unanimously in one direction;

and Sir Robert Ball adds that their circulation, owing to the more rapid rotation of the central mass, is along spiral paths.* They would accordingly present the twisted conformation so commonly observed in the heavens, and might even include subordinate centres of attraction, fitted to ripen and strengthen into a full-blown retinue of planets. Such are spiral nebulæ regarded in their direct mechanical aspect. Spherical nebulæ are their immediate progenitors; suns, with or without trains of dependent worlds, their lineal descendants.

Let us, however, consult some autographic records and weigh attentively what these peculiar objects tell us about themselves. We see at once that their curving lines, far from being laid down at the dictate of chance, follow a strictly defined plan. Spiral nebulæ are not formed like watch-springs by the windings of a single thread. They are always two-branched. From opposite extremities of an elongated nucleus issue a pair of nebulous arms, which enfold it in double convolutions. Their apparent superposition and interlacements occasion, in the Lyra nebula, the noted

* *The Earth's Beginnings*, pp. 243-247.

effect of a fringed and ruptured annulus, and it is of profound interest to perceive that even in gaseous masses the same constructive rule prevails as in the great Whirlpool in Canes Venatici.

Yet this circumstance is well-nigh irreconcilable with the hypothesis that an influx of material is in progress.* Falls due to gravity could not be limited to two narrow areas on the central body. Matter ejected from it might, on the other hand, quite conceivably follow this course. Interior strain could easily be supposed to cause yielding along a given diameter, and nowhere else. Solar disturbances partially and dimly illustrate such a kind of activity. Diametrically opposite prominences are not unknown. They indicate the action of an explosive force right across the solar globe. Similarly, the formation of a spiral nebula cannot be rightly apprehended otherwise than as the outcome of long-continued, oppositely-directed eruptions.

The history of the heavens involves the law of spirality. The scope of its dominion continually widens as research becomes intensified. The Huygenian 'portent' in the Sword of

* *Cf.* Moulton, *Astrophysical Journal*, vol. xxii., p. 165.

Orion now figures as merely the nucleus of the 'great winding Nebula' photographed by Professor W. H. Pickering in 1889. That the vast nebulosity encompassing the Pleiades is an analogous structure seems eminently probable, though the brilliancy of the enclosed stellar group obliterates most traces of its ground-plan. The magnitude of the mixed system, we are told by Professor Barnard,* who detected it in 1893 by means of a ten hours' exposure with the Willard lens, transcends our powers of realization. It covers 100 square degrees of the sky with intricate details. Again, some four minutes of arc to the north-west of the Ring in Lyra lies a small nebula discovered visually by Professor Barnard in 1893, and photographically resolved by Keeler into a delicate spiral. It is a two-branched, left-handed spiral, as the large adjacent object has also proved to be. One is, in fact, the miniature of the other, and they are now shown, by Professor Schaeberle's short-focus reflector, to be linked together by curving folds of nebulosity into a compound spiral system. The Dumb-bell is held, on the

* *Monthly Notices*, vol. lx., p. 259.

same authority, to be similarly conditioned, and the analogy frequently noted between its aspect and that of the Ring nebula has thus become incalculably widened in scale.

The galactic relations of the Magellanic Clouds are not easily defined. They are within the Milky Way, yet not of it. Enigmatical excrescences upon the universe, they suggest an origin from gigantic eddies in the onflowing current of sidereal arrangement. Their miscellaneous contents are, to all appearance, disposed along eddying lines. Mr. H. C. Russell's photographs* rendered this, in 1890, to some extent manifest, and their indications were ratified by the Arequipa plates, from the study of which Professor Pickering gained the conviction that the great Looped Nebula, 30 Doradûs, is the structural nucleus of the Nubecula Major. 'It seems,' he wrote,† 'to be the centre of a great spiral, and to bear the relation to the entire system that the nebula in Orion bears to the great spiral nebula which covers a large part of that constellation.'

On all sides, in the sidereal heavens, we can

* See *Knowledge*, vol. xiv., p. 50.

† *Harvard Annals*, vol. xxvi., p. 206.

discern the signs of the working of a law of convolution. Sometimes they are patent to view; sometimes half submerged; but they can generally, with attention, be disentangled from overlying appearances. They are exhibited by stars no less than by nebulæ, as the late Dr. Roberts pointed out from convincing photographic evidence; the 'hairy' appendages of globular clusters betray them by their curvilinear forms; they meet us in every corner of the wide nebular realm. Many investigators recognise in the Milky Way itself the stamp of spirality. Stephen Alexander, of New Jersey,* regarded the majestic galactic arch as a four-branched spiral, resulting from catastrophic breaches in a primitive, equatorially loaded spheroid, the currents of matter ejected by which should, owing to their lower angular rotation, lag behind as they retreated from the nucleus, and thus flow along helicoidal lines. R. A. Proctor subsequently devised convoluted galactic streams, which, however, corresponded imperfectly with what the sky showed. And Dr. Easton† has designed by way of simple

* *Astronomical Journal*, vol. ii., p. 100, 1852.

† *Astrophysical Journal*, vol. xii., p. 158.

illustration an elaborate series of spires, originating possibly from a central galactic condensation, the projection of which upon the sphere may, he thinks, account for the known peculiarities of the Milky Way.

Our interior situation, nevertheless, makes it extremely difficult to determine the real relations in space of the star-streams circling around it. The observed facts are, perhaps, equally compatible with many other structural schemes besides those based on the idea of spirality; and it will be prudent to adopt none, for the present, with settled conviction. We can, however, gather one sufficiently definite piece of information regarding the history of the Cosmos. All the inmates of the heavens, stellar and nebular, represent quite evidently the débris of a primitive rotating spheroid. Its equator is still marked by the galactic annulus, its poles by a double canopy of white nebulæ. The gyrating movement which it once possessed as a whole doubtless survives in its parts, but ages must elapse before the fundamental sidereal drift can be elicited.

CHAPTER XIII

THE PROCESSION OF SUNS

PHENOMENA are functions of time, and the form of the function has to be determined in each particular case. That is what the historical method comes to, and its use is prevalent and almost compulsory. We can no longer be satisfied with a simple bird's-eye view of the universe; our thoughts are irresistibly driven to grope into its past, and to divine its future. Statical conceptions sufficed for our intellectual forefathers. They aimed at establishing the equilibrium of things, while we see them in a never-ending flux. One aspect of them calls up the next, and that another, and so on *ad infinitum;* we cannot, if we would, balance our ideas on the pivot of the transient present.

The immutable heavens of the ancients

strike us to-day as the invention of a strange race of beings. We see them, on the contrary, with Shelley as a 'frail and fading sphere,' a 'brief expanse,' the seat and scene of change. The 'fixed' stars long ago broke away from their moorings, and began to flit at large through space. Of late a less obvious, more intimate kind of mobility has been attributed to them. Grooves of individual development have been assigned to them, along which they appear to shift as the tardy ages go by; and since everything that grows must decay, the orbs of heaven, too, incur the doom of mortality. But modern science has done much more than extend to them the dismal philosophy of the phrase, 'Tout passe, tout casse, tout lasse.' The grandiose enterprise has been not unsuccessfully essayed of tracing in detail the progress of sidereal evolution, and of marshalling the vast stellar battalions in order of seniority. This has been rendered feasible by the disclosures of the spectroscope. Apart from their guidance, the track might have been seen by elusive glimpses, but could never have been laid down with any approach to definiteness. Herschel found for it a *terminus à quo* in nebulæ of various forms, but attempted to pursue it no further. We do not hesitate to run it on, from station to station, right down to the *terminus ad quem.* Not, it is true, without the perception of outstanding difficulties and insecurities, which yet seem to be outweighed by a certain inevitableness of self-arrangement in the related facts.

The argument from continuity is that mainly relied upon. An unbroken succession of instances is strongly persuasive of actual transition, provided only that a principle of development (so to call it) may reasonably be assumed as influential. A series of mineralogical specimens, however finely differenced, does not suggest the progressive enrichment of one original mass of ore. In the stars, on the other hand, a species of vitality may be said to reside. They are not finished-off products, but spontaneously-acting machines. They are centres of energy, which they dispense gratis, supplying the cost out of their own funds. And the process is not only obviously terminable, but must be accompanied by constitutional alterations, which might be traceable by subtle methods of inquiry. They *are* traceable, unless we are deceived by illusory appearances.

Secchi's classification of the stars was unwarped by any speculative fancy. It was purely formal; it aimed only at providing distinct compartments for the convenient arrangement of a multitude of differently characterized items of information. Then, by degrees, the closeness of the gradations between one class and the next came to be noticed; partitions melted away; the methodized array showed itself to be in movement; and the bare framework took shape, under the auspices of Zöllner and Vogel, as a cosmic pedigree. The white stars were set forth as the progenitors of yellow, yellow of red stars; and the insensibly progressive reinforcement of the traits of relationship between the successive types went far towards demonstrating some partial, if not a complete, correspondence of the indicated order with the truth of things. It has since been found necessary to divide the first stellar class into helium and Sirian stars; and here, too, essential diversity shades off imperceptibly into likeness approximating to identity. All the groups hang together; the entire scheme is on an inclined plane of change. Helium stars, as they condense, pass into Sirian, these into solar stars, which finally, reddening through the increase of absorption, exhibit the badge of post-meridional existence in fluted spectra. The finality of the red stage is, indeed, very far from being absolute, but what lies beyond is matter of conjecture.

There are several good reasons for taking helium stars to be the 'youngest' or most primitive of the amazing assemblage that sparkle in the vault of heaven. The first is their affinity with nebulæ. Every star, perceived to be involved in folds or effusions of shining haze, has yielded—if bright enough for profitable examination — a spectrum of helium quality. Further, they are remarkably tenuous bodies. It has been ascertained with approximate certainty, from the investigation of stellar eclipses, that helium stars are commonly, perhaps invariably, of far slighter consistence than the sun. Radiation, however, is maintained by contraction; hence, orbs at the outset of their course must be, on the whole, the most diffuse. A third note of youth is membership of embryo systems, and this is affixed very markedly to helium stars. One-third certainly, probably one-half of those lately submitted to trial by Professors Frost and Adams proved to have spectroscopic companions. They are pairs believed to have been recently divided by the fission of a single parent-globe. And this is an operation which must, we should suppose, be undergone early, or not at all.

The spectra of helium stars are peculiar and suggestive. Those belonging to Miss Maury's earliest groups—many of them visibly nebulous—bear next to no traces of metallic absorption, showing instead lines of oxygen, of nitrogen, and of hydrogen in all its three series. The conditions, accordingly, needed to produce the 'cosmic' modification of hydrogen are realized in these inchoate bodies. What those conditions actually are we cannot tell, yet it may be confidently surmised that they will prove to be of an electrical nature. Hydrogen resembles the metals in being electro-positive; it collects at the negative pole during the electrolytic decomposition of water. There is, however, an unmistakable tendency in primitive sidereal objects to display absorption rays of electro-negative rather than of electro-positive elements. It is conceivable that hydrogen may be capable of altering its behaviour in this respect, and that the molecules radiating the Pickering and Rydberg series, in addition to the more familiar Huggins series, have, in fact, through some corpuscular rearrangement, assumed the electro-negative quality properly characterizing a non-metallic substance. The association of this form of hydrogen with oxygen and nitrogen in early helium stars would thus be naturally related to the simultaneous quasi-disappearance from them of the spectral badges of metals.

The helium-line most distinctive of this stellar family is situated well up in the blue. It appertains to the same vibrational sequence with D^3, which is also represented in Rigel, one of the more 'advanced' Orion stars. In Rigel, too, we meet a fairly prominent magnesium ray, lying below the blue helium emanation, while as yet iron is unapparent. Numerous fine, faint streaks, due to its absorption, only emerge when the Sirian type is fully reached, and they are mostly of the 'enhanced' kind. When the spark discharge is substituted for the arc as the source of illumination, certain lines in the resulting spectrum brighten relatively to the others, and these have been distinguished by Sir Norman Lockyer as 'enhanced.' Now, the rule is strikingly prevalent that the absorption rays in white stars are of this class; yet it can no longer be interpreted as indicating for them an excessively high temperature. Rather, it would seem that electrical conditions still imperfectly defined are in question, and their gradual removal or subsidence is, beyond doubt, largely instrumental in bringing about the transition to the solar stage. The effacement of helium-absorption is even more perplexing. No sooner does iron begin to show than it vanishes. There is still a faint trace of its 'blue' line in Vega; none survives in Sirius.

In spectra of the solar type two great bars of violet light are stopped out by calcium; otherwise metallic arc-lines predominate, while those of hydrogen are no longer so powerfully emphasized as in white stars. Moreover, the whiteness of the unveiled Sirian photospheres has become tinged with yellow owing to the development of a shallow envelope partly impermeable to blue rays. For this reason the comparative extension of their ultra-violet spectra affords, for stars of different types, no secure criterion of relative temperature. Sound in principle, it becomes inapplicable when the unknown factor of general absorption comes into play. The energy-curve of the solar spectrum, as it is, can be determined; the energy-curve of the solar spectrum, as it would be if unaffected by general absorption, has to be constructed from inference. But only photospheres bare to space give comparable results. Hence, there are no valid grounds for asserting that Sirius is hotter than the sun, or the sun than Betelgeux. It may be so, but the evidence at present available is inconclusive. The appearances expounded in this sense may bear quite different meanings.

The reasons for holding that solar mature into Antarian stars are of the same character, and of equal cogency with those tending to prove their own development from luminaries of Sirian type. There is a similar continuity of specimens. They can be ranged one after another in an unbroken series, in which, as we run down the line, primrose shades into orange, and orange into red; general absorption arrests an increasing percentage of the blue radiations, while specific absorption becomes strengthened by dusky channellings of titanium. Carbon stars are less easily located. Dr. Vogel regards them as coordinate with the Antarian class. The two varieties of red stars with banded spectra descend, in his opinion, from the common stock exemplified by our sun. Professor Hale also favours this view, some attendant difficulties notwithstanding. His photographs have certainly established for carbon stars links of relationship both with the Antarian and the solar families; yet the fact remains indisputable that the carbon type is, to a great extent, isolated from all the rest. Tokens of a genuine migration towards it are few and obscure.

The ultimate fate of both tribes of red stars can only be conjectured. Most of the objects constituting them vary in brightness, some to the verge of periodical extinction; and variability may be a symptom of interior dilapidation. But the organization of such bodies is profoundly enigmatical. They are exceptionally remote, and offer slight holding-ground for inquiry. No indications have been gathered as to their density or intrinsic light-power. Very little is known about their movements. They rarely form binary combinations, and those that they do form are almost always relatively fixed. No red star travels in a computed orbit; only one, η Geminorum, occurs on the long list of spectroscopic binaries. The revolutions of this curious system ought to prove, when thoroughly investigated, replete with interest and instruction.

Coupled stars present special opportunities to students of cosmogony. They are obviously contemporaries; they have started fair in the evolutionary race; identical influences have acted upon them; hence, differences in their standing can only result from dissimilarities in mass or composition. It is commonly taken for granted that a body containing less matter than its fellow must develop faster, and incur the final quenching sooner. But Sir William and Lady Huggins have adverted to the probability of the very opposite being the case.

Powerful surface-gravity may, they consider, serve to hasten the transition from a Sirian to a solar spectrum; and we should then have giant suns like Capella, advanced in type while at a very early stage of condensation. This perhaps explains the remarkable spectral relations of contrasted stellar pairs. Always, so far as we yet know, the Sirian spectrum is yielded by the lesser star, the mass of which, judging by analogy, must be even smaller than would be indicated by the proportion of its faintness. It is true that the distribution of mass in binary systems is often widely different from what might have been anticipated. Certain purplish satellites, for instance, of undetermined spectral quality exercise a gravitative sway of surprising force. Some results of this kind lately obtained by Mr. Lewis and others are likely to prove of fundamental importance to theories of stellar evolution.

What we know of 'dark stars' has been mainly derived from the observation of stellar systems. They are assumed to be the denizens of a stellar Hades, dim wanderers amid the shades, who 'have had their day, and ceased to be' as suns. In the 'cold obstruction' of these viewless orbs the grand cosmical procession is held to terminate. Their presence attests the downward progress of decay, and gives logical completeness to the argument for development. Yet there are circumstances warning us against too full an assurance that their status is really that of skeletons at the feast of light. They are very frequently found to be in close attendance upon brilliant white stars. Thus intimately, if incongruously, coupled, they circulate and compel circulation in brief periods, as members of systems just, it might be said, out of the shell. What are we to think, for instance, of the obscure body spectroscopically discovered to control the revolutions of the chief star in the Orion trapezium? It is evidently comparable in mass with that imperfectly condensed luminary. Is it credible that it has already traversed all the stages of stellar existence, and cooled down to planetary rank? So violent an assumption should at least not be made without due consideration; and we may more prudently hold our judgment in suspense as to whether globes so circumstanced—and they abound—

should be regarded as effete, or as abortive suns.*

Speculations on the exhaustion of stellar vitality have lately become inextricably involved with the complex problem of elemental evolution. A dim inkling has been acquired of the activity in the universe of obscure forces, availing, we can just see, to falsify many forecasts. The theory, among others, of the dissipation of energy needs to be revised or qualified. Nor was it propounded by Lord Kelvin with dogmatic certainty. He carefully noted the possibility that in 'the great storehouses of creation' reserves of energy might be provided by which the losses incurred through radiation could be, wholly or in part, made good.† The anticipated possibility is perhaps realized in the phenomena of radio-activity. But if we inquire how, we are met at the threshold by difficulties connected with the origin of helium. Helium

* It must at the same time be borne in mind that their total darkness is not proved. All that is certain is that their spectra are not bright enough to leave any impression on the exposed plates.

† Thomson and Tait, *Natural Philosophy*, Appendix E, p. 494, edition 1890.

appears to result from the disintegration of radium, its generation being accompanied by the setting free of enormous quantities of energy. Its copious presence, then, argues long-continued and lavish expenditure of heat and light. Yet it is as a constituent of highly primitive orbs that it is chiefly conspicuous. Gaseous nebulæ, too, include immeasurable supplies of it, while it is incompatible with whatever we seem to know about them to suppose that radium at any time entered into their composition.

The genesis of the elements has, in truth, not yet been made the subject of coherent speculation. Current ideas regarding it imply a double course of change, by aggregation first, and subsequently by disintegration. And this should give us a twofold series of elements. On one side there should be fixed survivals from the advancing process, on the other, products of decomposition, continuously evolved, and even now accumulating. If the claim of helium to take rank among these last should be finally established, our conceptions of the nature and history of nebulæ might have to undergo a strange inversion; but the outcome of the researches in progress is still uncertain, and may be far off.

It is, nevertheless, quite clear that the electronic theory of matter supplies no genuine explanation of the source of energy in the universe. What is given out when the atoms go to pieces must have been stored up when they were put together. Whence was it derived? This is the fundamental question which underlies every discussion concerning the maintenance of the life of suns. It is unanswered, and probably unanswerable.

CHAPTER XIV

OUR OWN SYSTEM

Our sun is clearly middle-aged. It bears none of the marks associated with juvenility in stars, while its decrepitude is in the distant future. It is crossing, most likely, a level tract where recuperation so nearly balances expenditure that radiation can be maintained for an indefinite time at a high and fairly uniform standard. Stars of the solar type pursue the even tenor of their way with particularly few interruptions. They show little tendency to intrinsic variability. Their periodicity, when it exists, is due to the presence of a companion. Variables, in other words, belonging to the spectral family of our sun, are binary systems; and they are usually, if not always, non-eclipsing binaries, on the pattern of δ Cephei. Light changes can thus be impressed upon sunlike stars by external influence; they do not conspicuously arise through native instability.

Our planet, accordingly, is attached to a safe and steady luminary, one subject, not to destructive spasms, but to vicissitudes so mild as to evade distinct meteorological recognition.* It is, moreover, governed by a polity settled on a broad basis of tranquillity and permanence. All this is as it should be. The conditions specified were a pre-requisite to the unfolding of human destinies. Nor can it be confidently asserted that they have been realized anywhere else. Our system may be unique; while, on the other hand, replicas of it might, imperceptibly to us, be profusely scattered through the wide realms of space. It is certain that a telescopic observer on Sirius or α Centauri would see our sun unattended; not even Jupiter could be brought into view by

* The uncertainty affecting the best attainable results in weather-cycle investigation is rendered strikingly apparent by a comparison of the able and laborious papers by H. W. Clough (*Astrophysical Journal*, vol. xxii., p. 42), and C. Easton (Petermann's *Geogr. Mittheilungen*, 1905, Heft VIII., and *Proceedings Amsterdam Academy of Sciences*, June 24, 1905).

optical appliances in any degree comparable to those at our disposal.

There are, nevertheless, strict limitations to the possible diffusion of planetary worlds like those that wander amid the zodiacal constellations. We have become aware of incapacitating circumstances, by which a multitude of stars are precluded from maintaining retinues of subordinate globes. Spectroscopic discoveries have compelled a revision of ideas as to cosmical arrangements. Especially the large proportion established by them of binary to single stars makes it impossible any longer to regard the solar system as a pattern copied at large throughout the sidereal domain. We cannot, then, compare it with any other; the mechanism of which the earth forms part must, perforce, be studied in itself and by itself, and it may, for aught that appears, be the outcome of special and peculiar design.

The machine in question is self-sustaining and self-regulating; no extraneous power noticeably affects its working. This immunity from disturbance is the fortunate consequence of its isolation. A great void surrounds it.

The span of Neptune's orbit is but a handbreadth compared with the tremendous unoccupied gulf outside—unoccupied, that is to say, by bodies of substantial mass. The feebleness of starlight relatively to sunlight affords some kind of measure of the impotence of stellar attractions to compete with the overruling gravitational power that sways the planetary circulation. This it is which gives to it such remarkable stability. The incomparable superiority of the sun over his dependent orbs not only safeguards them against foreign interference, but reduces to insignificance their mutual perturbations. Hence the strong concentration of force exemplified in our system—the absolutely despotic nature of the authority exercised—makes for a settled order by excluding subversive change.

The organization of the solar kingdom, as disclosed by modern research, is greatly more varied and complex than Laplace took it to be. His genetic scheme was, indeed, no sooner promulgated than deviations from the regularity and unanimity of movement upon which it was based began to assert their inconvenient reality. They have since multiplied; and, emerging to notice under the most unlikely aspects, they occasion incongruities which tax, for their explanation, all the resources and audacities of the most inventive cosmogonists. Let us briefly consider their nature.

The swarm of asteroids that bridge the gap between Mars and Jupiter revolve, it is true, with the general swirl of planetary movement; but they use a large license as regards the shape and lie of their orbits. And their partial exemption from the rules of the road becomes entire for comets and meteors, which have nevertheless proved themselves to be aboriginal in our system by their full participation in its proper motion. Finally, several of the major planets set convention at defiance in the arrangement of their several households, and thereby intimate departures from the supposed normal course of development so frequent and so considerable as to shake belief even in its qualified prevalence. Thus, the anomalously short period of the inner satellite of Mars, besides throwing doubt over its own mode of origin, tends to obscure the history of its more sedately circulating associate. Deimos cannot have been thrown off from its primary under conditions materially different from those attending the birth of Phobos.

The sub-systems of Uranus and Neptune exhibit, moreover, eddies of retrograde movement suggesting primitive disturbances of a fundamental kind; while the surprising disclosures connected with Saturn's firstborn and furthest satellite, photographically detected by Professor W. H. Pickering in 1898, have added one more knotted thread to the tangled skein we would fain unravel. Until acquaintance was made with Phœbe, counterflows of revolution within the same satellite-family were unknown, and, if contemplated at all, would have been scouted as impossible. One ternary star, to be sure—ξ Scorpii—had been recognised as probably owning an immediate and a more remote attendant, in oppositely directed orbital movement;* but the cases are in many ways disparate, and the analogy, though instructive, is imperfect.

If the ninth Saturnian moon is to be regarded as sprung from the condensing mass of the planet, a total change in the state of the parent body must have supervened during the

* R. T. A. Innes, *Reference Catalogue*, p. 155A.

long interval between its separation and that of its successor, Iapetus. The change, in Professor W. H. Pickering's opinion,* was nothing less than a reversal of axial movement. The nebulous spheroid destined to develop into the wonderful Saturnian system had, presumably, when Phœbe became detached from it, a diameter of sixteen million miles, and gyrated tranquilly from east to west, in a period of about a year and a half. But the action of sun-raised tides availed first to destroy and finally to invert this movement; for the natural outcome of tidal friction is synchronism, and this implies agreement, both in period and direction, between the rotation and revolution of the body acted upon. Acceleration through contraction did the rest; and by the time another satellite was ready to separate, the originating globe span normally in seventy-nine days, the actual revolutionary period of Iapetus. The view that such was the course of events is plausible at first sight; yet the doubt remains whether the cause alleged was

* *Harvard Annals*, vol. liii., p. 61, where, however, the reversal is explained by a shifting of the plane of rotation.

adequate to the effect produced. At the distance of Saturn, solar tidal friction exerts only about $\frac{1}{20000}$ its power on the earth;* its efficacy would, on the other hand, be greatly enhanced by the distension of the mass subjected to it; but approximately to what extent, our powers of calculation are impotent to determine.

This is not all. Exhaustive photographic research promises to unfold intricacies of construction in secondary systems demanding the patient industry of many generations for their complete unravelment. The families of the great planets will perhaps be found to include crowds of inferior members which pay slight heed in their circulatory arrangements to the trammels of convention. In those of both Jupiter and Saturn the phenomenon has lately been brought to light of 'asteroidal' satellites, as they may be termed, minute bodies travelling round their primaries at nearly the same mean distances, each group evidently representing the unagglomerated materials of a single full-

* G. H. Darwin, *Philosophical Transactions*, vol. clxxii., p. 526; Moulton, *Astrophysical Journal*, vol. xi., p. 110.

sized satellite. The pigmy components of such groups doubtless exist in multitudes; each great planet, most likely, is encompassed by at least one zone of moonlets; but so far only specimen-objects have been picked up. The tenth Saturnian satellite, discovered, like its predecessor, by Professor W. H. Pickering, is thus associated, by its period and locality, with Hyperion, the seventh and least prominent of Saturn's visual train, the apparent insignificance of which suggested to Sir John Herschel that it might have many co-occupants of the wide gap between Titan and Iapetus.* But the surmise had to await verification until methods were intensified beyond what seemed possible in the middle of the nineteenth century.

The corresponding Jovian pair found by Professor Perrine circulate far outside the boundaries of the original Galilean realm, in orbits which interlock as a consequence of their marked difference in eccentricity.† They are mutually inclined at an angle of 27 degrees, nor are they supposed actually to intersect, so

* *Monthly Notices*, vol. ix., p. 91.

† F. E. Ross, *Lick Bulletin*, No. 82.

that collisions are apparently out of the question. Direct movement is indicated, but cannot yet be claimed to belong quite certainly to both objects. We are only beginning to make acquaintance with the submerged populations of the Saturnian and Jovian kingdoms; they are perhaps multitudinous; they are certainly peculiar, and we await impatiently and curiously the further developments of their remarkable behaviour.

The one certain inference derivable from the diversity of facts ascertained within the last hundred years is that our world is not (so to speak) machine-made. The *modus operandi* employed to disengage the planets from their nebulous matrix was not of cast-iron rigidity; it was adaptable to circumstances; it left room for the display of boundless inventiveness in details. This was made, nevertheless, to consist with the perfect preservation of the main order, both in design and operation. The general plan is broadly laid down and unmistakable; the springs of the machine are undisturbed in their free play, and for the primary reason that departures from regularity, which might, in any way, prove a menace to stability, affect bodies of negligible mass. The great swing of settled movement goes on irrespectively of them. 'De minimis non curat lex.'

So the erratic procedure of comets is harmless only because of their insignificance. If imitated by substantially attractive masses, it could not fail to jeopardize the planetary adjustments. Even the asteroids would be unsafe neighbours but for their impotence; and it is remarkable that Mercury, by far the smallest of the major planets, circulates along a track of the asteroidal type. It would seem as if an important size carried with it an obligation to revolve in an orbit of small eccentricity, inclined at a low angle to the principal plane of the system. The reason why this should be so is not obvious; but were it otherwise the equilibrium, now so firmly established, would subsist precariously, or not at all.

The assertion, indeed, that it is firmly established can only be made under reserve. We are ignorant of any causes tending towards its overthrow; yet they may supervene, or be already imperceptibly active. One such lurking possibility is the presence of a resisting medium in interplanetary space. Waifs and strays of matter must, beyond doubt, be encountered there—outlawed molecules, self expelled from the gaseous envelopes of feeble globes; thin remnants of cometary paraphernalia, driven off amid the fugitive splendours of perihelion; products of ionic dissociation set flying by the impact of ultra-violet light—and all disseminated through an ethereal ocean, which 'is cut away before and closes from behind' as moving bodies traverse it. That its indifference is shared by ordinary material substances, when in the last stage of attenuation, is a plausible but unverified conjecture. It is only safe to say that retardation of velocity in what may pass for empty space is insensible or null.

There may, nevertheless, be springs of decadence in the solar system. Some of them have been discussed by M. Poincaré,* whose confidence in the reassuring demonstrations of Laplace and Lagrange is inversely proportional to the magnitude of the terms they were forced to neglect. They dealt with fictitious globes, devoid of appreciable dimensions, and

* *Annuaire du Bureau des Longitudes*, 1898.

swayed by the strict Newtonian law. But the real planets and their satellites are acted on by other forces as well, frictional, magnetic, radio-repulsive, the joint effects of which may not be wholly evanescent. The tidal drag on rotation undoubtedly occasions a small but irretrievable loss of energy. The moon, for instance, as M. Poincaré states, now gains, by the reactive consequences of tidal friction in widening its orbit, no more than $\frac{1}{28}$ the *vis viva* of which the earth is deprived by the infinitesimal slowing down of its rotation; and the remaining $\frac{27}{28}$, being dissipated abroad as heat, are finally abstracted from the system.

The ultimate state, we are told, towards which the planetary mechanism tends is that of the synchronous revolution, in a period of about twelve years, of all its members. This might, apart from the possibility of a resisting medium, have indefinite permanence; otherwise precipitation to the centre would gradually ensue, and one solitary sphere, cold, stark, and unilluminated, would replace the radiant orb of our cerulean skies, with its diversified and exquisitely poised cortège. Unsecured drafts upon futurity, however, are not among the most valuable assets of science, and a consummation so immeasurably remote may be anticipated by a score of unforeseen contingencies. What can be and has been ascertained is the relative durability of the scheme with which the visible destinies of the human race are so closely connected. It will unquestionably last long enough for their accomplishment. Curiosity that would seek to pierce the ulterior darkness is likely to remain ungratified.

But there is a further outlook. Other and incalculable items remain to be taken into account. The sun, although an autocrat within his own dominion, is himself subject to external influences. As a star, he is compelled to follow whithersoever the combined attractions of his fellow-stars draw him; nor can we thoroughly interpret the summons which he obeys. The immediate upshot in the transport of the solar system towards the constellation Lyra has, it is true, been determined, but the eventual scope and purpose of the journey remain profoundly obscure. The pace is to be reckoned as leisurely: twelve miles a second is little more than half the average stellar speed.

We should, however, probably suffer no inconvenience from being whirled through the ether in the train of such a stellar thunderbolt as Arcturus. Only the excessive velocities of any adventitious bodies we might happen to pick up would betray to ordinary experience the fact of our own swift progress. As it is, our sweepings from space appear to be scanty.

If shreds from inchoate worlds, or dust of crumbled worlds, strewed the path of our system, they should be annexed by it in its passage, temporarily or completely, and we should then expect to find the apex of the sun's way marked, if no otherwise, by the predominant inflow from that quarter of comets and meteors. Yet there is no trace of such a preference in the distribution of their orbits. Hence the enforced conclusion that the sun has attached to him, besides the members of his immediate household, an indefinite crowd of distant retainers, which, by their attendance upon his march, claim with him original corporate unity. To this rule there may be a few exceptions. An occasional aerolite probably enters the earth's atmosphere with hyperbolic velocity, and takes rank accordingly as, in the strictest sense, a foreign intruder; but the broad truth can scarcely be challenged that the sun travels through a virtual void.

We can, however, see no necessity why he should for ever continue to do so. Widely different conditions seem to prevail near the centre and out towards the circumference of the sidereal world. What may be designated the interior vacuity of the Milky Way is occupied mainly by stars of the solar type, including one to our apprehension super-eminent over the rest; they are separated by vast, apparently clear intervals; they are non-nebulous, and of stable constitution. This secure habitat is ours for the present, although it may at some future time be exchanged for one less exempt from disturbance. The shape and size of the sun's orbit are utterly unknown; the changes of environment, accordingly, that will accompany the description of it defy conjecture. Our actual course is inclined at a small angle to the plane of the Milky Way. It will presumably become deflected, but perhaps not sufficiently to keep our system clear of entanglement with the galactic star-throngs. In our ignorance of their composition no forecast of the results can be attempted: they are uncertain and exorbitantly remote. Moreover, the comparative slowness of the sun's motion in a manner guarantees the permanence of his subsisting cosmical relations. For anything that science can tell, they may ultimately be subverted by some preordained catastrophe; but the possibility lies outside the sphere of rational forecast.

The universe, as reflected in the mind of man, gains extent as the mirror acquires polish. Early astronomers conceived of but one solar system and one 'dædal earth,' upon which the 'pale populace of heaven' rained influences sinister or propitious. Later, human egotism took another form. The whole universe was assimilated to our particular little settlement in it. Terrestrial conditions were universalized. None divergent from them were counted admissible or profitable. But one answer seemed possible to the perpetual *Cui bono?* with which restless thought assailed the heavens. But one purpose was regarded as worthy of fulfilment, that of multiplying, in distant sidereal climes, copies of our own planet, and of providing suitable locations for myriads of intellectual beings, as little alien to ourselves as might be compatible with the minimum of diversity in their material surroundings.

The spread of this astral philanthropy has been in some measure checked by the advance of knowledge. Our position and circumstances have been shown by it to be, if not quite peculiar, at any rate very far from inevitable. It has reduced, by a process of exclusions, to a relatively limited number the class of stars that can fairly be regarded as possible centres of vitality; it has immensely widened the scope of discernible variety in cosmical arrangements, and held out warnings against errors of exposition due to inborn prejudices. And we shall surely not wander from the truth by recognising our inability to penetrate all the depths and complexities of Infinite Design.

CHAPTER XV

REMNANTS AND SURVIVALS

If the sun and planets were, in sober truth, wrought into their present shape out of a primordial nebula, the comparatively void surrounding space should naturally be strewn with fragments of unappropriated material. For the process of englobement could hardly, one would think, be carried out with such neatness and precision as to leave no shreds or shavings lying about the great atelier. Residual stuff there must be, unless our preconceived ideas are grossly erroneous; nor have we far to look in order to find it. We find it, apparently, under two forms presenting curious dissimilarities, yet belonging fundamentally, we can scarcely doubt, to the same order of things. These two kinds of waste product may be identified in the innumerable army of comets and in the strange, pale cone of the zodiacal light.

One of the most important and secure additions to knowledge in the department of cosmogony made during the nineteenth century was the establishment of comets in a position of entire, perennial, and aboriginal dependence upon the sun. That is to say, a vast majority, if not the whole of them, attend him on his sidereal journey. They are, accordingly, and have immemorially been his clients, and they can lose that status only through the effects of violent disturbance compelling them to depart irrevocably from their closed orbits along hyperbolic tracks. A trifling leakage of comets from our system is thus possible, which may or may not be compensated by annexations of adventitious members of the class, similarly banished from the precincts of remote stars. But this is a secondary consideration; the essential point to be borne in mind is that comets are native-born subjects of the sun, that they make an integral part of his cortège, that they own the same substantial origin, are dominated by his power, and must share his fortunes. Their study should then prove strongly illuminative as to the pre-history of our system, and for this especial reason, that they seemingly belong by right to that vanished world which it is the chosen task of cosmogony to reconstruct. They are, we can infer, the genuine primitives of the solar company; they retain something of prairie wildness, not having been broken in by steadily enforced gravitational discipline. Each perihelion passage is an adventure; between it and the next, fateful incidents may occur. Forces negligible on dense planetary globes act sensibly on their tenuous materials; they in part strikingly illustrate, and in part fantastically invert, the common modes of natural procedure. But it is their antiquarian significance that mainly concerns us here.

Admitting for the inchoate solar nebula such a constitution as that devised by Kant, and adopted with amendments by M. du Ligondès, we find ourselves confronted with the almost inevitable consequence of symptomatic survivals. Wisps of crude matter, in other words, which escaped being drawn into the vortices of embryo planets should continue to circulate, as they had from the first circulated, in all possible planes, and with no partiality for either a right-handed or a left-handed direction. These waifs and wastrels should, in fact, be indistinguishable from comets—'les seuls témoins,' according to the French cosmogonist, 'qui nous restent sur le mode de la circulation première.'* The identification is seductive to the imagination, and does not fall far short of convincing the reason.

There is clear evidence that what we may venture to call the native mode of cometary circulation is absolutely exempt from the rules which impress the movements of the planets with an unequivocal stamp of congruity. The few comets showing some degree of compliance with the general plan are those which have been subjected to manifold perturbations, and can hence no longer be called as unbiassed witnesses; while their untrained associates, left relatively free to follow the impulsion of their start, betray no geometrical preferences in their manner of travelling. They revolve indifferently with or against the course

* Ligondès, quoted by l'Abbé Moreux, *Le Problème Solaire*, p. 67.

of the signs; their paths are inclined at every possible angle to the ecliptic; they approach the sun in sensibly equal numbers from all quarters of the sky; they agree only in pursuing ellipses so elongated as to verge towards the parabolic limit. But just in this way, and no otherwise, we should expect to find bodies circulating which, having been aggregated at random (as Kant supposed) in the beginning, had departed to the least possible extent from the initial conditions of their systemic union. A good *primâ facie* case can, then, be made out for regarding comets as samples of the used-up nebula, as superannuated constituents of an inconceivable chaos, which, evading the operation of laws of change, have floated down the stream of ages virtually intact and undisturbed.

Yet the question has other aspects besides this purely mechanical one. They should all be harmonized by truth, which cannot be more securely guaranteed than by consilient testimony; nevertheless, there are difficulties in effecting the accommodation. Comets are not, in a chemical sense, closely related to nebulæ. They are fundamentally of carbonaceous composition—free hydrogen makes no spectroscopic show in them—while they include metallic ingredients occasionally rendered glowing by the powerful excitement of a perihelion rush-past. But gaseous nebulæ shine mainly with the light of certain unknown substances, reinforced by rays of hydrogen and helium. Carbon flutings and metallic lines are alike alien to their spectra. Nor is there any community that we yet know of between the chemistry of white nebulæ and that of comets. The nebular hypothesis of cometary origin is thus discountenanced by the results of light-analysis. Still, there are possibilities of reconcilement. Spectral conditions must be subject to change. The quality of light emitted by a body of mixed composition cannot fail to alter with the inevitable alteration of physical state brought about by external influences or internal change.

Selective illumination is beyond doubt largely concerned in modifying the information we are able to obtain as to the composition of remote masses, and its modes of action seem capricious because they are very imperfectly understood. Hence, spectral modifications may take place merely through the substitution of some elements for others in carrying (let us suppose) an electric discharge, though all were from the first simultaneously present in unvaried proportions. Moreover, chemical immutability can no longer be taken for granted. We have learned of late that even elementary individuality breaks down under the battering-ram of time. Sooner or later the stamp, however apparently inviolable, will be defaced, transformations of species will ensue, and novel combinations of material will subtly accommodate themselves to the needs of a growing world. These things, it is true, are involved in much obscurity, but we have caught glimpses of instability clear enough to convey an emphatic warning against dogmatic interpretations of spectral characters. Physical science may then license M. du Ligondès' theory of comets with a provisional *Nihil obstat.*

The zodiacal light suggests a different set of considerations. Comets being of pre-planetary origin, the ecliptical glow must be supposed post-planetary. It belongs to a later epoch, being composed, according to an accepted opinion,* of superfluous materials left over from the construction of the train of globes to which our own belongs. It might be compared to whey from which the curd has been separated. All the good has been got out of it; we might be tempted to throw it aside upon the rising rubbish-heap of the skies, with the importunate asteroidal throng, a few dozen undistinguished comets, and some hundreds of ill-defined meteoric systems. But celestial refuse is always worth sifting, above all, for tokens of genealogical descent, and we should be unwise to neglect the chance of finding them in the peculiar relations of the zodiacal light.

A triple phenomenon, it consists, when completely seen, of a cone, a band, and a counterglow. The connection of these parts into a whole is obvious, though enigmatical. Usually, however, only the cone is visible. It appears about the time of the spring and autumn equinoxes, after sunset and before sunrise respectively, as a faint lenticular illumination, tapering upward from the sun's place below

* Moreux, *Le Problème Solaire*, p. 133; Ledger, *Nineteenth Century*, March, 1905.

the horizon to an apex high up near the meridian. Under the name of the 'False Dawn' it was familiar, probably from an early age, to Oriental peoples. But they looked for it at the opposite end of the night from that favoured by European observers; nor did the phenomenon attract any particular notice here in England until 1660, when Joshua Childrey published a description of it in his *Britannia Baconica*. Yet it had been specifically observed about seventy years previously by Christoph Rothmann of Hesse, and must have been less intelligently perceived by numberless spectators, who most likely included it, with such miscellaneous objects as comets' tails, auroral beams, and meteor-trails, in the undefined class of appearances known from of old as *trabes*.

The light is ordinarily much feebler than the Milky Way, which it nevertheless on occasions unmistakably outshines.* Real fluctuations of brightness seem implicated in these

* Humboldt, *Cosmos*, vol. iv., p. 563 (Otté's translation); Maunder, *Journal of the British Astronomical Association*, vol. viii., p. 174; Max Wolf, *Königstuhl Report* for 1904.

changes; yet they follow no traceable law of periodicity, and are certainly independent of the sunspot cycle.

The counterglow, first remarked by Pezénas in 1730,* soon fell into oblivion, and had to be rediscovered after six-score years by Brorsen, who bestowed upon it its current title of the 'Gegenschein.' Of late it has been pretty constantly observed, particularly by Professor Barnard, to whom it presented itself, owing to the scantiness of the available records, as a surprising novelty.† Surprising it certainly is. The appearance of the Gegenschein is that of a large elliptical patch of diffuse light, measuring about 12 by 9 degrees, and situated diametrically opposite to the sun.‡ Now and again, though somewhat rarely, it is perceived to be united to the cone by the 'zodiacal band,' a strip of evanescent luminosity nearly following the line of the ecliptic. We cannot, then, be mistaken in recognising the great pyramidal beam

* *Paris Memoirs*, 1731, quoted by R. Wolf, *Geschichte der Astronomie*, p. 695.

† *Popular Astronomy*, vol. i., p. 337.

‡ Nijland, *Astr. Nach.*, No. 4,008.

centred on the sun, with the counterglow and its linking band, as sections of a single formation, constituting in a manner the substratum of the solar system. A recent observation made by Professor Newcomb under unique conditions proves it to be much less exclusively 'zodiacal' than had been supposed. Looking north from the summit of the Rothhorn, at midnight, on July 29, 1905, he perceived a well-marked glow spreading 35 degrees from the sun's place.* It was the light in its thwartwise aspect, which had never before been seen, or even looked for; and we learn from it the remarkable fact that the sun is enclosed in a vast, dimly luminous sphere, with a girth not much smaller than the orbit of Venus, and indefinitely diffused along the equatorial plane.

Notwithstanding its dim indefiniteness, neither the spectroscope nor the camera is wholly ineffective for the scrutiny of this extraordinary appurtenance. We have learned positively that its radiance is of the continuous sort, the origin of which through the reflection of sunlight from small solid

* *Astrophysical Journal*, vol. xxii., p. 209.

bodies seems more than probable. The whole structure must accordingly be of a pulverulent or meteoric nature; it consists of independently moving particles. But to the further question, Under what regimen do these particles circulate? no decisive answer is as yet forthcoming. M. Hansky* and others hold the light to be a true solar appendage, an extension of the corona, in which case it would have a formal, but no material permanence. It would represent the continually changing aggregate of multitudinous minute bodies issuing from or repelled by the sun, and in large proportion falling back towards his surface. Yet some difficulty is raised to this view by the vast dimensions of the problematical glow. That it extends far beyond the earth's orbit is rendered patent by the phenomena of the Gegenschein and the band. True, the scope of the sun's repulsive action cannot be limited; still, we might naturally expect its products to become too attenuated for recognition beyond a radius of perhaps fifty million miles.

* *Comptes Rendus*, 1905, No. 6; *Nature*, February 23, 1905.

Admitting, on the other hand, the residual character of the zodiacal light, we should attribute to it a constitution analogous to that of Saturn's rings. Each one of the cosmic atoms collected in it would revolve round the sun on its own account, scarcely disturbed by its neighbours. Nor need we despair of determining with reasonable certainty which way the truth lies in this matter. The rival hypotheses may be tried by a criterion the application of which is by no means remotely feasible. It is furnished by the geometrical relations of the zodiacal light. Evidently, if the sun can claim organic connection with it, its axis should coincide with the plane of the solar equator; while, if it represent wastage from the Kantian nebula, it should stretch along the principal plane of our system —the plane of maximum moment of momentum —the plane towards which the primitive agglomeration of revolving particles collapsed as it condensed. The question of planes is, then, crucial. Is the zodiacal effluence placed symmetrically as regards the solar equator, or does it appertain properly to the ecliptic, which deviates very slightly from the fundamental plane of the solar system? The evidence is, unfortunately, contradictory. Most observers have located the dim equinoctial cone right along the pathway of the sun; some, under exceptionally favourable circumstances, have perceived in it a marked departure from the track of the Signs.

M. Marchand's determinations from the Pic du Midi, for instance, indicated a probable coincidence between the solar equatórial plane and the axis of the light;* and Dr. Max Wolf succeeded, in 1889, in getting a photographic impression which, though partial and imperfect, tended to corroborate Marchand's inference.† Again, on November 16, 1904, when the cone showed a remarkable lustre, it was distinctly perceived at Königstuhl to sheer off and separate from the ecliptic as it mounted the sky. Now, however, that a beginning has been made in photographing this enigmatical tenant of the sphere (the feat has been performed at Flagstaff as well as at Heidelberg), we may confidently expect a speedy

* *Comptes Rendus*, tom. cxxi., p. 1134.

† *Sitzungsberichte*, Munich, Bd. XXX., p. 197.

reconcilement of inconsistent statements regarding its whereabouts. Until then we cannot venture to assert that it is in actual reality what it appears to be, a nebulous survival.

CHAPTER XVI

LIFE AS THE OUTCOME

THE making of worlds, we are assured, was not purposeless, and its most obvious purpose to our minds is the preparation of suitable abodes for organic life. No other seems of comparable importance; no other, indeed, comes within the full grasp of our apprehensive intelligence. Yet its limitations must not be forgotten. The human standpoint is not the only one from which the sum of things may be surveyed ; and although we be unable to quit it, we can still admit that the view obtainable from it is probably not all-embracing. We only know with certainty that the end which appears to us supreme has, in one case, been successfully attained ; how far it was sought to be compassed elsewhere must always remain a matter of speculation.

On our own globe the presence of life is none the less mysterious for being profuse and familiar. We can trace the strange history of its slow unfolding, but the secret of its initiation baffles our utmost scrutiny. The cooled rind of a once molten globe serves as the stage for the drama; beneath it primeval heat still reigns. Temperature rises steadily with descent into the interior of the earth; at a depth of about two miles it must reach the boiling-point of water at the sea-level. This temperature, which is absolutely prohibitive of vitality, was formerly, beyond question, that of the surface. At some long-past epoch, accordingly, our future oceans hung suspended as a prodigious envelope of vapour above a hot crust of slag and lava; our teeming planet lay barren; it harboured no promise, no potency, no visible possibility of life.

So it should have remained had the law of continuity been rigidly enforced; but there came a time for a new beginning, and a new beginning was made. A momentous alteration took place; inert Nature was quickened; what had been sterile became all at once fruitful; an immeasurable gulf was bridged, and movement was started along an endless line of advance. That the advance was set on foot and directed by an intelligent Will is the only inference derivable from a rational survey of the known facts.

Life can be studied in its manifestations, not in itself. Attempts to define it have served only to show our inability to 'lift the painted veil.' We can, however, see that its presence is attended by characteristic effects, brought about in harmony with the laws of inorganic nature, although not in blind submission to them. Their operation is somehow restrained, and appears to be subtly though securely guided towards determinate ends prescribed by the vital needs of each animal or plant. This modifying principle unmistakably regulates the economy of every living organism; the cessation of its activity means death.

Science has made no real progress towards solving the enigma of vitality. Its evasiveness becomes, on the contrary, more apparent as inquiry is rendered more exact. Under a laxer discipline of thought the contrast between life and death seemed less glaring. It was easily taken for granted that creeping things were engendered by corruption, aid being invoked, if required, from the *virtus cœlestis* of the eighth sphere. Thus, the birth of mice from the damp earth was, in the ninth century, held to be signified by the word *mus* (=humus);* and Van Helmont, at the height of the revival of learning, published without misgiving a recipe for the creation of the same animals.† Yet there was already better knowledge to be had for the asking; and Francesco Redi, in 1668, crystallized Harvey's opinion in the celebrated maxim, '*Omne vivum ex vivo.*' Its truth is incontrovertible. Challenged and tested again and again, it has as often been vindicated, and may now be said, despite certain anomalous effects of radium on veal broth, to stand outside the legitimate range of debate. 'That life is an antecedent to life,' Lord Kelvin declared in 1871, 'seems to me as sure a teaching of science as the law of gravitation.'‡

But the succession is not easy to start

* Hewitt, *Problems of the Age*, p. 105.

† Pasteur, *Annales de Chimie et de Physique*, tome xliv., p. 6, 1862.

‡ *Popular Lectures and Addresses*, vol. ii., p. 198.

within the terms of a strictly uniformitarian convention. The expedient is tempting, if scarcely satisfactory, of demanding from the past what we dare not claim from the present. Two and a half millenniums ago it was already in vogue. Herodotus dismisses a genealogical embarrassment with the remark, *γένοιτο δ'άν πᾶν έν τῷ μακρῷ χρόνῳ*, which may be freely translated, 'In the long run of time anything may happen.' Conditions, we are apt to think, may have been more elastic long ago. The proven impossibility of to-day becomes vaguely thinkable seen through the mist of uncounted yesterdays. 'If it were given to me,' Professor Huxley said,* 'to look beyond the abyss of geologically recorded time to the still more remote period when the earth was passing through physical and chemical conditions which it can no more see again than a man can recall his infancy, I should expect to be a witness of the evolution of living protoplasm from non-living matter.' To these first vital compounds he attributed a fungoid nature and mode of growth, and the choice deprived his speculation of any plausibility that might

* *Report British Association*, 1870, p. 84.

otherwise have belonged to it. Fungi are not self-supporting; they cannot supply themselves with nourishment from the raw materials of the mineral world; they depend upon the hospitality of differently organized beings. They were, then, certainly not among the 'first mercies of nature.' Mr. Herbert Spencer, too, was inclined to regard spontaneous generation as a superannuated process. The leap from the non-vital to the vital, now admitted by the saner kind of biologists to be impracticable, might have been taken, it seemed to him, when 'the heat of the earth's surface was falling through those ranges of temperature at which the higher organic compounds are unstable.' But the 'reason why' is to seek. A sterilized solution is precisely one which has cooled from a high thermal grade; a baked brick is similarly circumstanced. Why should the appearance of life in primeval times have been favoured by a state of things fatal to it here and now?

The essence of the biological crux resides in 'protoplasm.' The word was coined by Von Mohl in 1846, with the object of emphasizing the importance of the substance it signified, which indeed forms the bulk of every organism, animal and vegetable, man, mushroom, and amœba. Huxley rightly termed it 'the physical basis of life,' adding, however, the infelicitous conjecture that its production might have been one of the lucky hits of nature. It would have been a hit of incalculable moment, but of incalculable improbability. 'Odds beyond arithmetic' were against that particular throw coming out of the Lucretian dice-box. The 'primal slime' (to use Oken's phrase) is composed of oxygen, nitrogen, hydrogen, and carbon, with minute percentages of phosphates and other salts. But these constituents are put together in a highly artificial manner. Eight or nine hundred elementary atoms, in fact, go to the making of one molecule of protoplasm, forming a structure of extreme complexity, most delicately balanced and eminently unstable. It results, accordingly, from the employment of specially directed forces, and stores, for the benefit of the producing organism, the energy expended in its construction. Left to itself, it promptly goes to pieces, and yields back its component particles to their native inorganic sphere. The laws there ruling are in truth adverse to the existence of protoplasm; abandoned to their unmitigated action, it perishes. We should then as reasonably suppose that in the geological past rivers flowed uphill as that inorganic nature stumbled blindly upon this wonderful postulate and product of life.

Professor Huxley affirmed life to be 'a property of protoplasm,' the inevitable outcome of 'the nature and disposition of its molecules,' and he sought to cover the absurdity of the dictum by claiming as analogous a case wholly disparate. Water, he argued, has qualities totally unlike those of oxygen or hydrogen, and protoplasm may similarly, by mere intricacy of arrangement, and the evoking of latent affinities, become endowed with the transcendant powers connected with animated existence. 'What better philosophical status, then,' he exclaimed, 'has *vitality* than *aquosity*?'* 'True,' he added, 'protoplasm can only be generated by protoplasm, in a manner that evades our intelligence, but does anybody quite comprehend the *modus operandi* of an electric spark which traverses a mixture of

* *Collected Essays*, vol. i., p. 153

oxygen and hydrogen?' The illustration is inapt. The electric spark fulfils no constructive function. It simply agitates the molecules so as to bring their native affinities into play. It acts like a mechanical blow on dynamite. Further, water is a stable compound, because its formation is attended by loss of energy; it represents a plane permanently occupied because reached by a steep descent; but protoplasm is, in this respect, the antitype of water. It needs force for its composition; water needs force for its decomposition. Protoplasm needs force plus a suitable apparatus; it can be turned out only by an artfully adapted machine with a head of steam on. It is thus continually manufactured by plants under the stimulus of light. They provide the apparatus, sunbeams the energy. If the supply of power is cut off, the machinery comes to a halt, protoplasm ceases to be generated, the organism dies of inanition.

Many German biologists find themselves compelled, by the impossibility of explaining vital activities in terms of chemistry or physics, to associate protoplasm with some kind of psychical activity.* Individuality, at least, implies an ultra-material principle, and it asserts itself at the very base of the animal creation. An amœba is the simplest of living beings. Formerly called the 'Proteus animalcule,' it is 'everything in turn, and nothing long.' It can be round or radiated, spherical or lenticular, as momentary convenience prescribes. Organs it has none, its limbs are conspicuous by absence, it is 'sans everything' that belongs to the ordinary outfit of an animated creature. Yet such-like nucleated globules of protoplasm have flourished exuberantly during countless ages. Adaptability insured survival. An amœba is at home in almost any environment. What it has not ready-made, it can supply at a moment's notice. Out of any part of its substance it can improvise feelers and tentacles for the capture of its prey, as well as a stomach for its digestion, and it thus effectively goes through the full round of animal economy. Some varieties, too, are noted builders. Those called Foraminifera have the faculty of secreting

* Neumeister, *Betrachtungen über das Wesen der Lebenserscheinungen*, 1903.

carbonate of lime from sea-water, and construct with it fairy dwellings, perforated in all directions to allow of the protrusion of exploratory filaments. Fossil chambered shells of this type are extraordinarily abundant. Their dense conglomeration in the chalk elicited Buffon's exclamation that 'the very dust had been alive!'* The *calcaire grossier* of which Paris is built consists mainly of them, and to this day, in oceanic depths, the materials of future capitals are in course of preparation by the monumental industry of these unpretending creatures.

Such as they are, they maintain a status incomparable with that of non-living things. Incomparable, for instance, as regards the water in which they float. The contrast is startling despite its familiarity. An amœba incarnates a purpose; it embodies a spark of personal existence, unconsciously swaying the forces of inorganic nature towards the ends of its own well-being. The subordination is most real, though profoundly mysterious. In the organic and the inorganic worlds the same laws hold good; the same ultimate atoms exert their

* Owen, *Palæontology*, pp. 11, 14.

preferences in each; in neither is an uncaused effect possible. A bullet can no more be fired from a gun that has no charge than a man can lift a finger without a corresponding outlay of food-products. Accordingly, while plants store and animals expend energy, plants and animals are equally incompetent for its origination. What they can do is to appropriate and specifically apply it; and herein resides the essence of life. 'It would seem,' Sir George Stokes wrote in 1893,* 'to be something of the nature of a directing power, not counteracting the action of the physical forces, but guiding them into a determined channel.' What the power is in itself it would be futile to seek to define. We are only sure of its being extra-physical. Matter cannot evolve a principle which disposes of it as its master. Evolution means only the unfolding into self-evidence of something already obscurely present. The 'latent process' (to use a Baconian term) of the hatching of an egg is typical and instructive. Yet it is not the less recondite for being daily conducted before our eyes. A concourse of suns, indeed, fails to impress us with the

* *Gifford Lectures*, p. 46.

unutterable wonder of the 'flower in the crannied wall' apostrophized by the last great poet of the nineteenth century.

The two wide kingdoms of life lack a 'scientific frontier.' The boundary-line is ill-marked and irregular. So much so that a few naturalists have set up a neutral zone, or no man's land, inhabited by creatures of mixed or uncertain nature, by plant-animals, or zoophytes in the literal sense of the word. But the expedient avails to shelter ignorance rather than to advance knowledge. For it seems probable that there is no organism so imperfectly characterized as to be genuinely incapable of giving a categorical answer to the question, 'Under which king, Bezonian?' Fungi might, perhaps, on a superficial view, be taken for hybrids. They share the nature of animals so far as to be unable to elaborate their own food, while appearing in other respects to be authentic vegetables. They are, in fact, parasites and scavengers. Not the smallest reason exists for supposing them to constitute a genetic link between the two chief hierarchies. These are, in all likelihood, fundamentally distinct. Only by a gratuitous hypothesis can they be credited with a common ancestor. Each seeks a different kind of perfection; their ideals, so to speak, follow divergent tracks. That the tracks were marked out from the beginning may be safely affirmed; and this implies radical separation. Plants came first, since animals pre-suppose and imperatively require them; the antecedence having quite possibly been by a vast interval of time. On this point, geological evidence, though inconclusive, is suggestive. The Laurentian beds, which are among the very earliest stratified formations, contain no recognisable fossils. They were once supposed to enshrine the remains of a lowly organism dubbed *Eozöon Canadense;* but the markings that simulated animal forms are now known to be of mineral origin. Laurentian graphite, on the other hand, occurs plentifully; and graphite may be described as coal at a more advanced stage of mineralization. Such deposits, we are led to believe, consist of altered vegetable substances; and it seems to follow that these hoary rocks are the burying ground of a profuse succession of virgin forests. That they flourished beneath the sea—were, in fact, composed of algæ—was the opinion of Professor Prestwich,* and it is not easily gainsaid.

Primitive animal life was unquestionably marine, and the Huronian strata, which overlie the Laurentian, afford traces of it in a few sponge-spicules, the cast of an annelid, and such-like scanty leavings. Higher up, the Cambrian series swarms with oceanic invertebrates; fishes, the first type of vertebrates, came upon the scene in Silurian times; and so, by a various and surprising progression, life advanced through the ages, until the ascending sequence culminated with a being cast in a diviner mould, who walks the earth, even now, with face uplifted to the stars.

> 'Natus homo est; illum mundi melioris origo
> Finxit in effigiem moderantûm cuncta deorum.'

In the vegetable kingdom the vital law of development has wrought with less conspicuous effect. The superiority of recent to ancient floras is more significant than striking. A tree-fern or a sigillaria bears comparison with an oak much better than a trilobite or a plesiosaurus with an eagle, horse, or lion.

* *Geology*, vol. ii., p. 22.

The geological variations of plants, however, have unmistakably tended to make them more serviceable to man—more serviceable to his material needs, and also more gratifying to his æsthetic instincts. For him, flower-petals were painted and perfumes distilled; for him, the grasses of the prairie laid up stores of sustaining nutriment; in preparation for his advent, choice fruits ripened and reddened under Tertiary sunshine; while the barren and sombre vegetation of the Carboniferous epoch had already done its part by dying down into seams of coal for the eventual supply of power for human industry and warmth for human comfort.

It would be an abuse of our readers' patience to discuss the futile conjecture of an extra-terrestrial origin for life on our globe. The agency, in this connection, of germ-laden aerolites was first invoked by Richter of Dresden; and Lord Kelvin gave currency to the notion by an incidental reference to it in 1871 from the Presidential Chair of the British Association. Its adoption would oblige us to regard the denizens of our planet, fauna and flora alike, as salvage from the wreck of some unknown world in space. *Credat Judæus Apella.* To our minds, the adventures of Baron Munchausen appear more credible than the pre-natal history of the primal organism implied by this 'wild surmise.' Inquiry into the nature of the supposed organism serves to draw closer the web of embarrassment. The remarkable aridity of meteorites excludes the possibility of its having had an aquatic habitat. Members of the fungoid order are unsuited to act as pioneers, owing to their helplessness in the matter of commissariat; and the spores or lichens or mosses could scarcely be expected to survive the vicissitudes of such a journey as they must have performed if meteor-borne to terrestrial shores. The immigration hypothesis, moreover, even if it were plausible, could not be made useful. Difficulties do not vanish on being pushed into a corner; the problem of life is as formidable in one world as in another; we should not expect to find it easier to square the circle in Mars than Deinostratos found it in Greece; matter, we are convinced, has no more psychical initiative in the system of Arcturus than can be ascribed to it in the system of the sun. Profitless conjectures may then be dismissed; they do not help us out of the slough of intellectual impotence.

This need not, indeed, be absolute. The determination to regard things mechanically alone renders them unintelligible. Science becomes unscientific when it refuses to be guided by experience; and we have the plainest testimony of consciousness to the working in ourselves of originative faculties independent of, and irrepressible by, physical agencies. Here we hold the clue to the labyrinth. The intimation conveyed is distinct of a Power outside nature, continually and inscrutably acting for order, elevation, and vivification.

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