

ART. XV.—*Kant as a Natural Philosopher*; by GEO. F. BECKER.

KANT'S fame as a metaphysician has completely overshadowed his reputation as a physicist, at least outside of Germany. One occasionally sees a slight reference to the fact that he had an idea of some sort of nebular hypothesis, but usually the context conveys the impression that it was only a futile dream. Thus a well known historian of astronomy stated in 1882 that Kant had put forward "a true nebular cosmogony, though one in which the primitive reign of chaos was little likely to terminate." In 1869, however, Huxley wrote a few vigorous paragraphs on Kant's results\* and shortly afterwards Lord Kelvin, referring to Huxley's abstract, remarked that Kant's paper only wanted the knowledge of thermodynamics "to lead to a thoroughly definite explanation of all that is known regarding the present actions and temperatures of the sun and other heavenly bodies."†

All of Kant's earlier papers were on physical subjects and he retained his interest in natural philosophy through life. He studied Newton: at one time he lectured on mathematics, and his course on physical geography was repeated through many years. Some of his papers are now of little interest, but others, at least from an historical point of view, are very important. The titles of those which seem to me most noteworthy are given in a footnote below.‡

The first three of these papers, which are also the most original, were all published before Kant's poverty allowed him

\* Presidential Address. Geol. Soc. London, Discourses Biological and Geological, 1894. p. 320.

† Address to Geol. Soc., Glasgow, April 5, 1869.

‡ The volume and page numbers refer to Immanuel Kant's *Sämmtliche Werke*, edited by G. Hartenstein, Leipzig, Voss., 1868.

1754. *Untersuchung der Frage, ob die Erde in ihrer Umdrehung um die Achse, wodurch sie die Abwechselung des Tages und der Nacht hervorbringt, einige Veränderung seit den ersten Zeiten ihres Ursprungs erlitten habe*, vol. i, pp. 179-186.

1754. *Die Frage; ob die Erde veralte, physikalisch erwogen*, vol. i, pp. 187-206.

1755. *Allgemeine Naturgeschichte und Theorie des Himmels, oder Versuch von der Verfassung und dem mechanischen Ursprunge des ganzen Weltgebäudes nach Newton'schen Grundsätzen abgehandelt*, vol. i, pp. 207-345.

1756. *Neue Anmerkungen zur Erläuterung der Theorie der Winde*, vol. i, pp. 473-487.

1763. *Der einzig mögliche Beweisgrund zu einer Demonstration des Daseins Gottes. Siebente Betrachtung, Kosmogonie*, vol. ii, pp. 180-193.

1785. *Ueber die Vulcane im Monde*, vol. iv, pp. 193-202.

1786. *Metaphysische Anfangsgründe der Naturwissenschaft*, vol. iv, pp. 355-462.

1802. *Physische Geographie. Auf Verlangen des Verfassers aus seiner Handschrift herausgegeben und zum Theil bearbeitet von Dr. Fr. Th. Rink*, vol. viii, pp. 145-452.

to complete his studies for the degree of Doctor of Philosophy. The paper on the volcanoes of the moon gave him an opportunity of reasserting his belief in his nebular hypothesis after many years of reflection, and of making a very great addition to the cosmogonic apparatus. The discussion of the metaphysical bases of natural science contains interesting reflections and definitions. It is difficult to say how much of it was absolutely new, since all natural philosophers have dealt with the same ideas. His definitions of fluids and solids\* sound extremely modern. "A material in which a motive force, however small, produces shear is a fluid, no matter how powerful the cohesion of its parts." A solid is a body "which resists shear with a certain degree of force." "The resistance to shearing is die Reibung," by which he means what is now denoted by rigidity; liquids, he says, have none of it. In his theory of the winds Kant was anticipated by Geo. Hadley,† but he supposed himself to be the first to perceive the effect of the rotation of the earth on northerly or southerly winds. He deduced from this effect the cause of the easterly trades, the westerly winds of latitude 28° to 40° and the monsoons. Kant's paper on this subject was very probably intended as a reply to D'Alembert, whose theory of the winds procured him the prize of the Berlin Academy in 1746. D'Alembert endeavored to account for atmospheric currents as an immediate result of the attraction of the sun and moon. The physical geography was edited from lecture notes by a pupil when Kant was an old and broken man. There is good reason to suppose that it would have been more valuable if Kant had written it out himself at an earlier date.

Kant was indeed no dreamer, but one of the best informed men of his time. It was the great object of his life to discourage visionary speculations, "Schwärmerei," and to reduce all subjects to the confines of reason. His theory of the heavens, however it may appear to modern readers, was conceived from this point of view. Even Newton had felt himself called upon to attribute various details of the solar system to the direct intervention of the Creator, and it was the habit of that day, as of other days, to confound the mysterious with the miraculous. Kant endeavored to offer a rational explanation of many mysteries and in large measure he was successful. He saw, as well as one can see now, that astronomy has two divisions. In spherical and gravitational astronomy mathematics reigns supreme, and certainty is attainable. In physical and historical astronomy, on the other hand, a high degree of probability is the nearest possible approach to absolute truth. Kant says of his theory of the heavens: "In general,

\* Kant's Werke, vol. iv, p. 420.

† Phil. Trans., vol. xxxix, 1735, p. 58.

the highest geometrical precision and mathematical infallibility can never be demanded from a treatise of this description. If the system is founded on analogies and agreements, developed according to the rules of credibility and in a logical manner, it satisfies the conditions which its object demands." In judging of Kant's theory, allowance must be made for the faulty data at his disposal, particularly in respect to the masses of the planets, and for the undeveloped state of astronomical science. I know of no more striking way to emphasize the remoteness of the period when the theory was published than to note that in 1755 Lagrange was 19 years old, William Herschel 17, and Laplace 6. Kant was not always right, and indeed he himself threw doubt on certain of his results, but some of his great successors fell into some of the same pitfalls. That many of his theories are held to-day shows the keenness of his scientific faculty, and almost excites a regret that he did not remain loyal to Urania. It is doubtful, however, whether he could have been restrained from metaphysical inquiries. There is a small group of men, naturalists by instinct, who seem irresistibly compelled to include among the phenomena forming the object of their inquiries the mechanism of the intellect and the relations of ideas. Such are Aristotle, Bacon, Descartes, Kant and a living English philosopher.

Kant was not the first philosopher to speculate on the origin of the heavenly bodies, though he was the first Newtonian to do so. If one leaves aside some vague speculations of the ancients, there can be no doubt that the first germ of the nebular hypothesis is to be found in Descartes' *Principles of Philosophy*, published in 1644 (43 years before Newton's *Principia*). It may briefly and imperfectly be represented as follows. The content of the universe is divisible into three categories.\* The first corresponds nearly to the luminiferous ether of the present day and its agitation produces light, the second answers approximately to gas, the third to solid or liquid substances. This last Descartes calls "opaque matter." In the beginning these materials were almost uniformly distributed through space and possessed motion in nearly equal amounts.† The nebulous mass was divided into patches of common rotation, or the famous Cartesian *vortices*. In each vortex there were subordinate vorticules, eddies in a whirlpool. The motion of rotation was most rapid at the center, dimin-

\* *Les principes de la Philosophie*, Cousin's edition, 1824, part 3, sec. 52. The three categories are summarized as "être lumineux, être transparent, et être opaque ou obscur."

† In all, "Autant de mouvement qu'il y en a encore à présent dans le monde." (Part 3, sec. 46). Descartes supposed the momentum of the universe a fixed quantity. Leibnitz, I believe, was the first to assert the constancy of the total energy.

ished with increasing radius to a minimum, and increased again towards the edge. Nebulous material was driven from the center towards the periphery in the equatorial plane of the vortex and flowed back again along the axis of rotation. The first stage in the evolution of systems was the segregation of opaque matter in spots, such as are still to be seen on the sun. In the smaller subordinate vortices these accumulated until they formed a crust which partially or completely arrested the vertical circulation. The minor stellar bodies so consolidated were then captured by the larger vortices and were incorporated into them as passive constituents. These opaque masses sought a position of equilibrium in the rotating fluid of the vortex. At first such a body would descend towards the center. If, however, it possessed sufficient "solidity," which seems to be mass per unit of exterior surface,\* it soon acquired such centrifugal velocity as to be thrown out of the periphery of the vortex, passing into the next similar vortex and so on. It thus became a comet. If the opaque mass had less solidity, it found a position of equilibrium within the vortex and became a planet moving on an orbit of small eccentricity.† The planets of smallest solidity are nearest the sun.‡

Swedenborg also published a vortical cosmogony in 1734, forty-seven years after the appearance of Newton's *Principia*. Messrs. M. Nyrén§ and E. S. Holden† have each given some

\* Cf. part 3, sec. 122. Descartes regarded space as a "plenum" and does not here consider motion in a vacuum. The measure of force was solidity into velocity. The resistance of the plenum was proportional to the exterior surface of a moving mass.

† Et parceque toutes les petites parties de la matière qui compose un tourbillon ne sont pas égales ni en agitation, ni en grandeur, et que leur mouvement est plus lent selon qu'elles sont plus éloignées de la circonférence, jusques à un certain endroit au-dessous duquel elles se meuvent plus vite, et sont plus petites selon qu'elles sont plus proches du centre, ainsi qu'il a été dit ci-dessus, si cet astre est si solide que, devant que d'être descendu jusques à l'endroit où sont les parties du tourbillon que se meuvent le plus lentement de toutes, il ait acquis autant d'agitation qu'en ont celles entre lesquelles il se trouvera, il ne descendra point plus bas vers le centre de ce tourbillon, mais, au contraire il montera vers sa circonférence, puis passera de là dans un autre, et ainsi sera changé en une comète. Au lieu que s'il n'est pas assez solide pour acquérir tant d'agitation, et que pour ce sujet il descende plus bas que l'endroit où les parties du tourbillon se meuvent le moins vite, il arrivera jusques à quelque autre endroit entre celui-ci et le centre, où étant parvenu il ne fera plus que suivre le cours de la matière qui tourne autour de ce centre, sans monter ni descendre davantage, et alors il sera changé en une planète. Part 3, sec. 119.

‡ Therefore the earth must be less dense than Mars, which has the smaller diameter (part 3, sec 147), and therefore the earth must consist of a rigid shell with a fiery interior (part 4, sec 3), Descartes concludes. This is the first assertion that the earth has a fluid interior. Descartes was driven to make it by the exigencies of a false theory. The doctrine once accepted, its origin was forgotten; and but for Lord Kelvin, it would probably have remained a misleading article of faith with geologists to the end of the 19th century.

§ Vierteljahrsschrift der astronomischen Gesellschaft, 1879, p. 80. This paper is translated in the *New Church Review*, July, 1897.

† *North American Review*, vol. cxxi, 1880, p. 377.

account of this theory. The solar system, according to Swedenborg, was formed from a chaotic mass which rolled together to a great sphere and afterwards, by its rotation, threw off a ring. This by expansion burst, and the fragments shrank to planets. I see no important advantage in this as compared with the Cartesian cosmogony. Even if deductions from any such vortical theory were correct, they could still have no scientific standing, since they would be conclusions from false premises and their correctness therefore accidental.

In 1750 Thomas Wright (of Durham) published a book, "The Universe and the Stars," to an abstract of which Kant expresses obligations. It is so tiresome as to seem much longer than it is, and the only original conclusion which I can find is that the visible stellar system is spheroidal or cylindrical, the Milky Way marking the position of the periphery. At the center is "an intelligent principle" round which the system revolves. Wright, like Cassini, thought that Saturn's rings were composed of small satellites,\* a conclusion which he draws from the eccentricity of the rings.

Turning now to Kant's cosmogony, it may be interesting to note in the briefest terms the more striking of his views in a connected way, and then to draw attention to such of them as seem anticipations of the opinions held by subsequent investigators.

In developing his nebular hypothesis Kant regards the solar system from two points of view. The first contemplates the unity of plan. Six planets and nine satellites revolve in orbits about the sun, all moving in the same sense, that namely in which the controlling central body, the sun, rotates. Their orbits vary but little from a single plane, that of the sun's equator; the more distant bodies belonging to the solar system (viz: comets), however, show divergencies standing in sufficiently close relation to the deficiency of the impressed movement. This unity of plan indicates a single pervading cause of motion. On the other hand, from the second point of view, the interplanetary space is substantially empty; it contains no matter through and by which accordant motions could have been communicated to the system.†

Hence this space must once have contained matter, and the material abstracted from interplanetary space must be that which is now gathered in the members of the solar system; for the quantity of matter in the universe is inalterable. Kant therefore assumes that the materials of the solar system were

\* I have only seen the American reprint (without plates). Phila. Wetherill, 1837. This edition has amusing notes of the mystic order by C. Wetherill and C. S. Rafinesque.

† Kant's Werke, vol. i, p. 245.

originally disseminated in an elementary state, as atoms, throughout the entire space belonging to the system. The material is not supposed to be heated or in motion, the average density of the nebula is many times smaller than that of the terrestrial atmosphere, and the conditions are explicitly the simplest conceivable.\*

He proceeds to develop from this hypothesis not merely the conditions of the solar system but of the star cluster bounded by the Milky Way and other star clusters which he supposes to be represented by the nebulae. As the solar system is to the cluster of which it is an insignificant member, so is this to a greater group of clusters; and infinite space is occupied by a rotating group of similar constitution but of an infinite order of magnitude and of complexity.†

For the solar system he deduces many remarkable conclusions. The shrinking nebula acquires rotary motion, he erroneously supposed, in consequence of irregular impact of the component particles and their elasticity.‡ Tendencies to motions in all directions, excepting in one resultant plane, are suppressed by mutual interferences of the free particles. Most of the material accumulates at the center, in the sun, but a wide, thin disc of heterogeneous matter remains. This disc consists of discrete particles each of which has acquired such a velocity and direction as to maintain the appropriate orbital motion. On the whole the inner zones of the disc will contain a larger proportion of denser substances than are to be found in the outer ones; while the outer rings, being of relatively large circumference, will be of greater mass than the inner ones. Mutual attraction and adhesion, beginning at relatively massive particles, cause the agglomeration of the particles in any zone or ring to single planets or to groups of planetary bodies. The direction of axial rotation is deduced from the mode of formation, the outer part of any accumulating planetary mass moving with greater velocity than the inner portion.§ (The proof offered for this last proposition is unsatisfactory.)||

\* Kant's Werke, vol. i, p. 247.

† Kant's Werke, vol. i, p. 290.

‡ Though Kepler's law of areas was well known to Kant, he did not realize the more general theorem, that the moment of momentum of a system on which no external forces act is constant.

§ Kant's Werke, vol. i, pp. 267 and 258.

|| Mr. H. Faye (*L'origine du monde*, 1884, pp. 117 and 143) rejects Laplace's nebular hypothesis on the ground that the latter is in error in his deduction as to the rotation of the planets. Mr. Faye thinks that because the inner numbers of a swarm of particles tend to revolve with a higher velocity than the outer ones, retrograde rotation would ensue. This is a case where simple explanations are tempting but misleading. The problem rigorously dealt with involves the solution of the problems of three or more bodies. It does not appear to me that Mr. Faye has given any satisfactory proof of his position. The same may be said of Laplace, but it may be suspected that this great man had solved some particularly

Kant appeals to his theory of Saturn as a confirmation of the credibility of his whole hypothesis. Nevertheless he represents the rings not as a relic of a condensing nebula but as an emanation from the planet. The rings, according to his theory, are composed of discrete particles\* condensed from fumes and vapors which had been thrown off from the equator of the planet by rapid rotation while the planet was still in a highly heated condition. These particles acquired their moment of momentum from the planet and revolved in obedience to the law that this moment is constant. He attempts to account for the stability of the mass by its division into many rings, pointing out that if it were continuous, friction must destroy its motion.

Kant also computed the then unknown period of rotation of Saturn on the hypothesis that centrifugal force and attraction are equal at its surface, so that the rings are practically continuous with the planet. He obtained a period of 6<sup>h</sup> 23<sup>m</sup> 53<sup>s</sup>. Herschel in 1794 from direct observations found its period 10<sup>h</sup> 16<sup>m</sup>, which differs from Prof. A. Hall's determination by a very few minutes. Mr. Faye supposes the German astronomers to have omitted mention of Kant's prediction out of regard for the philosopher, the discrepancy between it and the observations being "overwhelming." The French astronomer, however, also remarks that the discrepancy, while calling for explanation, does not invalidate the theory. Perhaps Kant's theory of tidal retardation would have filled the gap. Kant also speculated on the flattening of Saturn and concluded that the density must increase towards the center of the planet. This conclusion he extended to Jupiter and inferred its applicability to other heavenly bodies.

In the zodiacal light he saw an analogue to the Saturnian rings, but he drew an essential distinction between the materials which reflect the zodiacal light and the rings of Saturn. The velocity of rotation of the sun being quite insufficient to maintain particles in free revolution near its surface, the heat of the sun must cooperate to keep the fame-like mass in a state of expansion even if the material came from the sun, as Kant thought probable. He also contemplated the possibility that it is a remnant of the nebula.

simple cases, applicable to the question in hand, of the problem of three bodies and generalized from the result. It seems impossible that he should not have perceived the true nature of the question, or that he should have committed himself without an inquiry which was qualitatively satisfactory.

\* Kant reached this result independently, but afterwards became acquainted with an investigation of Dominico Cassini's, *Mem. de l'Acad.*, Paris, 1705, p. 14, in which the rings of Saturn are regarded as swarms of minute satellites. This is nearly but not quite Kant's view; for his rings are, so to speak, raw material of which the satellites might have been made, but were not.

The planets in agglomerating become fluid. Newton, and indeed Descartes, had previously pointed out that planets had passed through the fluid condition. Kant seemingly ascribed the fusion of planets and satellites to the impact of their component parts.\*

Kant expressed in the clearest manner and with sufficient demonstration his view that the period of rotation of the moon was reduced to coincidence with that of its revolution by tidal action on the satellite while it was still liquid. He draws the conclusion that the moon is somewhat younger than the earth.† He also demonstrates that oceanic tides retard the rotation of the earth, and predicts that the earth will eventually turn one side only to the moon.

In a cooling planet, according to Kant, there is a rough and partial separation by density. Such a process is still progressing in Jupiter which Kant regards as still fluid. The planets eventually become solid throughout.‡ The obliquity of the axes of rotation to the planes of revolution may be in part due to changes in shape accompanying consolidation and in part due to irregular distribution of velocities in the gathering mass of a planet. The progressively increasing density of the planets as the sun is approached is due to the varying proportion of the heavier elements in the contracting nebula; the lighter elements being deflected into orbital paths more easily than the heavier ones. Kant in 1755 regarded the sun as a solid burning mass, attributing its small density to the fact

\* Kant's Werke, vol. i, p. 302.

† Ibid., p. 183 to 186. It may be of interest to translate a few sentences literally from this paper, "Ob die Erde in ihrer Umdrehung um die Achse einige Veränderung erlitten habe." "The water of the ocean covers at least one-third (sic) of its surface and is kept in continual motion by the attraction of the above mentioned celestial bodies [the sun and moon]. Moreover this motion is in one direction, exactly opposed to the rotation. . . . Since this flow is opposed to the rotation of the earth, we have here a cause which may be counted upon to retard and diminish rotation continuously to the extent of its capacity . . . The termination of this change of rotation will occur when the earth's surface, from the point of view of the moon, shall be relatively at rest, i. e. when it rotates in the same time as the moon revolves. If it were fluid throughout, the moon's attraction would soon bring its rotation down to this fixed remainder. This immediately reveals the cause which has compelled the moon in its journey round the earth always to expose to it the same aspect. . . . The attraction which the earth exerts on the moon, acting on the satellite while it was still fluid, must have reduced the rotation of the moon (formerly no doubt greater than now) to this fixed residue in the manner just explained."

‡ This is distinctly stated in *Allgemeine Naturgeschichte*; and in *Ob die Erde veralte*. One of the sentences in the preceding footnote is equivalent to an argument that, were the earth not solid, internal tidal friction would long since have reduced its period of rotation to that of the moon's revolution. This ingenious mode of reasoning on the earth's rigidity has not been revived or quantitatively tested so far as I know. It is worthy of consideration. In the *Physische Geographie*, 1802, however, he asserts that while the surface irregularities of the earth show solidity of the superficial portion, it does not follow that time enough has yet elapsed to carry consolidation to the center.

that the greater part of the material of the nebula acquired by impacts only a very small tangential velocity, and thus fell directly into the central mass. This fallacious explanation arose from his incorrect view of the generation of moment of momentum.

Further light as to the origin of the heat of stellar bodies came to Kant in 1785, thirty years after the publication of his theory of the heavens. Adair Crawford, in 1779, published his experiments on the development of heat by the compression of gases. These discoveries Kant says indicate a method of making comprehensible the development of any degree of heat as an accompaniment of the formation of heavenly bodies (suns or planets) from the initial nebula. He points out that the increase of temperature depends upon the initial and final densities and upon the brevity of the time of condensation. He infers that the central body, on account of its greatest mass and attraction, must develop the greatest heat and is rendered capable of being a sun.\*

Comets in Kant's system are derived from the extreme portions of the nebulous mass which gave rise to the solar system. The original position of the cometary matter being at so vast a distance from the center, gravitation acted but feebly; elastic impact of the gravitating material was therefore also feeble; the mass acquired but little tangential velocity and the resulting orbits show correspondingly great eccentricity. The feebleness of attraction and the tenuity of the mass at the exterior of the nebula may account for the independence of the elliptic manifested by comets; but Kant expresses his own dissatisfaction with this explanation. Retrograde comets Kant hardly attempts to explain; he even thinks there may be an optical illusion.† Kant supposed the eccentricity of the planets to increase with distance from the sun, and predicted that planets with greater eccentricity than Saturn and at greater distances from the sun would be discovered.‡ These in his opinion would form in a sense a transition to cometary bodies.

Kant considers the end of the solar system as well as its inception. The world itself is doomed to destruction as a habitable planet by the process of base-levelling and consequent flooding by the ocean.§ All the planetary bodies will eventually fall into the sun, the inner ones first, in consequence of the universal tendency of motion to gradual retardation. While Kant had a perfectly clear idea of the retardation of the motion

\* Ueber die Vulcane im Monde 1785: Kant's Werke, vol. iv, p. 201.

† Kant's Werke, vol. i. p. 265.

‡ Ibid., p. 243.

§ The process of base-levelling is excellently described in the paper "Ob die Erde veralte?" 1754, Kant's Werke, vol. i, p. 203.

of rotation by tidal action, and inferred the former more rapid rotation of the moon, I do not find in his papers a definite statement as to the means by which the dissipation of orbital energy is achieved. He did not regard planetary space as a perfect vacuum and may have relied upon the resistance of the interplanetary medium for the predicted effect. The fall of such great and numerous masses as the planets into the sun would, he says, immeasurably increase the heat of the central body. He also seems to have regarded the planets of small density as capable of combustion. The heat thus generated he believed great enough to dissociate the material of the system and to restore it to its original nebulosity.\* Then commences a fresh cycle of evolution.

Kant's doctrine of the restoration of the nebula by the dissociation attending the collapse of the solar system must certainly be pronounced false in the light of the second law of thermodynamics. It is almost impossible, however, to see how Kant could have avoided this error before Carnot's day. His attempt was to frame a theory for the universe, for all time, and some regenerative principle was a necessity to such a scheme. The second law of thermodynamics as now understood seems to divide everlasting time into two portions, the former of which is a perfect blank. In the light of present knowledge it would appear that the entire stellar system, planets and residual nebulae alike, must have been in the condition of an immensely diffused nebula not more than a few hundred million years ago and that the universe is now hastening towards eternal death. It is evident that the initial diffusion, whatever its date and its degree, can have lasted but an instant, during which the potentialized molar energy represented the maximum proportion of the total energy of the universe. By the principle of dissipation, molar energy is continually wasting away or undergoing conversion into molecular energy. Hence if the quantity of matter and the total energy of the entire system are constant, the molar energy at a period preceding that instant must have been smaller and must then have increased. The only alternative compatible with the second law seems to be to suppose that the total energy of the universe underwent an increase at that time. The universe would then not be a conservative system, the equation of energy would not apply to it, and aliquid ex nihilo fit. Such an increase of energy might or might not be due to a creation of matter. Thus if the molar energy was maximum within a finite period, either the quantity of energy in the universe is variable and has been increased or there is an undiscovered, regenerative, third law of thermodynamics

\* Kant's Werke, vol. i, p. 302.

which in some circumstances supersedes the second. In either event the number of the fundamental principles of natural philosophy would be still incomplete.

It is possible, however, to imagine the date of this critical period in the universe, the epoch of initial nebulosity, infinitely remote, though little intellectual satisfaction is to be attained by this means. If a strictly finite amount of matter were distributed in a space not merely relatively large but absolutely infinite, so that every atom should be at a truly infinite distance from any other, then a strictly infinite lapse of time would be required to produce a finite degree of condensation. Known laws would therefore account for present conditions if the ratio of space to mass in the universe is not merely large, but (like time itself) absolutely infinite. Such an assumption however seems preposterous, while it is far from incredible that some natural law remains to be discovered, even one which would make a *perpetuum mobile* of the universe as a whole.

The attempt which Kant made to create moment of momentum from the impact of nebulous matter is curiously out of accord with the rest of his investigation. In treating of Saturn's rings he avoided any such mistake, and the persistency of moment of momenta follows from his own scheme of the universe. When the solar system collapses, only to be restored to a nebulous state, as he supposed, it will be in rapid rotation, according to his own theory. It is thus only for the very first of the infinite succession of developments that his exposition asserts a fallacious source for rotational movement.

Kant seems to have anticipated Laplace almost completely in the more essential portions of the nebular hypothesis. The great Frenchman was a child when Kant's theory was issued, and the *Système du Monde*, which closes with the nebular hypothesis, did not appear till 1796. Laplace, like Kant, infers unity of origin for the members of the solar system from the similarity of their movements, the small obliquity and small excentricity of the orbits of either planets or satellites.\* Only a fluid extending throughout the solar system could have produced such a result. He is led to conclude that the atmosphere of the sun, in virtue of excessive heat, originally extended beyond the solar system and gradually shrank to its present limits. This nebula was endowed with the moment of momentum which Kant tried to develop by collisions. Planets formed from zones of vapor, which on breaking agglomerated. He appeals to the rings of Saturn as an illustration of nebular contraction; he also considers the Zodiacal light as due to a

\* The retrograde satellites of Uranus were discovered by Herschel in 1787, but Laplace in his hypothesis does not refer to them.

nebulous remnant. In the first editions of the *Système du Monde*, Laplace, like Kant, supposed some of the nebulae to represent stellar islands outside of the Milky Way system. In 1824 the work was revised and this explanation was omitted. In the revised edition, but not in the earlier ones, Laplace refers the equality of the moon's periods of rotation and revolution to tidal action caused by the earth's attraction in the still fluid moon.\* Comets were regarded by Laplace as little nebulae formed outside of the solar system, while Kant considered them as arising in the extreme portions of the solar nebula.

The main points of comparison between Kant and Laplace seem to be these. Kant begins with a cold, stationary nebula which, however, becomes hot by compression and at its first regeneration would be in a state of rotation. It is with a hot, rotating nebula that Laplace starts, without any attempt to account for the heat. Kant supposes annular zones of freely revolving nebulous matter to gather together by attraction during condensation of the nebula. Laplace supposes rings left behind by the cooling of the nebula to agglomerate in the same way as Kant had done. While both appeal to the rings of Saturn as an example of the hypothesis, neither explains satisfactorily why the planetary rings are not as stable as those of Saturn. Both assert that the positive rotation of the planets is a necessary consequence of agglomeration, but neither is sufficiently explicit. The genesis of satellites is for each of them a repetition on a small scale of the formation of the system. Each refers comets to nebulous matter more distant than the planets, but Kant thought it merely the superficial portion of the solar nebula. Both contemplated extragalactic systems of stars.

While Laplace assigns no cause for the heat which he ascribes to his nebula, Lord Kelvin goes further back and supposes a cold nebula consisting of separate atoms or of meteoric stones, initially possessed of a resultant moment of momentum equal or superior to that of the solar system. Collision at the center will reduce them to a vapor which then expanding far beyond Neptune's orbit will give a nebula such as Laplace postulates.† Thus Kelvin goes back to the same initial condition as Kant, excepting that Kant endeavored (of course vainly) to develop a moment of momentum for his system from collisions.

The extragalactic stellar systems imagined by Kant were

\* This seems to have been overlooked, for Lord Kelvin (*Geological Time*, Geol. Soc. Glasgow, Feb. 27, 1869) ascribes the discovery to Helmholtz

† On the Sun's heat. Lecture to Royal Inst., 1887, or *Popular Lectures*, vol. i, p. 421.

similar to those which the elder Herschel regarded as probable in the earlier part of his career, and in which Laplace believed prior to 1824. The subject has been under discussion ever since and is not definitely settled. Of late years the application of the spectroscope and the researches of Proctor have made it seem possible that only one stellar system is visible. If others exist they may be too far off for their light to reach the earth, or have progressed too far towards extinction to be sensibly luminous.\*

After Kant's explanation of the heat of the sun as due to compression, the theory does not seem to have been revived until Helmholtz enunciated it in 1854.† It now has the adherence of Lord Kelvin, and, so far as I know, of all physicists as the main source of solar radiation.

The novelty of Kant's view of Saturn's rings was that he supposed them to be composed of fume, or minute discrete particles, instead of satellites, as Cassini and Wright had done. It is rather strange that Laplace, though, like Kant, appealing to Saturn as an illustration of the nebular hypothesis, should yet have regarded the rings as solid. The older view, practically in the Kantian form, was reviewed by Maxwell,‡ who was evidently unaware of the earlier hypothesis.

Little advance has been made in explanation of the Zodiacal light since Kant's time. It is regarded as partly gaseous and partly composed of solid matter, perhaps meteoroids. Its spectrum seems to be that of reflected light.

Kant's idea of a transition from planets to comets has not received verification, and the orbit of Neptune is at present the most nearly circular of all the planetary orbits, excepting that of Venus, instead of the most eccentric as Kant would have supposed. Hence his prediction that planets exterior to Saturn would be found cannot be placed to his credit, its truth being accidental.

Kant was not the first to notice the decrease in density of the planets Earth, Mars, Jupiter and Saturn, while the densities of Mercury and Venus were unknown in his time. Such

\* The possibility that ether envelopes a stellar system like an atmosphere without extending indefinitely into space, is perhaps worth considering in reference to the hypothesis of the existence of distant star groups.

† Helmholtz's paper, *Ueber die Wechselwirkung der Naturkräfte*, was a popular lecture delivered in Königsberg and, according to Thomson and Tait, was on the occasion of a commemoration of Kant (*Nat. Phil.*, vol. ii, p. 493). In this paper appeared also his views on the tidal retardation of the earth and the moon, and the collapse of the solar system. Kant is mentioned as author of the nebular hypothesis, but not in connection with these more detailed questions. It is certainly most curious that at a Kant celebration Helmholtz should have announced the rediscovery of four of Kant's theories.

‡ *Proceedings R.S. Edin.*, vol. iv, 1858, and Adams prize essay, for 1856. Both may be found in his collected works.

merit as he possessed in the matter is consequently confined to the attempt to account for the greater frequency of relatively dense matter among the inner planetary rings. Euler supposed the densities to be proportional to the square roots of the mean motions. If  $a$  is the mean distance, this is equivalent to making the density proportional to  $1/a^{3/4}$ . Lagrange in 1782\* assumed the density to be proportional to  $1/a$ . In this hypothesis Lagrange was anticipated by Buffon† in 1769.

Modern results do not indicate such simplicity. Since there is compression in the inner portions of a planetary body, mean density must be a function of mass. This is perhaps a sufficient explanation of the fact that Earth has a higher average density than Mercury, Venus and Mars. The planetary densities are divisible into two groups. Those planets just named do not differ very greatly in this respect. The outer group from Jupiter to Neptune are vastly less dense, but it is not certain that the diameters of these bodies represent anything except the exterior of their atmospheres. They are probably still highly heated, and their average density is not very different from that of the sun. Now the sun is certainly vastly hotter and more expanded than the outer planets, and it must therefore be composed of material which would be denser than the mass of Jupiter at the same temperature. It is conceivable that this difference is due solely to the greater pressure within the sun's mass.

Kant's opinion (1755) that Jupiter is still fluid seems to be the earliest expression of that view. Buffon in 1778 announced his opinion that both Jupiter and Saturn are fluid.‡

The theory of base-levelling has been so generally accepted by geologists and physical geographers throughout the century that it is scarcely worth while to mention individuals, but some of those who do not happen to be familiar with Kant may be glad to read a few of his vigorous sentences on the subject. "In respect to change of the earth's shape there remains to be discussed a single cause which can be reckoned upon with certainty; it consists in the fact that the rain and the streams continually attack the land and sluice it down from the highlands to the lowlands, gradually making the elevations into plains and, so far as in them lies, strive to rob the globe of its inequalities. The action is certain and no matter of opinion. The land is also subject to this action so long as there is material on the

\* *Nouveaux Mém. Acad. Berlin*, 1782, p. 153.

† *Oeuvres comp.* Paris, 1827, vol. i, p. 215.

‡ *Époques de la Nature. Oeuvres complètes de Buffon*, Paris, 1827, vol. v, p. 84. Miss A. M. Clerke in her *History of Astr.* in the 19th Century, 2d edition, errs as to the date of Kant's publication on this subject and assigns the priority to Buffon.

declivities which can be attacked and transported by rain water.”\*

In 1754, according to Kant, the Berlin Academy offered a prize for a solution of the question “Whether the rotation of the earth which produces the alternation of day and night, has undergone any change since the time of its origin? What is the cause and how can the fact be established?”† Kant’s paper printed in the same year dealt with both the tidal retardation of the moon while still in a fluid state, and the retardation of the earth’s rotation by the marine tides. The subject seems then to have fallen into complete oblivion for nearly seventy years. The retardation of the moon’s rotation was rediscovered by Laplace in 1824. The earth’s retardation was maintained by Prof. James Thomson in conversation about 1840, as Lord Kelvin mentions.‡ J. R. Mayer expressed the same opinion in print in 1848.§ Helmholtz in 1854 discussed the tidal retardation both of the moon and of the earth.|| William Ferrel and C. Delaunay afterwards again suggested tidal retardation of the earth. It was only at a later date that Kant’s paper was brought to light.

So far as I know, J. J. von Littrow, in 1830, was the first to revive the Kantian idea of a final collapse of the solar system.¶ In 1854 Helmholtz again recurred to it. He explains the future annihilation of the rotation of the planets by tidal friction, and relies on a certain inevitable amount of resistance in interplanetary space to destroy orbital motion. Thomson and Tait, in 1867, showed that after the earth has come to expose to the moon a constant aspect, the effect of the solar tides will be to reduce the distance between earth and moon until they come together. By a similar argument it is said to follow that loss of energy (irrespective of a resisting medium) will not cease until all the bodies of the solar system “subside into a state of motion in circles round an axis passing through their center of inertia, like parts of one rigid body.”\*\* It does

\* Kant’s Werke, vol. i, p. 203.

† I find in the memoirs of the Academy no mention of this prize, and Kant’s paper printed in 1754 does not seem to have been offered in the competition. Peschel and Leipoldt, however, refer to it as having taken the prize. (*Physische Erdkunde*, vol. i. 1884, p. 54.)

‡ Geological Time, Address Geol. Soc. Glasgow, Feb. 27, 1868.

§ Beiträge zur Dynamik des Himmels, Heilbronn, 1848. Translated in *Phil. Mag.*, vol. xxv, 1863, p. 403.

¶ *Populärwissenschaftliche Vorträge*, 2d Fascicle, p. 130.

¶ In *Vorlesungen über Astronomie*, second part 1830, p. 146, he announces this approaching catastrophe and ascribes it to external influences acting on the system. Later he indicated friction in a resisting medium as the external influence. This explanation probably appeared in the first edition of his work, *Die Wunder des Himmels*, 1834.

\*\* *Nat. Phil.*, 2d ed., sec. 276. The text of this section is the same as in the first edition of 1867.

not seem certain that Kepler's laws are sufficiently rigorous for application to ensuing conditions, but if they are so, the number of bodies would seemingly reduce to two. By the third law, if  $T$  is the time of revolution and  $a$  the mean distance,  $T^2/a^3$  is the same constant for all the planets. Hence if the solar system reaches a condition in which  $T$  is the same for all the planets,  $a$  must also be the same, and all the planets must revolve on the same circle. In view of Lagrange's investigations on the stability of the solar system, it hardly seems possible that all the planets should acquire and permanently pursue the same exactly circular orbit unless they were to coalesce to a single mass.

In his preface to his *Theory of the Heavens*, Kant says: "I seek to evolve the present state of the universe from the simplest condition of nature by means of mechanical laws alone." After more than one hundred and forty years of rapid progress in science, it cannot be denied that his attempt was astonishingly successful.

Washington, D. C., December, 1897.