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Theories of Cosmic Evolution

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THEORIES OF COSMIC EVOLUTION

I

The framing of theories is an occupation in which men like to indulge. To imagine how things may have come about is probably the nearest approach to a creative act to which we finite beings will ever attain; and the field of astronomy has been an especially tempting one in which to try our creative powers. We like to do things on a large scale; and it is quite as easy to construct, in imagination, a planet or a solar system as something less pretentious. From the first men have been explaining how the cosmos came to be; naturally these imaginings have reflected strongly the philosophy of the times and places and peoples that gave them birth. We have had theories spiritual, theories fanciful, and theories frivolous. Men have told us how the civil engineers on neighbouring planets run their lines and dig their Culebra cuts; and long before this age of engineering they have explained how the starry sky was peopled with divinities and heroes.

Of all these many hypotheses which have been proposed to account for the universe of suns and planets as we see it to-day it would be hardly profitable, I am sure, to give even a resumé. Some of them have been slain at last by one or two stubborn facts which were lurking unnoticed by the wayside; others, once popular, are now ignored and forgotten because the world has quietly drifted away from them into new and safer channels. And yet some of these abandoned hypotheses were by no means useless; for even a flight of fancy has often led the way to fruitful research. Far from being stumbling-blocks in the path of progress, they have often been stepping-stones from which other men have climbed to greater heights.

In the development of the theory of the universe and the explanation of the celestial mechanism, there are five great names which stand out clearly from among their fellows: Ptolemy, Copernicus, Tycho Brahe, Kepler, and Newton. Some of these represent a group of men or a school of thought rather than an individual. Thus Ptolemy is only a spokesman; the Ptolemaic

theory is not wholly or mainly his own, but sets forth the conceptions of that brilliant group of men who took the first real step towards a correct understanding of the celestial machine in the centuries just preceding the Christian era, when Roman arms and Greek culture had overspread the Mediterranean world, and Alexandria was a centre of learning,—men such as Eudoxus, Aristarchus, Eratosthenes, and especially Hipparchus.

It is the fashion to speak of the Ptolemaic theory of astronomy as an erroneous and abandoned theory. It is all that; but it is the fundamental step which made a better theory possible. Up to the time of Eudoxus men had been content to say of six thousand of the stars that they are fixed, and of five others that they wander; it remained for these keen observers and sagacious thinkers to inquire how they wander, and why. They found that there was method in their wanderings; that Jupiter or Saturn, for instance, moves mainly eastward among the constellations, but about once a year it slackens its pace, and then retrogrades for a time before again beginning to forge ahead. They saw that these apparent vagaries are really methodical and can be represented by a double circular motion, by imagining a point in the sky to travel steadily around the sky eastward while the planet is swung regularly around this point in a secondary circle or epicycle, and is thus carried alternately ahead of its mean place, and then behind it. We know now that the regular forward or eastward motion is real and is due to the planet's own orbital motion, while the looping backward is apparent and is due to the fact that the earth overtakes it and passes it. But all the observed facts and all the measurements which they were able to make with their crude instruments are equally well accounted for by supposing either that the planet is moving around a point which is itself in motion, as they believed, or else (as we now know) that the planet is moving simply in its own orbit while we observe it from a moving earth. The important thing at the time was to analyse the apparently aimless wanderings of the planets and to show that they could be represented by a circle moving upon another circle. And it was a brilliant analysis. How generally is it known to-day, do you suppose, that the planets alternately advance and retrograde in the sky? How soon would a plausible explanation of the fact be suggested, if all knowledge of astronomy were lost? When the erratic behaviour of the wandering stars had been analysed and explained as a motion of one circle upon

another it remained for Copernicus only to make the comparatively simple and obvious suggestion that both the earth and the planets were probably revolving about a common centre and that all their orbits were centred at the sun.

The second great name is that of Copernicus, with whom again we must associate others, such as Galileo; but I doubt whether they deserve our praise quite as much as the men who, centuries earlier, made the Copernican theory possible. Let us not make the mistake of regarding the Ptolemaic theory merely as an old and incorrect and abandoned theory, and the Copernican as the true theory. The Copernican conception is far from being a correct one; it is still a theory of epicycles—a motion about the sun, it is true, but in circles compounded with circles, as if carried by rigid arms. Copernicus never conceived of the planets as tethered to the sun by an elastic force which could allow the planet to swing out to aphelion, and could then coerce it back to perihelion. He and his contemporaries piled epicycle upon epicycle in the attempt to represent a little more closely the facts of observation, until King Alfonso, when presented with the elaborate scheme which his astronomers had worked out, announced somewhat irreverently, "If I had been present at creation, I could have given some good advice."

Astronomy had indeed reached a point where theory had out-run observation. What was needed was not better reasoning but more precise data such as should compel better theory. Opportunely there arose a great practical astronomer, Tycho Brahe. His instruments were crude devices, huge wooden circles, crudely graduated, adjusted by means of plumb-lines and sighted as we point a gun. On an island in the Baltic, in an observatory built for him by the King of Denmark, he spent twenty-one fruitful years observing and measuring. He tested his instruments with scrupulous care and he used them with skill and patience. He did not accept the Copernican theory, partly because he thought the Bible taught otherwise, and partly for a very good scientific reason. If the earth revolves about the sun, he reasoned, the stars should show a yearly parallax; but in measuring their positions from time to time he could find not the slightest displacement. We know now that his instruments were hopelessly, ridiculously inadequate to detect the parallax of the stars. But he knew that unless the stars were at least a thousand times more distant than the sun, his measures

should have revealed a parallax. And that such preposterous intervals as this prevailed in the universe, who could believe?

Tycho never made much use of his own observations, but left them, a rich legacy, to others. The man who discovered the mint of gold in Tycho's measurements was his pupil Kepler. His fondness for correlating facts and reaching conclusions was as great as Tycho's zeal in gathering them. To Kepler belongs the distinction of being the first to discover and formulate any true laws of planetary motion. Kepler's three laws, which assert that planets move not in circles but in ellipses, and which define very simply and exactly the manner of their motion, are the *Magna Carta* of astronomy.

At the outset, naturally enough, Kepler could not but take it for granted that planetary motions are in epicycles; he could not believe that a heavenly body would do so unseemly a thing as to move in any other path than a circle,—the “perfect curve” of the ancients. From a study of the more accurate measures that Tycho had made, and particularly from an extensive series of his observations on the planet Mars, he supposed that his problem consisted in determining what combination of circles represented the actual motion of the planet through space. But he presently reached the conclusion that either Tycho's observations were sometimes as much as 8' in error, and this he could not believe to be the case, or else that no possible combination of epicycles could represent them; and having thus broken faith with all the philosophy of the past and confessed himself an astronomical heretic, he quickly found that an ellipse would beautifully satisfy the facts of observation if the sun were located, not at the centre of the ellipse, but at one of its foci, leaving the other empty. Now it may not seem that the difference between a circle and an ellipse is a very material or important one; but as long as a planet was thought of as moving in a circle or in some combination of circles, it was difficult to escape the conception that it was pivoted in some rigid way, almost as if it were operated by a material connection. Such a notion could not suggest that elastic bond of gravitation which can make a planet move, now faster, now slower, and which can now bring it nearer and now carry it farther. The search for such a force and the finding in it of the perfect key to the cipher code of planetary motion, could not well begin until Kepler's laws had shown the way. Kepler knew no reason why planets should move in ellipses, or why the

sun should be at one focus, or why the radius vector should describe equal areas in equal times, or why the square of the periods should vary as the cube of the distances; he simply found that the planets do so move. And it remained for Newton to show, seventy years later, by a simple geometrical demonstration, that if bodies attract each other inversely as the square of the distance, then Kepler's laws would necessarily be true.

And so we reach the summit of the long hill; in this simple law which Newton formulated it would seem as though we had the complete explanation of the motion of all ponderable masses in space. Though the elliptical motion of a planet is not exactly the actual motion, it would be so if the sun alone were the controlling body, and fortunately, for the progress of knowledge, the sun is so enormously more massive than any other body in the solar system that it is almost true. And yet as a matter of fact the earth never twice describes quite the same path through space; for it is constantly, if slightly, perturbed by the feeble attraction of the other planets, whose distances and directions from us are never exactly repeated. The moon's place in the sky is calculated in the nautical almanac for every hour of each day in the year, more than eight thousand positions in all; in the calculation of each of these positions, more than one hundred small perturbations have to be computed. If the sun were not so massive and therefore so dominant, the problem would generally be beyond the reach of our mathematical processes. An astronomer dwelling on a planet which belongs to the system of the double star Castor or the triple star Polaris, has probably not the slightest intimation where his planet will go next year, or next century, unless his mathematics greatly transcends that which has as yet been developed on the earth. But in our system the perturbations are calculable because they can be treated as only slight departures from the simple laws of Kepler. Of course, these perturbations are not defects in the system or imperfections in the law of gravitation; the very fact that they can be computed is the crowning glory of Newton's great generalization, though Professor Young tells us of a good old theologian who maintained that the perturbations of the planets are a consequence of the fall of Adam. Certainly the law of gravitation—the simplest and most sweeping of all material laws, though its application taxes the skill of the world's greatest mathematicians—may lay claim to being the greatest scientific generalisation ever made.

To this law as we know it here in our solar system conform the orbital motion of the distant binary stars as far as we can discover and the motion of every particle of matter in the universe. We should not think of the earth as a whole attracting the moon as a whole, but of each grain of sand in the earth as having its own peculiar and appropriate pull on every particle of the moon, and conversely—as the molecules of the tides are free to take the positions which their varying distances from the moon require. It was probably with some such thought as this in mind that Lagrange declared Newton to be “the greatest genius that ever existed and the most fortunate, for we cannot find more than once a system of the world to establish.” But Newton said of himself: “I do not know what I may appear to the world; but to myself I seem to be only like a boy playing on the seashore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me.”

II

But let us turn from the past to the present, from the history of science to science in the making. Ours is the era of great telescopes, great not merely in size but in perfection of image as well. Lord Ross with his six-foot mirror never saw the nebulae with anything like the delicate detail of structure that Ritchie has obtained with the 60-inch mirror on Mt. Wilson, or Keeler with the 24-inch Crossley reflector at the Lick observatory, or Roberts with the 20-inch at Edinburgh. The photographic art, too, has greatly come to their aid; so that now the 60-inch reflector on Mt. Wilson, with its great light-gathering power and wellnigh perfect curvature, and its long exposures in the clear atmosphere a mile above the haze and dust of the plains of Southern California, is pursuing these nebulous phantoms far into the depths of galactic space.

What then have we learned about the nebulae? In the first place, they prove to be exceedingly numerous; as indeed we might expect if the slow process of stellar evolution is forever in progress. From counts recently made on the Sigma Lumière plates exposed at Mt. Wilson, it is estimated that the total number of nebulae which can be caught by the 60-inch with an exposure of one hour, on such a plate, is about 162,000. In the second place,

the vast majority of these nebulae are of the peculiar type known as spiral. And where the structure can be at all made out, they are two-armed spirals; that is, they consist of a brighter central nucleus, from which emerge, at exactly opposite sides, two fainter arms or coils, which wind around the nucleus in a common direction, either clockwise, or counter-clockwise, sometimes closely coiled, sometimes more loosely divergent; encircling the nucleus once or twice. The two arms are usually almost perfectly symmetrical, and wind their way out to about equal distances from the nucleus. These coils are studded more or less abundantly with small bright nodules, or nuclei. This prevalent structure of a bright central nucleus, surrounded by smaller and fainter nuclei, immersed in a filmy haze suggests to the eye at once a solar system in embryo. Again, these nebulae as a rule are not gaseous bodies; at least they give a continuous spectrum. There may be and doubtless is more or less of gaseous matter associated with the nebulae; but their predominant light is that which would be emitted by solid or liquid matter, like a luminous dust-cloud or a shower of sparks. Only a few are gaseous, and these vary from irregular in shape and brightness to small and round and compact, a very small number showing an annular or ringlike structure. Finally, a census of the nebulae shows a rather curious fact with regard to their distribution in space. They are most abundant in just those directions in the sky where stars are least numerous. The arrangement of the stars in space, as we have long known, is in a comparatively thin, flat stratum, perhaps indefinite in extent, perhaps limited within a disc-shaped or coin-shaped area. The Galaxy or Milky Way is simply that zone in which we are looking out radially towards the edges of the disc, or in the plane of the cluster. It is for this reason that the universe looks so different from what it is. It looks like a hollow vault; it is a vast cluster and we are somewhere in the heart of it. All its members appear equally distant because the eye cannot judge of their distances. The moon and a star seem side by side; and yet the nearest star is a little more than a hundred million times more remote than the moon. The evidence by which we determine the shape of the cluster is as follows. The brighter stars—that is, those that are, on the average, nearest to us—are not obviously more numerous in one direction than in others. With a small telescope five or ten times as many may be distinguished along a given vista towards the Milky Way as are

found perpendicular to it. As the light-gathering power of the telescope is increased, we get scarcely any more stars at the poles of the Galaxy than with smaller instruments, while the number greatly increases in the direction of the Galaxy. Again, in the perpendicular direction there are found not very many stars fainter than the eighth or tenth magnitude, while in the galactic plane the census of the Herschells with their great mirrors found the relative number increased to thirty-fold and the predominant magnitudes dropping to the fourteenth; that is, stars in the galactic direction are in general fainter, presumably because they are mostly more remote; and they are more numerous because we are looking out through a longer vista of them. It appears, then, that the stellar host is marshalled mainly, although very irregularly, in a rather flattened cluster or stratum; and that the nebulae are distributed mainly along the flanks of the main army.

Dismissing the nebulae for a moment, we must notice a remarkable fact about the stars themselves which the spectroscope is every year making more certain. As a rule they are not isolated bodies but are grouped in close pairs. This information we get through the spectroscope rather than the telescope, for there are only a few hundred binary systems in which the two components can be distinguished with any telescope. But when the spectrum of a star is photographed, it very commonly reveals two spectra superposed, indicating a double source of light. The lines of one of these spectra are displaced towards the violet, those of the other towards the red, indicating what the telescope could not see, namely, that one member of the pair is approaching and the other receding. A few nights later, or sometimes a few hours later, a second observation will show that the motion is apparently reversed, indicating that the pair is revolving around its common centre of gravity. When a sufficient number of spectrograms have been obtained, the complete orbit of such a double star can be determined. And, since the spectroscope measures thus the actual velocity in miles a second, regardless of the distance of the system from us, the size of the orbit comes out directly in miles and not merely in seconds of arc. The orbits are generally very small; often the two components are almost in contact with each other. In many cases one of the spectra is too faint to measure, and still more frequently it is entirely invisible; that is, only one set of lines can be seen. And yet by the regular and periodical shifting of these lines the orbit of the bright com-

ponent is determined, and this implies the invisible companion revolving with it. The number of such known binary systems is rapidly increasing, and it is now fairly safe to say that double stars are the rule rather than the exception. Of course, as yet but a small number of such cases have been actually worked out, for this research has been conducted for only about two decades. The process, too, is a slow one; for a ray of starlight, when spread out into a spectrum, is so feeble that telescopes of less than twenty or thirty inches aperture can hardly cope with this problem. Even then an exposure of several hours is generally required to get a measurable spectrum; and twenty or thirty or fifty such spectrograms are required to determine an orbit. A dozen years ago Campbell was telling us that about one star in nine which he had investigated, proved to be a spectroscopic binary. Frost now puts the ratio, from his investigation, as one out of two. Evidently a large percentage of cases must escape detection, either because the companion is not massive enough to produce measurable motion in the visible star, or because the orbit lies so nearly perpendicular to our line of sight that the orbital motion does not produce an appearance of approach or recession. It thus appears, not only that nebulae are predominantly two-armed spirals, but that stars are predominantly binary systems. The universe seems to be built on the sacred number two.

III

With these facts in mind let us turn to a review of the several theories of planetary evolution. The ring-nebula theory of Laplace need not detain us long. Every one is familiar with its main features, and with the elegant manner in which it has seemed for a century to fit in with all the known orbital and rotational motions of the planets and their satellites. Let me point out merely how widely our present conception of a typical nebula has drifted away from the idea which Laplace entertained, and also how stubborn are some of the facts which have recently been discovered to discredit the theory. To begin with, the nebulae are not mainly gaseous bodies as he supposed, to say nothing of the circumstance that among the hundreds of thousands of known nebulae those that show the ring-like form required by his hypothesis may almost be counted on one's fingers.

Furthermore, if all the matter now composing the sun and the planets were expanded into a gaseous nebula as large as the orbit of Neptune, its density would be only one 250-millionth that of the air we breathe. It could not obey the laws of gaseous diffusion as we now know them; it would represent only here and there a lone molecule wandering through space. It is hardly conceivable that such a nebula could ever separate into rings, or that such rings could ever agglomerate into discrete planets. In addition, it requires considerable gravitational stress exerted by a planet in order that it may retain its atmosphere, especially the lighter gases. Thus the massive sun has an atmosphere rich even in free hydrogen; while the earth's atmosphere has practically none and the little moon has lost even its heavier gases, as oxygen and carbon dioxide, if, indeed, it ever had them. And all this is as it should be, considering the relative masses of the sun, moon, and earth. Now if the earth were once a ring and later a sphere of gaseous elements, as yet uncombined, its feeble gravitation could not have retained any free hydrogen out of which the oceans might later be formed. While finally, it has been proved to be not a fact, as was supposed, that the satellites of the planets revolve in a common direction; for Phoebe, the outermost satellite of Saturn, discovered by Pickering in 1899, is revolving around Saturn in a direction opposite to that of her nine sisters. And in 1908, when the eighth and outermost satellite of Jupiter was discovered, its motion was also found to be retrograde.

To replace or supplement the Laplacean hypothesis, which for a century has seemed secure in scientific favour, there are three theories of planetary evolution which seem at present to be, all of them, possible or probable explanations of the origin of the solar system. These are George Darwin's theory of tidal evolution, the planetesimal theory of Chamberlin and Moulton, and T. J. J. See's capture theory.

The planetesimal theory of Chamberlin and Moulton is based upon the fact that the predominant type of nebula is the spiral rather than the annular, and upon the assumption that it is swarmlike rather than gaseous. The central core is assumed to form the sun, while the smaller nuclei become planets and satellites. Each of these gathers to itself by gravitation the matter in its immediate vicinity and so grows by accretion. The orbits which it will finally assume will depend upon its initial motion, and the proximity and velocity of neighbouring masses. The

central sun will mainly dominate the motions of the system; the larger masses will generally succeed in sweeping in most of the gaseous matter and also the smaller masses in their vicinity. But any such smaller nuclei as are moving with sufficiently great velocities of their own, will escape this fate and remain as satellites of the planets, retaining their integrity but not their independence.

This hypothesis, besides conforming well with what we know about the nebulæ, seems so far to have avoided successfully the pitfalls which beset the older theory. Mathematical analysis, for example, seems to show that planetesimals thus gathered in by a growing planet will tend, although not inevitably, to give it a rotation in the same direction as that in which the particles of the whole system are mainly travelling, and that this tendency will be least decisive in the case of the outer planets; as actually seems to be the case, since Neptune and Uranus and their satellite systems show the most abnormal direction of all. In the same way it appears that the tendency of satellites in a given system will be to revolve in a common direction—but again not inevitably—and that exceptions will most easily occur, as they do occur, in the outer members of the system. On the planetesimal theory, it is to be noticed, the earth was probably never gaseous or even liquid; also the moon, since it grew by accretion, as did the larger planets, might naturally retain in its pitted surface the huge scars which mark its early bombardment by planetesimal bodies small and great, for the moon's gravitation was too feeble to retain any atmosphere that might heal by erosion these scars of war; while the earth by its aqueous and atmospheric agencies has been able to conceal its like wounds and to cover its scars with verdure and flowers. It has always seemed to astronomers difficult to explain the lunar pits as veritable craters of volcanic origin, since they are often twenty or thirty miles in diameter, and sometimes sixty or eighty. But this celestial bombardment, which the theory assumes, would be abundantly adequate to produce them in a pristine "wreck of matter and a crash of worlds."

Chamberlin and Moulton have also ventured a farther step in the genealogy of the planets, inquiring into the possible origin of these prevalent two-armed spirals, from which solar systems are thought to have developed. In this case they have not perhaps quite so successfully accounted for the observed facts.

They believe that a spiral nebula might naturally result from the breaking up of a sun or star, partly from internal forces, but determinately from the chance passage near each other of two stars in space. We know that the stars are all in motion. There are no fixed stars; only the immensity of stellar distances prevents such motions from changing obviously and rapidly the configuration of the constellations. The stars are moving in sensibly straight lines in all directions and with all sorts of velocities. The average stellar velocity is something like twenty miles a second, while in individual cases it reaches three hundred miles a second. In the long æons of astronomic time stars must occasionally pass in close proximity to each other, although calculation shows that such an event would be, humanly speaking, very rare. When any two stars pass near each other, the known operation of tidal forces will produce in each body two equal and opposite bulges, which in the case of a close approach will become extensive protuberances. Now we know that powerful explosive forces are continually operating in our sun, and presumably in other suns. Ejections have been observed and measured which reached a velocity of two to three hundred miles a second. And since this is almost enough to exceed the sun's gravitational power to bring the matter back again, it is not difficult to see how such internal forces, aided and directed by the assumed tidal strain, might produce two similar and opposite streams of ejected matter. This matter, moving out and around the star under the control of gravitation, would produce the two spiral arms, while the extent and closeness of the coils would depend upon the age of the nebula. It should be noticed that the two spiral arms do not represent the paths along which the outgoing matter moves, but rather the position into which this matter is finally carried; they are like the terminal moraines which the glacier piles up at its front, the moraine lies across the path of motion.

The capture theory which See has advocated is not essentially different from the planetesimal theory as far as the development of planets out of a spiral nebula is concerned. But the formation of the antecedent spiral nebula in the manner proposed, he thinks, is unlikely, and he believes that it too is a case of capture, not due to disruption in a finished sun by the tidal strains inflicted upon it by a neighbour, but rather to the meeting and coalition of two purely nebulous masses which have drifted into each other's way—two dust clouds of cold, dark matter whose impact has

generated the energy that makes the nebula self-luminous. Two such swarms, moving at random through space, would not usually meet in a direct line; the collision would naturally be more or less tangential and so would generate the slow rotary motion which their coiling seems to suggest, just as two water currents or two air currents, meeting at an angle, produce a vortex. On this theory the two arms which we see are not ejections moving spirally outward, but are two streams of cosmic dust moving spirally inward. The spiral nebula is not a case of divorce where the couple have turned their backs upon each other, but of a happy pair who are rushing into each other's embrace and whirling in ecstatic dance, doubtless to that music of the spheres of which the Pythagoreans dreamed. In support of his suggestion See points out that if nebulae are formed from the disruption of stars, they ought to be most numerous where stars abound, for here close approach would most frequently occur; but, as we have seen, just the opposite is true. He computes from the approximately known distances of the stars and the velocities with which they are moving that the chances of a sufficiently near approach to produce disrupting tidal strains would be too rare to account for the abundance of nebulae; in fact, that cases of this sort would be almost negligible. As against See's theory, it must be confessed that we have no very definite knowledge of the abundance of cosmic dust out in the region where the nebulae abound; but it might easily be very abundant so that meetings and coalitions might be frequent occurrences.

The theory of tidal evolution which was proposed by George Darwin, son of the eminent naturalist, does not undertake to account for solar systems in general but only for pairs of bodies like the binary stars or the moon and the earth. The moon produces constantly in the earth a tidal strain which tends to elongate the earth a few feet in the direction of the moon, making two tidal bulges. These travel around the earth daily, or they seem to do so; that is, they are really anchored to the moon by gravitation, while the rotating earth turns under them. There can be no doubt that they must act, feebly of course, as a brake to check the rotation of the earth; and in the earlier ages when Darwin finds reason to believe that the moon's orbit was much smaller than now and the attraction therefore greater, these tidal brakes would have been more powerful than at present and actually very effective. Such tidal strains operate also in what

we call the solid earth, which is by no means entirely rigid. Further, our planet should act in the same way on the moon and much more powerfully. There is no escaping the conclusion that the tidal forces acting between any such pair of bodies must tend to check the rotation of each. This tendency has reached its ultimate goal as far as the moon is concerned, since the moon now keeps the same face constantly towards the earth. Numerous other cases like this are known in the solar system; for instance, some of the other satellites certainly, and all of them probably, have the same hemisphere directed always toward the planet. Now this tendency of the tides to retard rotation must have had some effect upon the earth; the earth must be rotating somewhat more slowly now than it did formerly. Darwin computes from the mass and density of the earth and the moon and from their present motions that the earth's rotation period was, at the outset, about five hours in place of twenty-four. Now, as Newton tells us, "to every action there is an equal and contrary reaction": while the moon pulls backward on the tidal bulges which it has raised in the earth, these tidal bulges must pull forward on the moon and so accelerate its velocity in its orbit; but increase in velocity begets a larger orbit and this results in a longer month. Beyond question the tendency of tidal forces is constantly to lengthen the day and also the month, and to increase the size of the moon's orbit; the only question is, whether these forces have been adequate to produce the results claimed. At any rate Darwin concludes that the earth must formerly have rotated faster than it does now, the moon must have been nearer and its period of revolution shorter. If so, these forces would have then been still more powerful and effective; and so he reasons back to a time when the moon was practically in contact with the earth and the pair revolving in a period of about five hours.

But let us leave the process here for a moment and begin at the other end. Poincaré and other physicists have calculated mathematically what might happen to any plastic body rotating at high speed. They find that such a body might become unstable, acquiring a pear-shaped figure, which would then tend to become constricted and finally to separate into two contiguous globes, exactly the point to which Darwin was able to reason back by acute mathematical analysis beginning with the present status of the moon and the earth. In a word, then, this is the assumed process of evolution of the earth-moon system: first, a plastic

globe rotating in five hours; this develops unstable equilibrium and finally detaches a portion of itself; at this stage we have a day of five hours, a month of five hours, and the moon practically in contact with the earth; tidal retardation now sets in; the day grows longer, the moon's orbit enlarges, and the month increases rapidly at first, then more slowly; until now we have a day of twenty-four hours, a month of twenty-seven days, and a lunar orbit of 240,000 miles' radius. These tendencies are still feebly acting and can be expected to cease only when the earth turns constantly to the moon, as the moon now to the earth, a changeless face; that is, when the day and the month are again equal. It is computed that this will occur when the earth's axial rotation has been retarded to a rate that will give a day of about the duration of two of our present months. But this can be only æons hence. It is not believed that any such disruption of a planet could take place unless the two bodies thus separated were somewhat comparable in size. It is hardly possible that moons as small as those of Jupiter could be detached thus from a planet as large as he; and it is regarded as rather doubtful whether a planet as small as the earth and a satellite as large as our moon could thus part company. But when we consider the vast number of double stars, many of them globes of nearly equal size, the theory of Darwin is regarded by astronomers as an exceedingly plausible explanation of their origin. Dr. See has shown how well it accords with very much that we know about the binary systems, such as their various eccentricities and dimensions and periods. But he thinks it hardly possible that the moon could have originated in this way; more likely it was a wandering waif, captured by the earth from out the original nebula.

IV

But what of the evolution of the sidereal universe as a whole? Have we any glimmer of light as to the origin of the nebulae themselves and their tendency to congregate along the flanks of the galactic cluster? There seem to be two opposite, or at least complementary, processes going on in the sidereal universe: one is the gravitation of all masses of matter towards a common centre; the other is the dissipation of radiant energy, which tends to disintegrate the minuter particles of matter. For example, there is some force acting upon every comet when near the sun, tending to

drive out from the head those molecules or atoms or ions of matter, whatever they may be, that form the tail. This force is probably none other than the radiant energy of the sun, which is capable, as the physicists have shown, of exerting a definite push upon the particles of ordinary matter, provided they are very minute. At any rate by some such repulsive force cometary matter is being driven off into space against the force of the sun's gravitation; and these particles are apparently never recovered by the comet.

The sun itself is probably losing matter all the while into space in a variety of ways. The solar corona which extends out in faint wisps, often to several times the diameter of the sun, is an appendage which shines mainly by reflected sunlight, as its spectrum shows. It is therefore probably made up of dust-like matter ejected in some way from the sun. Radio-activity too is doubtless giving off from the sun emanations of radium and its congeners. Again, solar eruptions, as already mentioned, sometimes eject matter from the sun with such explosive violence that its particles are probably never able to return. These eruptive forces are beyond the power of language to picture. Newcomb remarks that "if we call the sun's atmosphere an ocean of fire, we must remember that it is an ocean hotter than the fiercest furnace and deeper than the Atlantic is broad; if we call its movements hurricanes, we must remember that ours blow only about a hundred miles an hour, while those of the sun move as far in a single second. . . . When the mediæval poets sang

'Dies iræ, dies illa,
Solvat sæclum in favilla'

they gave rein to their wildest imagination, without reaching any conception of the magnitude or fierceness of the flames around the sun." And every other star is doubtless a like source of radiant energy and a centre for the distribution of cosmic dust.

It seems inevitable that in ways such as these, and probably in many others that we know not of, the whole extent of interstellar space is more or less dust-filled. Kapteyn's recent investigations of the stoppage of light from distant stars seem to show that interstellar space is not wholly transparent, probably because of the distribution throughout it of meteoric or dust-like particles. If so, what becomes of all this matter? If the million

of stars which form our cluster are all engaged in the operation of dissipating and distributing matter, where shall the straying atom, like Noah's dove, find a resting place for the sole of its foot? Does it, like the evil spirit of holy writ, wander in empty places, seeking rest and finding none? Or does it finally escape from the galactic stratum, where radiant energy abounds, and reach a zone where its own feeble gravitation is again able to assert itself and the process of integration again begin? If so, these streams of nebulous particles, out on the confines of the cluster, would tend slowly but surely to become aggregated into new *nebulæ*. Any two such dust clouds of considerable extent, chancing to pass, like ships in the night, would begin to feel each the mystic spell of the other's presence, and be drawn slowly but irresistibly into union with it. By the impact they would become animated anew with radiant energy and begin again the age-long process of planetary evolution.

If this be so, it would seem that the binary structure, so prevalent in the universe, is a matter of the easiest possible explanation. The chance that two masses of matter should approach each other is enormously greater than that three such masses should meet in the same place at the same time. In other words, stars are binary and *nebulæ* are two-armed for the absurdly simple reason that two is the next larger number than one.

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each other false? Why give them ear? Kant, instead of asking how are synthetic judgments *a priori* possible, should have asked the simpler and more profitable question, how are synthetic judgments possible. Perhaps he had then been led to a correct theory of induction. As for a *Ding an sich*, it could be only a thing out of relation—that is, out of existence. Mill's *Logic* he characterised as a great philosophic work, embodying the philosophy of ordinary mankind. But Mill did not know what was important in science. To such a degree was this true that most of the instances of scientific induction which he gave, in the first edition of his book, afterwards turned out to be bad inductions. Mill should have concluded from this fact that there was something wrong with his theory. Moreover, though on first reading seemingly clear, Mill is really not so; study of his work brings out ambiguities and contradictions. During the beginning of one's study of logic, we were told—that is, during the first ten years—one should devote oneself entirely to learning the exact meaning of words. Mill had neglected this.

Perhaps I have, in some measure, reproduced the atmosphere of Peirce's Hopkins lectures. To complete the conception of the man, it would be necessary to exhibit him in his talks before the Logic Club, necessary to speak of his papers in the old *Journal of Speculative Philosophy* and in the *Monist*, besides more technical papers elsewhere. But this would require profound and long-continued study. I may say merely that the deeper one enters into the spirit of Peirce's teachings the more logically and philosophically satisfying, the more complete and harmonious and inclusive they seem to be.

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