the spectroscope will note the change is about half a mile per second. To obtain a source of light moving with such a tremendous velocity inside a laboratory, the only practicable plan appears to be to make use of multiple reflections from systems of mirrors mounted on the rims of rapidly revolving wheels. For the velocities used, the change of wave-length on reflexion from a normally moving mirror is identical with that due to a motion of a source with double its velocity, and the effect would evidently be augmented by multiple reflexion, the alternate sets of mirrors (mounted on the rim of moving wheels) being rotated in opposite directions. After such repeated reflexions the light is analysed by a powerful spectroscope which reveals the change of wave-length.

To Stark is due the brilliant discovery of a second method by which the Doppler effect may be demonstrated in the laboratory, and this was the employment of the Canal rays due to the electric discharge in a vacuum tube. These Canal rays are supposed to be positively charged gaseous particles which are shot down the tube with a tremendous velocity (a few hundreds of miles per second) and may be isolated by using a perforated Cathode through which the rays emerge into the space beyond. The light emitted by these particles in the direction of their motion when analysed by a spectroscope shows the Doppler effect in a remarkably striking way. As the exhaustion of the tube proceeds, a wing appears to split off from the spectrum lines and gradually moves towards the violet sides of the spectrum. The detached line is somewhat broad and diffuse on account of the differences in the velocities of the different particles. There is always a line present also in the original position, showing that some of the particles emitting the light do not share in the motion of the Cathode rays.

The Nebular Hypothesis.

By W. A. Lee.

The oldest views of the Universe represented the hosts of heaven as persons who had lived on Earth. This idea seems to have been widely held in Europe, in Asia, and by Negroes in Central Africa. Beliefs are gradually modified, they are subject to the universal law of evolution, and accordingly ideas as to the personality of celestial bodies gradually changed until in the Middle Ages it was generally believed that the planets

were directed in their orbits by Spirits or Gods Later it was shown that gravitation sufficiently explained and accounted for the movements of planets in their orbits, and the old belief had to be further modified, and the God or Spirit holding each planet in its orbid was abandoned, and for this belief was substituted the theory that each planet was separately made and started off in its appointed orbit by an omnipotent Creator. Within the last 200 years this speculation as to creative methods has been gradually replaced by a finer conception.

In the middle of the eighteenth century a Mr. Thomas Wright, a mathematical instrument maker in Fleet Street, wrote a book called "A New Hypothesis of the Universe," in which he suggested that the stars formed a regular system, an idea not previously published. He believed that the Sun is a member of the group of stars forming the milky-way and that the milky-way is one of many systems of stars, and that other galaxies form with the milky-way a system of stars. He suggested that the nebulæ are other galaxies.

In 1755 Emanuel Kant published "The Natural History of the Heavens" based upon Wright's work, and he proceeded to argue from Wright's hypothesis of the structure of the Universe that such systems as the solar system might have originated from the condensation of a nebula. He was puzzled to account for uniform planetary motion, and he tried to prove, what we now know to be impossible, that the interaction of its particles could set up a vertical swirl in the nebula. Kant supposed the centre of a nebula to be an aggregation of atoms which gradually grew by the falling upon it, under the action of gravity, of further atoms. He thought that the particles in falling together by gravity were unable to fall directly towards the centre because of collisions with other particles, and from these collisions indefinitely multiplied he believed a swirl or rotation would result.

Kant thought that the planets originated through the formation of other and smaller nuclei in the original nebula. His mental vision saw a principal nucleus in the original nebula and a number of lesser nuclei, and he thought the Sun originated through the growth and accretion of the largest nucleus, and the planets and their moons through the growth of the smaller nuclei. It was in accounting for the movements of the planets that Kant's theory broke down. As each planet was separately formed and its rotation separately determined by the interaction of the particles falling together during its formation, the rotation would be as likely to be retrograde as to be direct, as likely to be in one plane as another, and the

uniformity of direction of movement in the solar system puts out of court a theory of origin which assigns an independent fortuitous origin for such a number of similar movements.

At the end of the eighteenth century Laplace published his hypothesis. He assumed the existence of an extended nebula of great tenuity, but at a high temperature, and with an initial swirl or rotatory movement. Laplace endeavoured to demonstrate the probability that the nebula in cooling contracted, and in contracting accelerated its movement of rotation. This continual acceleration of rotation proceeded until the centrifugal force was equal to the attraction of gravitation and caused separation of a portion of the equatorial region of the rotating mass, in the form of a ring. The ring so thrown off would continue to rotate at the speed of rotation of the mass at the time the ring was thrown off, and would gradually coalesce into a planetary globe, and the successive throwing off of such rings, as the great nebula contracted, would form a succession of planets. The planetary nebulæ as they cooled and contracted would similarly throw off rings which would form subsidiary globes of satellites. Laplace worked out his hypothesis in great detail, and endeavoured to account for all the observed phenomena in the solar system. The very precision of his theory made it vulnerable, and objections and difficulties had more destructive force than they would have had on a more vague theory. The Nebular Hypothesis took such a hold of the scientific imagination of astronomers that it has persisted for a century and a half in spite of criticisms that in their time have appeared destructive. This has been partly due to the fact that the hypothesis has also from time to time received support by discoveries and theories of later date.

One of the earliest difficulties arose by the discovery of the retrograde systems of Uranus and Neptune, whose satellites revolve round their respective primaries in the reverse direction to the moons of all the other planets. It was eventually pointed out, however, that if the contracting nebula threw off nebulous matter in the form of a ring it would depend on the shape of the ring whether the direction of movement is direct or retrograde.

Then the Nebular Hypothesis obtained support, as strong as it was unexpected, from the discovery of the conservation of energy and its application to celestial phenomena. Laplace had postulated a primordial nebula extremely tenuous, but he had to assume that his nebula was already extremely hot. This was a great demand upon the imagination, and when it was shown that the action of gravity under which the nebula

was assumed to contract would be accompanied by a continuous evolution of heat, the Nebular Hypothesis acquired a new importance, and the demonstrated fact that energy is indestructible lent support to the hypothesis just where support was badly wanted.

Another difficulty arose from Lap lace's dictum that as each planetary ring of matter was thrown off by the original nebula it would continue to revolve round the central nebula at the speed, and in the period at or in which the surface of the nebula rotated at the moment of separation : that is to say, that the Sun which now rotates in little less than a month would have rotated in a year when it filled the Earth's orbit, at the time when the ring of nebulous matter which was to form the Earth had just been separated.

The energy of rotation of the Sun must have been the same in all ages, the moment of momentum is invariable, time neither adds to it nor can time take anything from it, and therefore it is a matter of simple calculation to see what the period of rotation of the Sun would be if it were swelled up in size to the dimensions of the Earth's orbit. It would rotate not in one year but in 3,000 years. This means that at the time when the nebulous Sun was separating off the ring of nebulous matter which was to form the Earth, not only was the Sun not rotating in one year, but it was not rotating fast enough to throw off a ring of matter; it was rotating so slowly that the force of gravity was not overcome by the centrifugal force.

Similarly if you imagine the Sun expanded to the size of the orbit of Neptune its rotation period must have been thousands of centuries—far too slow to throw off any of its substance and so form planets.

The Nebular Hypothesis, indeed, requires that the contracting Sun shall rotate all the time at such a speed that it is in a state approaching unstable equilibrium, and the centrifugal effect of rotation is only just counterbalanced by the action of gravitation. It would require that the Sun should be now rotating at such a speed that its equatorial particles are only just held together by gravity. I need hardly say that this is not the case : it would require the Sun to rotate, not in a little under a month as it does, but in less than an hour.

The Nebular Hypothesis, as stated by Laplace, requires the contracting nebula to rotate more and more rapidly as it contracts. This is also shown to be a necessity by the theory of the conservation of energy ; it follows that each planet, after having thrown off a satellite, as it goes on contracting rotates more rapidly than it did at the time when the satellite was

formed. Now, according to the Nebular Hypothesis, the satellite revolves round its primary in the period in which the primary rotated at the time the satellite was formed. Therefore the contracted primary must rotate at a more rapid rate than that at which the satellite revolves round it. This is observed almost throughout the solar system, but there are at least two, perhaps three, instances of the contrary. The inner satellite of Mars revolves round is primary in one-third of the period of rotation of Mars, and Saturn's inner ring revolves in half the time the planet rotates. These are discrepancies that have not been explained, and which are difficult to meet.

Another criticism has lately arisen based upon the modern view of the mechanism of a gas.

The molecules of a gas are in continuous and rapid movement, and this would cause, it is alleged, a continuous loss of the constituents of a gas expanded to the extent assumed for the primordial nebula. The lighter gases, those whose molecules are the most active, would naturally be the first to leak away into space, and in this way all the hydrogen would be lost, and then helium and other gases in proportion to their lightness.

But all the hydrogen and helium has not disappeared from the solar system ; both are present in enormous quantities, in very large proportions, in the Sun.

As far as we feel at liberty to apply knowledge gained on Earth of the materials of which the solar system is composed, we are able to say that the Sun in radiating heat into space is cooling, that in cooling it is contracting and that its contraction is accompanied by the evolution of heat. The limit of the heat which the sun can radiate is therefore limited by its contraction, and when it can contract no more it can only radiate the quantity of heat that it then happens to contain. We can therefore oresee a time when the radiation of the Sun will cease, and it will be dead and cold, and we can calculate more or less approximately when this will be.

Applying the same reasoning in the other direction we believe that at one time the Sun was larger than it is now. Perhaps the preglacial men, a quarter of a million years ago, if they had been armed with instruments of precision could have measured the face of the Sun as being perceptibly larger. We believe that in the ages represented by the time of deposition of the sedimentary rocks the Sun has shrunk considerably and that it was a distinctly larger Sun that shone on the world when our coal mea ures were being formed. Thinking back further we see the Sun expanded to the size of the Earth's

orbit, before that to fill the orbit of Jupiter, earlier it filled the orbit of Saturn, still earlier that of Neptune. There seems no escape from this. In the present state of our knowledge it is unavoidable.

Then if the present conditions make it appear that the Sun has contracted from a nebula having a diameter as great as the orbit of Neptune, and when we see the uniformity of the movements of the planets and the Sun, we are naturally attracted to the belief, no matter what its difficulties, that the planets were somehow formed during the contraction of the Sun from a great nebula engulfing the whole of the solar system, although it is questionable how far the present uniformity of movement can be regarded as proof of original uniformity.

Extracts from Publications.

A Simple Eclipse Experiment.—The phenomena of an eclipse may be well reproduced by a simple experiment made as follows :—

Make a smooth round hole, about one-eighth of an inch in diameter, in a visiting card or thin sheet of metal, and allow the rays from the Sun or other source of light to pass through the hole and fall on a sheet of white paper held parallel to the card, and at right angles to the rays. Take a pin with a round head of black glass, of a diameter very little less than the hole in the card, and holding it about an inch from the card, pass it very slowly across the hole. The bright image of the Sun will then pass through all the stages of an eclipse, commencing with the " first contact " as the head of the pin first emerges into the rays at the edge of the circular disc of light, and forming all the successive crescent phases until it lies co-axially with the hole in the card, when the appearance of an " annular eclipse " is reproduced. Further movement of the pin in the same direction will reproduce the phases which occur after totality has been reached, giving, finally, the phase of " last contact."

If the bright annular ring of light be examined carefully, when the eclipse is at its maximum, it will be seen to be free of blurs or blemishes if the edges of the hole and the head of the pin are both clean and free from projecting particles. Now coat the head of the pin with fine dust, such as flour or