THE NEBULAR HYPOTHESIS.

BY N. N. SEN, M.Sc.

The present poper is an instalment of the results of my investigations on the shapes and nature of various nebulae which have as yet been discovered. A thorough knowledge of them is indispensable to all researchers on Nebular Hypothesis which has been put forward to explain the process of evolution of stars from nebulae. I have discussed the general history of the discovery of nebulae, their classification and description with special reference to the variable nebulae and nebulae of dark species and recent discoveries of their proper motion and rotation. In the last portion of the paper. I have attempted to explain the formations of diffirent nebulae in the light of nebular hypothesis. Such an explanation will never be absolutely conclusive but the marvellous progress in spectroscopy which plays such an imporant part in astrophysics will, I hope, in the near future rmove most of the difficulties.

In 1656, the celebrated Dutch physicist and astonomer Huyghens discovered a nebula in the sword handle of the Orion. But the first astronomer to make a list of nebulae was most probably Halley who made a small catalogue of 6 such objects. Then came the celebrated French astronomer Charles Messier who made a catalogue of 103 nebulae which are still distinguished by his initial M. After him, came Sir William Herschel who made a catalogue of 2509 nebulae which are distinguished by a special sign with the number of the class (for he divided the observed nebulae into different classes) by Roman Capital letters. His son Sir John Herschel increased the number to 3926. Those nebulae that were discovered by him at the Cape are marked (h) and others, (H). Then came the renowned discoverer Lord Rosse who with his 6-feet reflector studied several nebulae and who was the discoverer of the Spiral nebulae, which, as we shall see presently, play such an important part in the modern nebular hypothesis. An enlarged edition of Sir John's catalogue was published by the Irish astronomer (Dreyer) 1888 which contained 7840 nebulae distinguished by his initial D. The other observers who must be mentioned in this connexion are Sir William Huggins, M. M. D. Arrsst, Von Pahlen, Isaac Roberts, E. E. Barrard, J. E. Keeler, A. S. Eddington and others. F. G. Pease of Mount Wilson Observatory with the 60 inch reflector has taken magnificent photographs of various nebulae between 1911 & 1916.

Sir William Huggins opened a new line of research by his Spectroscopic examination of nebulae and earned an undying fame by his famous discovery of the cosmic gas nebulium, so important in Laplace's nebular hypothesis. J. E. Culer in 1890 was the first to observe radial motion of nebulae. His example was followed by Campbell, Slipper and others. H. D. Curtis studied proper motions of as many as 100 nebulae, while Pickering and Kieleu announced that O type stars (Wolf-Rayet stars) and planetary nebulae gave the same spectra and Bright went so far as to assert that planetary nebulae were such stars in embryo. V. M. Slipper published the detection of nebular rotation, observed in Virgo nebula in 1914 and Wolf detected the rotation of M 81, while in 1915 Campbell and Moore announced the rotation of the planetary nebula N. G. C7009, and V. Maaken studied the rotation of the spiral nebula M 101. The nebular hypothesis which requires the primordeal nebula to be a rotating coherent mass, has thus been placed on a firm footing.

The total number of nebulae bright enough to be photographed has been estimated by E. A. Forth at 160,000[2], But Perrine makes the number not less than half a million. I believe the photographs of different portions of the sky taken with better telescopes will reveal as many as these.

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1. Astro. Phy. Journal Vol 46,24,1917

2. „ The relation between Wolf-Rayet Stars and planetary nebulae"—Wright, Ast. Phy. Journal Vol. 40,466,1914.

These nebulae may in general be divided into three principal classes viz (1) vaiiable (2) fixed and (3) dark. Their photographsare so very different from each other that it is next to impossibility to attempt to classify, them according to shapes, as in that case, we shall evidently get almost as many classes as their number. Examples may make the case clear. The nebula Canum Venaticorum M 51, as observed by the late Earl of Rosse is like a double branched spiral, the nebula Coma Borenices (H. V 24) is like Saturn with its rings, 977, Ursa Majoris is like a big planet as observed by Sir. J. Herschel, 37 HI IV Draconis is like a helix as observed by Holden with the great Lick telescope, 57 M Lyral is annular according to Sir J. Herschel, 1M Tauri resembles a crab as observed by Lord Rosse, the great nebula in the sword handle in the Orion is like the wing of a bird, the nebula 1717 Sobieski is like a horse shoe, 27 M Vulpecule appeared to be dumb-bell shaped to Sir. J. Herself and Smyth. There are many nebulae which resemble the planets of our system in shapes which are generally spherical and ellipsoidal for they received the name of planetary nebulae from Sir William Herschel. There are others which appear like clouds and are irregular in shape. Over and above these, there are many nebulous stars.

To add to the difficulty the very shapes of nebulae upon which the classification is made differ widely in telescopes of different powers. Thus, the spiral nebula 51 M presented to Sir John Herschel the appearance of a bright globular cluster surrounded by a ring at a considerable distance from the globe, while the aspect of this object was entirely changed in Lord Rosse's telescopes where it appeared as a spiral and several such instances can be cited. But the most remarkable instance is most probably the so-called Dumbbell nebula 27 M Vulpecule. In a small telescope it appears

1. "Preliminary evidence of the Internal motion in the spiral nebula M 101," Astr. Phy. Journal 44,210,1916.

2. Eddington. "Stellar, movements and structure of the universe" 1241

like two roundish nebulosities in contact with each other, Sir John Herschel saw it with one elliptical outline of faint light, enclosing the two chief masses; but Lord Rosse's 3ft and 6ft reflectors totally changed the appearance of the object. His 3ft reflector destroys the regular elliptic outline seen by Sir John Herschel and his 6ft instrument makes the general outline to resemble that of a chemical retort and reveals many stars! Thus what was a continuous mass in the telescopes of Sir John Herschel and Smyth gave the aspect of a cluster of stars in the big telescopes of Lord Rosses. From the history of the successive stages of observation of this nebula, a rash conclusion was drawn that no distinction existed between the stellar and nebular regions. Laplace's hypothetical coherent mass in the observed nebulae was disproved and his nebular hypothesis was at a stake for sometime till Sir William Huggins came to its rescue in 1804 when he announced the spectroscopic discovery of the cosmic gas "nebulium" to which we shall refer once again in this paper.

Sir William Herschel distinguished 8 differant classes viz (I) Bright Nebulae (II) Faint nebulae, (III) Very Faint nebulae, (IV) Planetary nebulae (V) very large *nebulae* (VI) very compressed rich cluster (VII) Pretty much compressed clusters (VIII) coarsely scattered clusters.

The above methods of classification have little practical utility. What seems to me more scientific and useful is to arrange nebulae according to their spectra. If nebulae be in a state of evolution into stars which have been divided according to their spectrum 8 leading types (O, B, A, F, G, K, M and N) between every two of which there is a continuous series of gradations, this method of classification is justified. The difficulties which confront us in attempting in such a classification are not a few. The study of the photographs of spectra of nebulae is very difficult owing to

1. For photographes of nebulae. See Chambers, Handboon of astronomy 1013, P 63-94 G. F. Pease. Astr. Journal 46,24,1917 E. E. Barnard, Do 49,1,1919

complexity of their nature and the photograghs themselves are oftentimes very faint owing to the feebleness of light. The great progress in spectroscopy is expected in the near future to remove the difficulties.

However, of the different spectra of ·nebulae, two varieties are well recognised. One consists of a few narrow bright lines with sometimes a faint continuous spectrum the other consists of a continuous spectrum crossed by dark lines and is indistinguishable from those of ordinary stars. The former variety shows that the light comes out of diffused incandescent vapour. Nebulae showing such spectrum are called gaseous. Irregular, anruar and planetary nebulae give such spectrum. What is more interesting is the visual spectrum which is marked by 3 bright lines in the green and blue of wave lengths 5007, 4959 4861×10^{-5}. The last is B—line of the hydrogen series. The other two are of unknown origin; as they are always associated together and have always the same relative intensity, they have both been attributed to the same unknown element named "Nebulium" by Sir William Huggins who in 1864 discovered this mother material from which the stars are supposed to be evolved. The bright lines in the spectrum indicate that this cosmic gas is a rarefied incandescent gaseous mass which alone can give such a spectrum Several other lines of helium, hydrogen and nitrogen series can be detected. The great majority of nebulae however show 2nd kind of spectrum and are supposed to be irresoluble star-cluster. The spiral or white nebulae generally give such spectra and are therefore supposed to be very distant star-clusters. Sir William Huggins took photographs of several spectra and arranged them in the probable order of stellar development. Spectroscope has been doing invaluable service in astrophysics. It not only gives us spectra to study the nature of objects but measures their radial velocity and has recently revealed to us the internal motion and rotation of nebulae as well. The out look of the suggested method of classification is, therefore, quite hopeful.

Variable nebulae like variable stars undergo several phases of brightness, and shape, whence they are so called. The first nebula was discovered by Hind on October 11, 1852. It is N. G. C. 1555 in the constellation of Towers. On October 3, 1861 D'Arrest of Copenhagen found that the nebula totally vanished. On January 26, 1862 Le Verrica could not find a trace of it from the Paris Observatory. Seechi of Rome fared in a similar way the following night; but the nebula was again seen at the Pulkooa Observatory on December 29, 1802 and by March 22, 1863 it so far increased in brightness as to bear a faint illuminosity, but on December 12, 1863, Hind and Talmage failed to establish any trace of its visibility. In 1860, in a paper to Royal Astronomical Association, Pogson announced that M 80 was also a variable. It was at first supposed to be a compressed Nebula cluster situated in the same field of view of the variable stars R. and S. Scorpii. On May 7, 1860. Pogson saw the nebula without anything *stear* in it. On May 28 of the same year when seeking these two variables neither of which was then visible he saw a star of the 7th magnitude in the place previously occupied by the nebule. On June 20, the star vanished but the cluster shone with unusual brilliancy and with a marked central condensation. Argus is also supposed to be a variable nebula, but there is a great difference of opinion regarding this. Schmidt of Athens discovered in 1861 a small nebula just beside Coronac Australis (N. G. C, 6729) which is now announced to be a variable nebulae. The discovery is confirmed by observations of Inner and Knox-shaw who in British Astr. Association, 1861 announced that it changed in shape and brightness from week to week. The nebula N. G. C. 2261 has been recently announced to be a variable one. The nucleus of the nebula has long been known to be a variable star. Lassell states that it is a nebulae nucleus as that of the great spiral in Andromeda and Barnard confirms this by visual observations. Innes observes another variable nebula near the north of N. G. C 6729 and Barnard attributes variability to the planetary nebula 7662 as well, One very remarkable fact to be recorded in this connexion is that all the variable nebulae are found in so particular portions of the sky marked by peculiarly dark shots which are supposed to be due to interposition of mass of dark nebulosity between us and stars whose light is thus cut off.

The researches of Barrard[1] go to prove this hypothesis in a convincing way. This dark nebulous mass is rendered visible by a luminous region behind it. A highly interesting account of such an example is given by Barrard who writes in Ast. Phy Journal 44,..............1916—"An excellant example of how such a thing may be possible is shown by a-phenomenon which presented itself to me in one beautiful transparent, moonless night, in the summer of 1913, while I was photographing the Southern Milky way with the Bruce Telescope, I was struck with the presence of tiny cumulous clouds scattered over the rich star clouds of Sagittarius......... Against the bright back ground they appeared as conspicuous and black as drops of ink. In his paper on "Slellar Evolution," W. D. Macmillan[2] expressed some views against the existence of such black objects, but in his paper "the dark mark ings of the sky with a catalogue of 182 such objects" (vide Ast. Phy. Journal Vol 49,1,1919) Barnard has, by force of his exhaustive observations, established the existance of such objects in a convincing manner. These masses are supposed to lost their brilliancy by the dissipation of energy and thus to be opaque and solid as much as our moon A very peculiar characteristic of these black nebulae is that they are usually connected with diffused nebulosity which often surrounds and is condensed about one or more bright stars. An excellent example of this facts is found in the constellation of

1. "The variable nebula N. G. C 2261." Ast. Phys. Journal—E. Hubble of the Yerkes Observatory. vol 44,190,1916

1. See monthly notices, vol 55,442,1895
Do and vol 40,1,1919
Also see Ast. Phys. Journal vol 41,253,1915 and vol 43,-1916,

2. Ast Phy. Journal vol 48,35,1918. and vol 49,1,1919

Corrona Austrina ...,Visual observers have asserted that the region has a leaden or slightly tinted appearance as though a cloud were covering part of the field." Barrard's photographs referred to above, furnish many other such examples. They are found principally in the milky way.

The hypothesis of variable nebulae is highly interesting. E, P. Hubble[2] in his paper on 'The variable nebua N. G, C 2261" takes into consideration many factors, the most probable of which is, according to him, that the nebula is eclipsed by dark matter. The position of the nebula is highly significant. It lies in and near the end of a dark lane. This portion of the milky way is rich in dark nebulosity. So that the changes of the nebula may reasonably be attributed to the dark matter. Examinations of other nebulae confirm this hypothesis. Hind's variable nebua[3] N. G.·C 1555 is also situated in a dark line, so is the case with the variable nebula N. G. C 9729.

The fixed nebulae are found in several stages of evolution. The most striking class is the spiral nebulae also known as white or whirlpool nebulae from the fact that they are brilliant and spiral-shaped. They are most probably the the most numerous of all nebulae. This spectrum is non-gaseous and ressemble those of early type stars. This peculiar characteristic is that they avoid the milky way and abound chiefly in land near the two galactic poles. They are mainly double-branched the two arms leaving the nucleus at opposite points and coiling round in the same sense. The researches of E. V. D, Pahlen show that the spiral is a logarithemic one. The arms however often present irregulaities and numerous knots and variations of brightness. From the data supplied by Van Maanen, Jeans[4] has

1. "Stellar movements and structure of the universe"—Eddington. Page 237

Ibid 5. Eddington—"Stellar movements and Structure of the universe" Page 240

2. Ibid.

3. F. G. Pease, "Astro Phy. Journal." 45,89,1917.
Barnard, Monthly notices vol 45 and 49. Ibid.
See "Ast. Phy. Journal 40,466,1914

4. Scientia. Vol 24, R 279-80,1911

calculated the distance mass and densety of M 101 to be 15000 parsce or 5000 light years (1 parsce=distance corresponding to parallax (=$19{\cdot}2 \times 10^{12}$) miles Light year=$5{\cdot}9 \times 10^{12}$ miles $10{\cdot}37$ grammes) i.e. 5000 suns and 4×10 gramme.

The nebulae that give gaseous spectrum are mostly planetary and irregular nebulae. They cluster in the milky way and an its boarders generally. The nebulae in magellanic clouds are supposed by A. R, Hinks to be unlike anything found elsewhere. Many of the principal nebulae are gaseous. The distance of the lesser magallenic cloud is found to be 10,000 parsces[2] * * * * See[1]

The researches[3] of Pickering, Keeler and Bright have proved beyond doubt that most planetary nebulae are stars in embryo. What is, then, the exact process of stellar and planetary evolution? In spite of the huge research work in astrophysics, our present knowledge is too scanty to unfold the mystery in any other way than by hypothesis, viz. the Nebular Hypothesis.

I have already referred to the fact that the mass of the giant spiral nebula M 101 has been estimated at 5000 suns. Other spiral nebulae are believed to be very much bigger than this. These gaint nebulae are therefore reasonably believed to be stellar system, separated from each other by vast empty space. C. Easton propounds the hypothesis that the system of stars together with the milky way whose spiral has been well established forms a big spiral nebula with the central nucleus in the rich galactic region of cygnus. Perrine[2] confirms that planetary nebulae belong to this system. Eddington[3] shares a similar opinion, his hypothesis

1. C. Easton, "A photographic chart of the milky way and the spiral theory of the galactic system." Astro Phy Journal. Vol 37,105, 1913.

2. C. D. Perrine, "Planetary nebulae belong to own system" Astro. Phy. Journal, Vol 46,M5,1917.

3. ibid. P 243.-44.

disagreeing with that of Easton only in one respect that the former places the sun in the central nucleus of the spiral. The magellanic clouds is supposed to be analogus to the small nebula connected with Lord Rosse's spiral nebula M5[1] can explain most, if not all, of the nebular observations. Laplace's hypothesis that the primeval nebula was a rotating coherent mass has been confined by the spectroscopic discovery[1] of nebulium and nebular rotations. Without a knowledge of the temperature and density of nebulae an exact mathematical treatment of the hypothesis is impossible. But in 1855, an extreme limiting case of matter was taken into consideration by Roche who considered the rotating coherent mass of Laplace so compressible that practically the whole mass may be supposed concentrated close to the centre of gravity, the outlying parts forming merely an atmosphere of density negligible in comparision with that of the central region. This mathematically simple problem is very easy to solve. As far the figures assumed by the gaseous boundary as it shrinks and therefore the rotation increases, it is found that with slow rotation[2] the boundary will be a spheroid but as the rotation increases with the shrinkage, the boundary assumes shape of an elongated spheroid. When a critical velocity is reached, the figure developes a perfectly sharp edge round its equator and takes the form of a symmetrical double convex lens. Now, a very curious phenomenon takes place ; any further increase of velocity produced by further shrinkage does not result in a further change of shape, but results in matter being thrown out from the perephery of the lens while the lens retains its shape but of course with diminishing size.

Laplace followed by Roche expected the ejected matter to form a ring. It must have been the case if the rotating mass were alone in the universe. But the real astronomical mass rotates in a universe tenanted by other masses of gas similar to itself. The lenticular figure already in a critcal state of

1. Ibid. 2. The preliminary rotation of nebulae believed to be slow *e.g.* The period of rotation of M. 101=85,000 years. Scientia ibid.

equilibrium and ready to give up matter from its perephery may be acted upon by tidal forces from other fellow masses. Therefore acting at two opposite points of the perephery reinforce centrifugal force against the attraction of the mass with this effect that the break up of mass will begin at these two points earlier than at any others. Hence the matter will be ejected not in rings but in filaments from two antipodal points in the perephery. The path of such filaments in space has been proved by Jeans to be equiangular spiral under high velocity. The filaments when sufficiently substantial have been theoretically found to be unstable through nuclei forming at regular intervals. The remaining matter condensing upon these nuclei form a chain of detached masses which contracting, form stars. These individual stars may again shrink to densities far greater than they originally had. The mathematical investigation of Jeans indicates that Roche's model will give extra ordinarily accurate representation of the behaviour of actual gas, so long as the density of the gas is less than about a quarter of that of water, but about a critical density of nearly a quarter of that of water, a sharp and sudden change occurs and for higher densities the motion of a rotating gas approximates closely to that of an incompressible mass. The problem of a rotating homogenous incompressible mass has been studied by many emiment mathematicians such as Maclaurin, Taobi, Lord Kelvin, Poincare and Sir. G. Darwin. The rotating mass takes the form of a oblate spheroid of small eccentricity when the density is low and rotation is slow. As shrinking goes on and rotation increases thereby, eccentricity increases until the ratio of axes of the spherod is 7 : 12 : 12. Further shrinkage leads to an ellipsoidal figure which as shrinking goes on becomes pear shaped ellipsoid with the axes in the ratio 6½ : 8 : 19. This figure is unstable and finally divides into two unequal detached portions. Shrinkage and rotation go on in both the masses. The history repeats itself and the greater of the masses breaks first. The binary and triple systems are thus formed.

All the above theoretical investigations have been confirmed by practical obsarvations. Thus the nebular hypothesis can, as I have already observed, explain many, if not all the nebular formation. Our present knowledge is undonbtedly inadequate ; but the outlook is quite hopeful.

TESTING A PHOTOGRAPHIC LENS.

BY. DR. T. ROYDS. D. Sc.

Most people possess a Camera with a lens but probably few have tested their lens, except perhaps by ordinary photographs, relying mostly on the salesmen's assurance that it would give "beautiful definition sharp as a needle." For those members who would care to investigate their lenses, this paper gives some simple experiments which are not difficult to carry out and do not require special apparatus.

As many members are aware astronomical lenses are tested by examining the images of star more especially by examining the pattern into which the light is distributed when the star is out of focus. This method can be applied to a photographic lens but it is more convenient to have an an artificial star. A pinhole in a thin metal plate with a light, even a candle, behind it will serve as an artificial star. Beyond this and a darkened room one only requires an eyepeice of medium power with which to examine images of the pinhole formed by the lens. A photographic lens is ordinarily required to produce pictures of distant objects; hence one should set up the camera as far away as the size of the room and the brightness of the light from the pinhole will allow.

The defects shown by a lens may be any or all of the following, which are here only briefly and non-technically defined, but more informations about them can be found on any book on Optics.