The Gaseous Nebulæ.¹

By J. H. REYNOLDS.

IT has been recognised for many years that the nebulæ fall into two great divisions—the spirals and the gaseous and diffuse. The distinction between the two is fundamental, for there can be no doubt now that the spirals are extra-galactic, and the gaseous inter-galactic formations, although it is impossible yet to define the scale and distances of the spirals with any certainty. Since Huggins's great discovery of the gaseous nature of certain nebulæ, the principal work on these objects has been done in America, especially at the Lick Observatory and at Mt. Wilson; and coupling up these investigations with recent advances in physics in which Great Britain has played no mean part, we are able to form a good general idea of the meaning and origin of the gaseous nebulæ.

The first important fact which emerges from the physical work of Fowler, Saha and others, is that only the elements of simplest constitution, such as hydrogen and helium, are known to be present, and that ionisation of known elements is probably responsible for all the unknown lines in the nebular spectrum. Then, again, the gaseous nebulæ are only associated with stars of the highest temperature, as the stars in the centre of the planetaries are usually "O" type stars of the Harvard scale, which yield an emission or absorption spectrum of ionised helium on a continuous background, and the "B" type stars, which are next in order of temperature, and are associated with the irregular gaseous nebulæ in Orion. Until recently it was supposed that the so-called "nebulium" identified with the nebular radiations at $\lambda\lambda 5007$ and 4959 , and other well-known lines such as $\lambda\lambda 4363$, 4686 and 3727 , represented unknown gases in the same sense that helium was unknown until identified in the laboratory by Sir William Ramsay, but the work of Moseley and Aston and the formation of the scale of atomic numbers has taught us that there is no room for any more unknown elements in the atomic scale of the lighter gases, and we must look in the direction of ionisation of the known elements in the first ten numbers of the scale for these unknown nebular lines.

These considerations and the progressive spectra of Novæ lead to the conclusion that in all gaseous nebulæ we are dealing with the same material, and that the differences found in the spectra are to be assigned to differences only in physical conditions, and the key to these conditions is to be found in the effective radiation of the star or stars involved in the nebula. Only the first two numbers of the atomic scale are definitely established as appearing in nebular spectra, the helium appearing often near the nuclear star in its ionised form. But Wright in Lick Observatory Pub., vol. xiii., provisionally identified certain nebular lines with carbon and nitrogen, and the presence of the former at any rate is now accepted.

The principal nebular lines of unknown origin are the following:

$$\begin{array}{l} \lambda 5007 \\ \lambda 4959 \end{array} \} \lambda\lambda 4363, 4340, 3868, 3727-9.$$

The first two are invariably found in all the gaseous nebulæ in the same relative strength, and they evidently form a doublet. $\lambda 5007$ was the first gaseous radiation to be discovered in a nebula, and with its companion it exists in a very marked form in nearly all the objects of this class yet observed. The other

radiations vary much in relative strength, and sometimes seem to be absent altogether. Perhaps the most remarkable is that usually described as $\lambda 3727$, which has been found by Wright to be in reality a doublet separated by only two Ångström units. It is astonishingly brilliant in the Orion Nebula, and with the hydrogen radiations it is responsible for the great photographic effect of this object. It is always of maximum extension, and is found in regions far removed from the involved stars, where the hydrogen radiations are comparatively faint. An investigation by means of screened direct photographs was undertaken by the writer some years ago as to the relative distribution of the doublet $\lambda(5007, 4959)$, the hydrogen series, and $\lambda 3727$ in the Orion Nebula. The principal results were:

(1) To establish Keeler's conclusion that the doublet $\lambda(5007, 4959)$ was conspicuous only in the central region surrounding θ Orionis, where it was very brilliant.

(2) To demonstrate that the hydrogen radiations extended faintly to the most remote regions of the nebula, and

(3) To show that the radiation $\lambda 3727$ was much stronger than the hydrogen in these outer regions, besides giving certain differences in detail.

We have then in the Orion Nebula a bright central portion where the radiations $\lambda(5007, 4959)$, the hydrogen and helium radiations and $\lambda 3727$ are integrated together, an intermediate region where hydrogen and $\lambda 3727$ appear of about the same strength, and an outer region where $\lambda 3727$ predominates. There is no difficulty in ascribing $\lambda(5007, 4959)$ probably to an ionised form of one of the elements heavier than helium, as we should expect the heavier elements to predominate in the central regions surrounding the star θ and the other involved stars. There is, however, very great difficulty in explaining the distribution of $\lambda 3727$. It must be remembered that the "B" type stars involved in the nebula are not of the highest stellar temperature, and it is almost impossible to imagine the existence of ionisation at all in these remote regions. There is, indeed, good reason for thinking that $\lambda 3727$ is a comparatively low temperature radiation, as it is either faint or absent altogether in the planetaries containing "O" type stars, and it does not occur so far as can be ascertained in the nebular stages of Novæ.

An interesting point bearing on the distribution of this radiation is brought out by an examination of the nebulosity surrounding the star Bond 734 to the north of the principal nebula. In the screened exposure of the radiations $\lambda(5007, 4959)$ no nebulosity appears round this star, and the absence of these radiations is confirmed in Lick Observatory Pub., vol. xiii. The hydrogen image is quite strong, and is accompanied by an equally strong image in $\lambda 3727$. It is quite evident, therefore, that there is no direct relation between the radiations $\lambda(5007, 4959)$ and $\lambda 3727$, and it is known that the hydrogen radiations occur without either. But the question arises as to whether $\lambda 3727$ can exist independently of hydrogen. The differences of detail visible in the photographic images given by hydrogen and $\lambda 3727$ certainly suggest an independent origin, but a complete answer to the question is impossible, as hydrogen is found in varying strength in all the gaseous nebulæ and novæ. If it were not an impossibility, one would naturally look for the radiation as some element actually lighter

¹ Substance of an address delivered before the Birmingham University Physical Society on March 14, 1923.

than hydrogen. The origin of this radiation $\lambda 3727$, therefore, seems to be one of the most interesting and difficult problems which the astrophysicist has to deal with at the present time.

We will now pass on from the Orion Nebula, which may be taken as a good example of the irregular gaseous nebulae connected with "B" type stars, to the planetaries. Here we have to deal with involved central stars which are of the "O" type, of a considerably higher temperature. In the spectra of these nebulae the doublet $\lambda(5007, 4959)$ is still usually the strongest radiation, and hydrogen is invariably present. On the other hand, $\lambda 3727$ is often comparatively faint or absent altogether, although $\lambda 3869$ is still one of the strongest radiations in the spectrum. Ionised helium at $\lambda 4686$ is also very conspicuous, but does not extend far from the nucleus, showing that ionisation only takes place in the neighbourhood of the star itself. Another bright radiation at $\lambda 3426$, found in the spectrum of Nova Cygni III, also makes its appearance, but its extension from the nucleus is small.

A very remarkable feature in the high dispersion spectra obtained with the three-prism spectrograph of the Lick 36-in. refractor was the character of the lines under magnification. When the slit of the spectrograph was placed across the major diameter of the planetary nebula disc, the resulting lines in the doublet $\lambda(5007, 4959)$ were not parallel-sided, but spread out in the centre, each end being slightly curved in opposite directions. If we are to interpret this phenomenon on the Doppler principle in the usual way, this means that the gases are both receding from us and advancing towards us in the line of sight, coupled with a slight rotation of the gaseous

spheroid as a whole. The only feasible explanation is that the gaseous shells forming the nebula are still expanding, and we are at once led to a comparison with novæ such as Nova Aquilæ III, which now has developed an expanding gaseous disc.

The later spectroscopic stages of novæ are comparable in every detail with the planetary nebulae; the galactic distribution of both is similar, and the evidence is now overwhelming that the planetaries had their origin in novæ, and the gaseous shells of the planetaries are the remains of past outbursts. It may be asked why the planetary nebulae are comparatively few in number, but it is evident that if the central star fell to a lower temperature than the "B" type, the radiation would be insufficient either to keep the gases in a state of equilibrium or to illuminate them, and the aspect of a planetary nebula would disappear. The same remarks apply to objects like the Orion Nebula connected with "B" type stars. Here the radiation energy is not so intense as the "O" stars, and we do not get an equal degree of ionisation: the strength of the radiation $\lambda 3727$ is also evidence of different physical conditions, but the Orion and other irregular gaseous nebulae have every appearance of being swept away from the involved stars, and they all probably indicate a former outburst of several stars culminating in an "O" type of spectrum and a high radiation pressure.

The old idea that the gaseous nebulae were the primitive forms of matter from which stars were evolved must, it seems, be given up for the exactly contrary hypothesis that they had their origin in stellar outbursts, where matter passed from complex to simpler forms by atomic disintegration under the stress of extreme temperature development.

Plants in Relation to the Health of Man.¹

CINCHONA, the plant which yields quinine, known under the name of "Jesuits' Powder" since 1655, was introduced into India about the years 1858 to 1862. Seedlings and seeds were brought to Great Britain from the Andes of Bolivia during those years, principally by Sir Clements Markham and Mr. Richard Spruce, and the plants, which were raised at the Royal Botanic Gardens, Kew, were taken to India and Ceylon. The cultivation in India was mainly established in the Nilgiri Hills and in Sikkim. The three species of Cinchona which are particularly valuable as sources of quinine are *C. Calisaya*, *C. Ledgeriana*, and *C. succirubra*.

The Dutch had also been experimenting with Cinchona and established the plant in Java about the same time as the English were introducing it to India. So successful have the plantations been in India, thanks to the labours of Dr. Thomas Anderson, Sir George King, Messrs. Wood and Gammie and Sir David Prain, that in every post office in India it is now possible to procure doses of from seven to ten grains of pure quinine for a *pice*, which is about equal to a farthing. In this way, more than eight thousand pounds avoirdupois of quinine are distributed yearly, and in addition to this a large supply is furnished to hospitals, etc. Efforts are now being made to extend the cultivation of quinine in Malaya and Burma. Substitutes for Cinchona as a source of quinine were used in the Cameroons by the Germans during the War.

Other interesting plants are *Efwatakala* grass, *Melinis minutiflora*, which is reported to be obnoxious to the tsetse fly; citronella grass, the source of lemon grass oil, which is repellent to mosquitoes; and *Ocimum viride*, the Basil plant, which at one time

was thought to be repellent to mosquitoes, but now is known to be of no value for the purpose.

In connexion with the preservation of the health of man in temperate climates, the plants yielding india-rubber are of first importance. The principal source of india-rubber is *Hevea brasiliensis* (Para rubber). This again is a native of South America. Seeds and young plants have been distributed to the various tropical colonies of the British Empire since the year 1873, when it was brought over from South America, mainly owing to the successful efforts of Sir Henry Wickham. Other sources of rubber are the Ceara rubber, *Ficus elastica*, Funtumia, and the tropical African Landolphia. The rubber now used commercially is mainly derived from plantations in the East, to which region it was introduced through the Royal Botanic Gardens, Kew.

Another source of protection against damp and cold is furnished by the various plants which yield tannin, the preservative of leather. The principal sources of this are oak galls and bark, mangrove bark, Myrobalans, Quebracho, and *Acacia decurrens*. Extensive plantations of the latter plant, which is a native of Australia, have been made in South Africa and are a source of considerable wealth to Natal.

Cinnamomum Camphora, which is a native of Formosa, is the source of camphor, valuable as a drug and also a preservative of clothing against moth. Trade in camphor is a monopoly of the Japanese, but seeds have been freely introduced to British colonies, largely through the agency of Kew. It is now found there are two forms of camphor, but only one of these yields the solid camphor which is of value.

Erythroxylon Coca is the source of cocaine, the alkaloid which has so many useful as well as harmful effects.

¹ From a Chadwick public lecture delivered by Dr. A. W. Hill, F.R.S., at the Chelsea Physic Garden, on June 13.