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565TH ORDINARY GENERAL MEETING,

HELD IN THE CONFERENCE HALL, THE CENTRAL HALL WESTMINSTER, ON MONDAY, MARCH 1ST, 1915, AT 4.30 P.M.

THE REV. PREBENDARY H. E. FOX OCCUPIED THE CHAIR AT THE OPENING OF THE MEETING, AND WAS FOLLOWED BY

SIR FRANK W. DYSON, F.R.S., ASTRONOMER ROYAL, AT 4.45 P.M.

The Minutes of the preceding Meeting were read and confirmed.

The SECRETARY announced the election of the Rev. Martin Anstey, M.A., B.D., and of the Rev. George Campbell Morgan, D.D., as Members of the Institute.

The CHAIRMAN, the Rev. Prebendary Fox, invited Professor Alfred Fowler, F.R.S., Secretary of the Royal Astronomical Society, and Professor of Physics in the Royal College of Science, to address them on the subject of "The Spectra of Stars and Nebulæ."

The lecture was illustrated throughout by lantern slides.

THE SPECTRA OF STARS AND NEBULÆ.

By PROFESSOR A. FOWLER, F.R.S.

IN this lecture it will be my endeavour to give some indication of the way in which the wonderful power of the spectroscope has been utilized in investigations of the chemistry of stars and nebulæ, and of the bearing of such knowledge on the question of celestial evolution.

The only intelligible message that a star sends to the earth is borne on its rays of light, and if we are to learn anything at all of the composition and physical state of the star, it must be by the analysis of that light. The spectroscope is an instrument which enables us to make such an analysis, by taking advantage of the dispersive power of a prism or diffraction grating, whereby a complex beam of light is separated into its component parts.

Before we can understand the language of the spectroscope it is necessary to study very carefully the sources of light which can be artificially produced. If we examine the light from an incandescent solid body, such as a gas mantle or the filament of a glow lamp, we find that the spectroscope spreads it out into a band showing the glorious colours of the rainbow in their greatest purity. The colours from red to violet merge into each other by insensible gradations, and we say that the spectrum is a *continuous* one, because there are no interruptions of any kind. All incandescent solid bodies give precisely the same result, and it follows that we cannot distinguish between one luminous substance and another so long as they remain in the solid state. The same is true of incandescent liquids.

The effects are very different when the substances examined are in the state of luminous gas or vapour. They then emit special kinds of light by which they can be identified, and it does not matter in the least whether they are in our laboratories or far away in the depths of space, so long as their light reaches our instruments with sufficient intensity. The spectra are no longer continuous, but consist of a number of bright lines of different colours, which are really a succession of images of the narrow slit through which the light is admitted to the spectroscope. Thus, hydrogen is characterized by a line in the red, another in the blue-green, and others in the blue and violet, and since these lines are exhibited by nothing but hydrogen, they serve to indicate the presence of hydrogen wherever it occurs in the luminous state. Similarly, helium signifies its presence by a number of lines, of which one in the yellow is especially conspicuous. Each of the other elements also has its own distinctive family of spectrum lines, some consisting of a few members only, but others, such as iron, occurring in hundreds.

Many compounds which can be excited to luminosity without decomposition also exhibit characteristic spectra, which are quite different from those of the elements of which they are composed.

The luminosity necessary for spectroscopical analysis may be artificially produced in various ways. Gases are usually enclosed in vacuum tubes containing the gases at reduced pressures, and are illuminated by electrical discharges. Substances which are solid at ordinary temperatures may be vaporized and rendered luminous by the oxy-hydrogen flame, the electric arc, the electric spark, and in a variety of other ways which need not now be specified.

It is most important to study the spectra in as many different ways as possible, because, in opposition to early ideas, it has been found that the same substance may give different spectra when excited in different ways. Thus, at flame temperature, or under the action of gentle electric discharges, many substances give spectra consisting of broad bands, or flutings, such bands consisting of a multitude of very fine lines closely packed together. At the higher temperature of the electric arc these bands are replaced by lines which occupy quite different positions in the spectrum.

Further modifications, involving the weakening of some lines appearing in the flame or arc, the brightening of others, or even the appearance of new lines, are often found when the substance is submitted to the violent action of the condensed electric discharge.

Lines which are intensified, or only appear under spark conditions, have been called "enhanced lines," and it is by the study of such lines, initiated by Sir Norman Lockyer, that much of the recent progress in the interpretation of solar and stellar spectra has been due.

We see, then, that the same substance may give widely different spectra under different experimental conditions, but the spectrum is nevertheless always the same under the same conditions, and no two substances ever give the same spectrum. This multiplicity of spectra might at first sight appear to be an undesirable complication in spectrum analysis, but in reality it enormously increases the interest of observations of the celestial bodies, because it enables us to learn something of the physical conditions which prevail as well as of their chemical constitution.

We do not yet know the precise cause of the variations in the spectrum of a substance, but it is generally believed that, while band spectra are produced by the vibrations of molecules, or of electrons which form part of molecular systems, line spectra are only produced when the applied energy is sufficient to break up the molecules into atoms. As to the change in the line spectrum which is often observed on passing from the arc to the spark spectrum, modern theories of atomic structure suggest that further dissociation takes the form of the removal of one or more electrons from each of the atoms involved. Whatever the ultimate cause may be, we do know that the change from bands to lines, and from ordinary flame to arc lines, and again from arc to enhanced (spark) lines, accompanies the application of greater energy to the molecules and atoms, whether it be in the form of heat or electricity.

So far, reference has been made to emission spectra only. Kirchhoff's famous experiment of 1859 proved that a luminous vapour has the property of absorbing precisely the same kind of light that it emits, so that if such a vapour lies in front of a source at higher temperature giving a continuous spectrum, the result is a continuous spectrum crossed by *dark* lines. This is called an absorption spectrum, and Kirchhoff's observation is of fundamental importance in astronomy, because the spectrum of the sun and the spectra of nearly all the stars show dark lines on a bright, continuous background. The experiment shows that we can identify the substances which produce such dark lines, just as surely as if they were bright, by the process of matching them by emission spectra artificially produced.

Such, then, are the main principles of spectrum analysis. We may next consider their application to celestial bodies, beginning with the sun, which may properly be regarded as the nearest star.

The dark lines which are characteristic of the spectrum of sunlight were first accurately mapped by the German physicist Fraunhofer in 1814, and have since been known as the Fraunhofer lines. In more recent times the magnificent photographs obtained by Rowland exhibit not less than 20,000 of these lines, which have been carefully entered in a great catalogue, showing their relative intensities and their positions on the scale of wave-lengths of the vibrations which produce them. The chemical significance of a great number of these lines has been determined by the application of Kirchhoff's principle of the reversal of lines, by Kirchhoff himself, and subsequently by Lockyer, Rowland, and others. The great majority of the more prominent lines have, in fact, already been matched by spectra produced in the laboratory, largely from common substances such as hydrogen, sodium, magnesium, iron, and calcium.

In accordance with Kirchhoff's experiment, we interpret the dark lines of the solar spectrum as indicating that the bright central ball of the sun—which of itself would give a continuous spectrum—is surrounded by luminous gases and vapours which produce the dark lines by their absorption. At ordinary times this atmosphere is not visible, because it is not so bright as the diffused light of the sky, but its existence is fully confirmed by observations during total eclipses of the sun, when the glare of the surrounding sky is shut off by the moon's shadow. Under these conditions the direct emission spectrum of the sun's atmosphere may be observed or photographed. In place of the usual dark Fraunhofer lines the expected multitude of *bright* lines is then observed in the spectrum at the sun's edge during the few seconds that this comparatively shallow "reversing layer" or "flash stratum" remains uncovered by the moon. It is now generally agreed that this "flash" spectrum observed during total eclipses corresponds essentially with the dark line spectrum ordinarily observed. There are, it is true, certain divergences between the intensities of the dark and bright lines arising from the apparently undue brightness of enhanced lines in the flash spectrum, but it would take too long to discuss them and to indicate how the differences may be explained.

The reversing layer, as ordinarily understood, is about 500 miles in depth and is situated close to the sun's surface, at the base of the chromosphere, which extends to a height of about 5000 miles. The upper part of the chromosphere may be observed any time that the sun shines. The bright lines thus observed indicate that the chief gases in this region are hydrogen and helium, but during solar eruptions the lines of various elements, projected into it from the reversing layer below, are also observed. The bright helium lines of the chromosphere do not ordinarily occur among the Fraunhofer lines, but they are occasionally observed as absorption lines in the neighbourhood of sun-spots, where, it may be supposed, there are special accumulations of this gas.

It should be mentioned that the solar corona, which is the most striking feature of a total eclipse of the sun, has apparently nothing to do with the production of Fraunhofer lines. The greater part of the corona gives a feeble continuous spectrum, and it is only the inner corona which gives distinctive bright lines. The chief line is usually one in the middle green, and has been attributed to a hypothetical element, "coronium," which is not yet known in terrestrial chemistry. Strangely enough, this line was not observed in the corona of last August, but was replaced by a bright line in the red, which is also at present of unknown origin. There are no Fraunhofer lines corresponding to these unknown emissions of the corona.

From the point of view of the chemical composition of the sun, very little advance has been made on the work of Kirchhoff, Lockyer, and Rowland. Very substantial progress has been made, however, in the identification of additional Fraunhofer lines with lines of elements previously known to exist in the sun. The unidentified lines are mostly of low intensities, and it is too early to conclude that they may represent forms of matter which are special to the sun. They may, in part, correspond to still uncharted faint lines of the various metals; or, with equal probability, they may represent the constituent lines of a complex band spectrum, the origin of which has not yet been traced. It has sometimes been supposed that these unidentified lines may represent the products of the dissociation of the ordinary chemical elements under the influence of solar temperatures, but the circumstances that nearly all the stronger lines, and many of the faint ones, have been reproduced under laboratory conditions renders this very improbable.

In the present state of our knowledge of spectroscopy, we are certainly not entitled to conclude that any unknown forms of matter are represented by the unidentified Fraunhofer lines. The only strong indication of elements not known on the earth is given by the corona, and the discovery of terrestrial helium encourages the hope that even these may yet be run to earth.

Another side of this question calls for a few remarks. Many of the known elements have not yet been recognized in the sun, and some explanation of their seeming absence is called for if we are to suppose the sun and earth to be composed of the same materials. Some of the non-metallic elements are especially notable among the missing elements, but it is a common experience of the laboratory that such elements often fail to show their spectra when they are admixed with metallic vapours. Also, the Count de Gramont has shown that in the case of several of the missing elements, non-metallic and metallic, the most sensitive lines are situated in the ultra-violet, in a part of the solar spectrum which is cut off by the absorption of our own atmosphere. Another indication that we must not too hastily conclude that elements not represented by Fraunhofer lines are absent from the sun is afforded by the detection of lithium in the spectra of sun-spots, where the physical conditions are apparently more favourable for the exhibition of this element. Further, it is quite reasonable to suppose that some of the heavier metals which fail to give spectroscopic indications of their presence may exist in the interior of the sun, where our spectroscopes are unable to penetrate.

The outcome of the spectroscopic analysis of the sun, therefore, is to indicate that although there is no complete proof of absolute identity, we should not be justified in supposing that there is any material difference in the composition of the sun and that of the earth. As Rowland expressed it, if the earth were heated to the temperature of the sun it would probably show the same spectrum.

The sun has been dealt with at some length, because it may be regarded as a typical specimen of the thousands of stars which present us with spectra which cannot be distinguished from that of the sun itself, when sunlight is taken as a whole, and because it has the advantage of being nearer to us, so that it can be analysed more completely than the stars.

When we reflect that the stars which can be observed or photographed with the large telescopes now in use are to be counted by hundreds of millions, it will be evident that the field of investigation is practically unlimited. It is neither possible nor necessary, however, to observe the spectra of all the stars. The two or three hundred thousand which have actually been observed to the present time may surely be taken as representative examples.

Our present knowledge of stellar spectra has been made possible through the application of photographic methods. By the use of prismatic cameras with prisms of small angle, it is now possible to record the spectra of hundreds of stars with a single exposure of the photographic plate, and we are indebted to the Harvard College Observatory for a descriptive catalogue of the spectra of many thousands of stars obtained in this manner.

Such photographs only reveal the more general features of the spectra, but detailed studies of individual stars have been made with more powerful instruments by Huggins, Lockyer, and many other astronomers in various parts of the world. From the specimens exhibited it will be realized that a marvellous amount of detailed information is obtainable by this spectroscopic analysis of even the feeble light of a star, if we are skilled enough to interpret its message.

All stars are alike in the sense that they are highly-heated self-luminous bodies, but the spectroscope shows that they are not all alike in the character of the light which they emit. As already remarked, many of them are indistinguishable from the sun.

What we have already learned about the sun is therefore applicable to all stars of this class, and the presence of helium and "coronium" in such stars, for example, may reasonably be inferred, though there are no direct indications of their presence.

It was early found that, although there are many stars which are unlike the sun, the number of distinct varieties is by no means great. The first systematic investigation of a large number of stellar spectra was made in 1864 by the Italian astronomer Father Secchi, who found that the great majority of the stars could be classed in one or other of four types, numbered from I to IV, which were associated with well-marked differences of colour. This classification still serves to mark the broad features of the different classes of spectra.

It was not long before this classification of stellar spectra came to be regarded as representing something more than a mere convenience of description. If we look at a few stars at random we might see no obvious relation between their spectra, but when there is a sufficient number to choose from, it is found that the spectra can be arranged in a continuous series in which the successive types merge into each other. That is to say, the different types of stellar spectra are not abruptly divided, but are connected by spectra representing well-marked transition stages.

Here we get a definite indication of an evolution of the stars somewhat analogous to that which Darwin enunciated for organic life. The differences in the spectra of the stars are not believed to be due primarily to differences in chemical composition, but to their having reached different stages in an orderly development from masses of similar materials. The continuity of the spectral series practically compels us to believe, for example, that our sun was once a star like Sirius, and that Sirius will in due course become a star like the sun, the sun meanwhile having become a red star with a spectrum of bands. The order in which Secchi numbered his types is accordingly regarded as representing the general sequence of spectra as a star passes through different stages in its evolution, and we now speak quite freely of young, or early-type, stars, and of old, or late-type, stars.

This idea of a celestial evolution is the foundation of all subsequent attempts to classify the stars on a rational basis. While there is nearly unanimous agreement as to the sequence of the various spectral classes, different systems of naming them have been suggested. Secchi's numeration is by no means obsolete, but on the ground of greater adaptability for the distinction of intermediate types, the Harvard classification is now most widely adopted, though it is recognized that it may not be final. Here the designations are alphabetical, but it is rather unfortunate that the sequence of the letters is not in entire accordance with the order of types.

The relation of the Harvard to the Secchi classification is shown in the appended table, which also gives the chief characteristics of the spectra and indicates the names of typical examples. Intermediate stars on the Harvard system are indicated by such symbols as F 5 G, indicating that such a star is five-tenths advanced from type F to type G. It will be noted that a few classes of stars not adequately provided for in Secchi's system are recognized in the Harvard scheme. Attention should especially be drawn to the group at the head of the series, which includes the "Wolf-Rayet" stars, showing spectra chiefly distinguished by bright lines.

This sequence of various types has been arrived at entirely

CLASSIFICATION OF STELLAR SPECTRA.

Harvard.	Secchi.	Other titles.	Special features.	Examples.
O		Wolf-Rayet	*Bright* lines of H, He, and unknown.	γ Argûs.
B		Orion	Dark lines of H and He predominant; lines of Si, C, O, N; enhanced lines of Mg and Ca.	β, γ, δ, ε Orionis and Virginis.
A	I	Sirian	Lines of H predominant; enhanced and arc lines of metals.	Sirius, Castor, Vega.
F	I–II	Procyonian	Lines of H less prominent than in A; metallic lines stronger.	Procyon, Canopus.
G	II	Solar	Arc lines of metals, with some enhanced lines.	Sun, Capella.
K	II	Arcturian	Enhanced lines weaker, and flame lines stronger than in G.	Arcturus, Pollux.
M	III	Antarian	Flutings of titanium oxide; flame lines of metals.	Antares, Mira, Betelgeuse, and Herculis.
N	IV	Piscian	Flutings of carbon; flame lines of metals.	19 Piscium, 152 Schjellerup.

from considerations of the spectral phenomena. It is strongly supported, however, by spectro-photometric observations which lead to approximate estimates of the surface temperatures of the stars. Thus, the Potsdam astronomers have estimated that the temperature of the N or 4th type stars is about 3300 degrees C., of the M or 3rd type 4200 degrees C., and so on to 10,300 degrees C. for the A or 1st type stars and 11,600 degrees C. for the B stars. These figures may be considerably in error as absolute measurements, as the observations are extremely difficult, but the important thing is that the sequence of temperatures is in satisfactory agreement with that derived from the spectral lines.

There is not time to go into much detail, but it will be interesting to see what progress has been made in the interpretation of the spectral phenomena. The inclusion of solar, or second type, stars in the evolutionary scheme necessarily implies that all the stars are similar to the sun in chemical constitution, but we shall see that independent evidence of the universal distribution of terrestrial kinds of matter is to be found in abundance in the analysis of individual stars.

It will be most instructive to begin at the lower end of the series, where there is every reason to believe that the temperatures of the stars involved are relatively low, so that the reproduction in our laboratories of the lines and bands by which they are characterized should present the minimum of difficulty, provided we have the same substances to deal with.

In the type IV, or N, stars, which are all faint, Secchi himself recognized that the principal dark bands were identical with those seen in the blue base of a candle flame, and attributed to carbon. This has been beautifully confirmed by Professor Hale's photographic studies of these stars, which also proved the presence of other dark bands, due to cyanogen, in the violet region beyond the range of visual observations. Many of the numerous lines which accompany the bands are traceable to various metals, such lines being capable of production at relatively low temperatures in our laboratories. Professor Hale's photographs also show a gradual progression from stars in which the carbon bands are very strong to stars in which these bands are very weak, as would be expected on the hypothesis of evolution.

The bands which are characteristic of stars of the third, or M, type, were not traced to their source until 1904, when they were identified by the lecturer with bands of titanium oxide. There is no obvious reason why this substance should be selected for such striking manifestation in stars at this stage of their evolution, and we have just to accept it as a fact of observation and experiment; it is a significant fact, however, that the strongest of these bands occur also in the spectra of sun-spots, which we have other reasons for believing to be at a lower temperature than the solar surface in general. The *lines* which occur in the M stars are generally similar to those of the N stars.

The second, or solar, type (G, K) stars present us with the same problems as the sun, from which many of them are not distinguishable. If we look, for example, at a photograph comparing the spectrum of Capella with that of the sun, even an expert would find it very difficult to say which was which if they had not been labelled. The Harvard classification recognizes two slightly different varieties, G and K. Arc lines of the various elements are the chief features in both, but there is evidence of a greater general absorption in the violet region in the K than in the G stars. Also, the enhanced or spark lines of various known elements, to which reference has already been made as requiring greater energy than arc lines for their production, are somewhat stronger in the G than in the K stars.

The F stars of the Harvard classification are intermediate between the second and first types of Secchi. Hydrogen lines are now much stronger than in the solar spectrum, while metallic lines, as a whole, are somewhat enfeebled. A fact of special significance, however, is that the enhanced lines of various metals have gained in intensity relatively to the arc lines.

As a typical specimen of type I, or A, stars we may look at the spectrum of Sirius. The lines of hydrogen now dominate the spectrum, but among the fainter lines we recognize that the enhanced metallic lines occupy the most prominent place. A most beautiful illustration of the gradual replacement of arc lines by enhanced lines has been given by Professor Hale in a series of photographs of several stars showing the behaviour of two titanium lines which are almost side by side; the arc line occurs alone and with great intensity in the fourth type spectrum and gradually thins out in passing through the series, while the enhanced line appears about the middle of the series and remains alone when the Sirian stars are reached.

In the B stars there are a few enhanced lines of magnesium and calcium, but for the most part we find lines of non-metallic elements. Helium, which does not show its absorption lines in any of the previous types, now appears prominently in association with hydrogen. Among the remaining lines, the majority have been traced to oxygen, nitrogen, carbon, silicon, and sulphur. The change from metallic lines of previous types to non-metallic lines in B stars is especially striking.

In some of the B stars there are certain lines of nitrogen and carbon which can only be produced in the laboratory by specially strong spark discharges, as first shown by Lockyer and his assistants.

A few of the B stars are further distinguished by a set of lines of exceptional interest. They were first noted in the spectrum of the star Zeta Puppis by Professor Pickering, who attributed them to hydrogen, although they were not found in the laboratory spectrum of this gas. The ground for this interpretation was that the "Zeta Puppis lines," or "Pickering series," appeared to have a numerical relation to the ordinary lines of hydrogen, such as had been found to exist between different systems of lines in the spectra of other elements. This view was strengthened later by Rydberg's calculation of a third, or "principal," series of associated lines, the first of which, at wave-length 4686, was also found in stars in company with the Pickering lines; the other members of this series occur in the ultra-violet beyond the range transmitted by our atmosphere, and therefore could not be observed.

On the basis of these observations and calculations, there was for many years a widespread belief in the existence of a form of hydrogen which was beyond the reach of laboratory experiments. It was frequently called "cosmic hydrogen," or "proto-hydrogen," and was thought to be a simplified form of hydrogen produced only under the extraordinary conditions which might be supposed to prevail in the hottest stars. About two years ago, however, it was found by the lecturer that these lines could be obtained by passing very strong discharges through helium, the strongest discharges in fact that glass or quartz tubes will bear.

In these experiments it is almost impossible to remove all traces of hydrogen, and in the first instance the new lines were attributed to hydrogen, in accordance with previous deductions. Numerically, the lines were closely related to the hydrogen series, and had no apparent connection with the known lines of helium.

Later work, however, has shown, in accordance with certain theoretical deductions made by Dr. Bohr, that the Zeta Puppis lines are really due to a simplified form of helium, and do not belong to hydrogen at all. They are now designated spark lines of helium, or lines of "proto-helium."

These lines, first observed in the stars, are of great importance in connection with theories of the structure of atoms, and Dr. Bohr has given what appears to be a very satisfactory explanation of the close agreement of some of them with the lines calculated for "cosmic hydrogen" by Rydberg. The point of immediate interest is that the experimental resources of our laboratories are already sufficient for the reproduction of some of the lines which appear in the spectra of stars which are believed to be among the hottest in the heavens. It has not been necessary to discover new elements to match these celestial spectra, but only to develop new lines from old elements by increasing the energy of excitation.

The lines of proto-helium, as we may now call them, are of further importance as a connecting link between the B stars and the Wolf-Rayet stars, which present us with spectra consisting chiefly of bright lines. The familiar lines of hydrogen, and sometimes those of ordinary helium, are prominent as bright lines in these spectra, and are accompanied by several other lines among which only those of proto-helium have yet been identified. These stars seem to fall naturally just before the B stars in the order of development, and are so placed in the Harvard classification.

Nearly all the stars which have been spectroscopically examined fall into one or other of the classes which have been described, and in seeking for the antecedents of stars we naturally look to nebulæ, which were regarded as representatives of the parent masses from which stars had been developed, long before the spectroscope was thought of.

Nebulæ take many varied and beautiful forms, and are spectroscopically divisible into two great classes. One of these classes includes the spiral nebulæ, of which several thousands are now known, and the spectra have in recent years been found to consist of dark lines very similar to those of the sun or of the F type of stars. Where to place these nebulæ in a scheme of celestial evolution is a difficult problem. The supposition that they represent universes exterior to our own would, perhaps, be in best accordance with the spectra, but, as Herbert Spencer pointed out long ago, their peculiar distribution in the heavens is a serious obstacle to the adoption of this view. Any doubt which might have remained as to their consisting of the same kinds of matter as the sun and stars has now been removed, but why they should all present the same spectrum as star clusters is still mysterious.

The second class of nebulæ, exemplified by the Great Nebula in Orion and the Ring Nebula in Lyra, show spectra consisting of a comparatively small number of bright lines. The chief line in the visible spectrum, in the green, has not yet been found in any terrestrial source, and has been attributed to a hypothetical element, "nebulium." Several other lines are also of unknown origin, but others are definitely identified as belonging to hydrogen and helium. In some cases the chief line of proto-helium at wave-length 4686 is also present and serves, with helium and hydrogen, as a connection between the nebulæ and Wolf-Rayet stars.

Very important evidence in this connection has quite lately been obtained at the Lick Observatory, where some of the most characteristic lines of nebulæ have been found in the atmosphere round one of the Wolf-Rayet stars, while the chief lines of these stars have been proved to occur in the nuclei of several planetary nebulæ. It can scarcely be doubted, therefore, that the Wolf-Rayet stars of class O represent the first results of the condensation of the gaseous nebulæ to stellar forms, and, as we have seen, they stand at the head of the stellar sequence.

The spectral sequence from nebulæ, through the Wolf-Rayet stars to the various classes of white and yellow stars, to the red stars, and presumably onward to a stage where luminosity ceases, thus seems to be complete. It cannot be claimed that every star falls into this scheme, but only that this is in all probability the normal course of the evolutionary process. There are a few stars which for the present we must be content to regard as "peculiar."

The widely accepted view that the ancestors of stars are represented by the gaseous nebulæ would seem to require that these bodies should contain all the materials of which stars are known to be composed, and it has been quite properly felt that some further explanation of the simplicity of the nebular spectrum is called for. The explanation given by Tait, and advocated by Sir Norman Lockyer in connection with the Meteoritic Hypothesis, is that nebulæ are swarms of meteorites, in which gases released by collisions are rendered luminous by electrical discharges, thus accounting for the bright line spectrum, while the metallic elements remain in the solid form and consequently exhibit no spectrum at all.

Another view is that in the nebulæ most of the chemical elements do not exist in the finished state, but are gradually evolved from the nebular substance as condensation proceeds.

Remarkable mathematical work has been done in this connection by Professor Nicholson, who has found close agreements between the theoretical vibrations of atoms of assumed simple structure and those which are represented by the nebulium and other lines actually observed in nebulæ. He concludes that the nebulæ must be largely composed of a set of chemical forms, not found in the Periodic Table, which are the simplest forms in which matter can exist; and that these are the atomic structures from which all the heavier elements have been derived by an evolutionary process which must be the exact converse of radio-activity. Since the modifications of atoms which occur in radio-active processes consist of the expulsion of α and β particles from the nuclei of the atoms, it may be supposed that change of stellar condition proceeds by a progressive modification of the atomic nuclei. Professor Nicholson has ventured so far as to give the name "Archonium" to the hypothetical element which he holds responsible for a strong nebular line in the ultra-violet (wave-length 3729), and has even calculated its atomic weight as 2·95. Very substantial support of his deductions is afforded by the work of Fabry and Buisson in quite a different direction, their measurements of the breadth of the line in question having led them to a value also approximating to 3 for the atomic weight of the element producing it. For the other hypothetical element, nebulium, the deduced atomic weight is 1·3.

Professor Nicholson has further found that some of the unknown lines which are observed in the Wolf-Rayet stars may be calculated from some of the constants relating to nebulium, such lines representing atoms which are the first products of an evolution from the still simpler atoms of the nebulæ. Hydrogen, and perhaps helium, may be the next in order of development.

The spectrum of a nebula has been aptly described by Professor Nicholson as the "spectrum of chaos." He tells us that, whatever may be the case with terrestrial atoms, the electrons in a nebula are not held firmly in the atoms, and that a continual interchange of electrons must be taking place, with a necessary bombardment of atoms by free electrons, to which the luminosity of nebulæ is probably due. The physical state of a nebula must be analogous to that of a highly exhausted vacuum tube of enormous extent.

If time had permitted I should have referred to the changing spectra of "new stars," which seem to me to give pretty definite evidence that, in spite of its simple spectrum, a nebula either actually contains such substances as iron or the materials from which such elements can be evolved.

The subject of this lecture is a very large one and could hardly be dealt with adequately in the course of an hour. I hope, however, that I have been able to give some indication of the nature of the evidence in favour of celestial evolution, and of the way in which the efforts of astronomers, experimentalists, and mathematical physicists have been combined in the attempt to trace its course.

Further investigations in many directions are still needed to complete the story, but all the modern work tends to strengthen our belief in the chemical unity of the universe, and in an evolutionary development of stars from the primitive condition represented by nebulæ.

DISCUSSION.

The CHAIRMAN (Sir FRANK W. DYSON, Astronomer Royal) regretted that he had not been present at the opening of the Meeting, as he had been delayed by an accident on the railway line. It would have given him great pleasure to have introduced Professor Fowler to the Meeting. A large part of the recent progress in the application of the spectroscope to astronomy had been due to Professor Fowler's own work; he it was who had been successful in identifying the dark bands in the orange stars, with bands given by the oxide of titanium; similarly he had identified the elements giving rise to the dark bands seen in the spectra of sun-spots; he had obtained photographs of the spectra of the tails of comets, and identified the corresponding elements; he had also identified some of the most interesting hydrogen lines in stellar spectra. In many ways the Lecturer had made contributions to science in this department of the very greatest importance.

The subject of stellar spectra is one of great complexity, for the stars present us with differences, not only in the substances shown, but in the temperatures at which they exist, and these may be so high that we are not able to work with them in our laboratories. The result of between 50 and 60 years' work has been to show how the spectra of stars may be classified, and that they can be arranged in a continuous sequence. In chemical constitution they are very like the sun, and they differ from it in that some are hotter and some are cooler, the temperatures ranging from about 3000 degrees C. up to 12,000 degrees C. When we notice that these two lines of observation agree—that is to say that we get the same order of sequence when we group the stars according to their temperatures as when we group the stars according to their spectra, we must conclude that we are watching stars that are in the process of cooling. It is difficult to take any other view than that we see the stars in order of temperature, and that our sun once had a higher temperature, and that that temperature is gradually and slowly falling.

The subject thus presented to us is one of the greatest philosophic interest. We find in the stars, in the main, the same substances which are found upon the earth, and we have good hope that we shall yet find—perhaps in Professor Fowler's laboratory—the remainder of the unknown substances represented in the spectra of the stars and nebulæ. The final conclusion is that the stars differ from one another greatly in temperature, but are composed of the same substances as the sun and earth.

Mr. WALTER MAUNDER rose to propose a vote of thanks to Professor Fowler not only for the high value of the lecture, but for the personal sacrifice which had been involved in his delivering it to them. Professor Fowler was a very busy man, and of his two assistants, one had recently enlisted and the other was ill at the present time, so that Professor Fowler was single-handed. He has himself borne a large and very important part in the marvellous discoveries which have been made by means of the spectroscope, and only a fortnight ago the Royal Astronomical Society gave him its gold medal; nor has that medal ever been more worthily bestowed. Of all the discoveries made during the last hundred years, those made in connection with the spectrum have been the most fascinating and romantic of all, if, perhaps, we except the decipherment by Rawlinson and others of the cuneiform inscriptions, whereby a crowded mass of wedge-shaped dents were revealed as written languages, and made to yield up their meaning. The reading of the language of the lines of the spectrum is not less striking; indeed, in one respect it is more striking still, for the rainbow, which is the typical example of the spectrum as we find it in nature, shows no lines—these had to be discovered. The story, therefore, reminds us of the romance of the "Gold Bug," told by Edgar Allan Poe. There the cryptogram to be interpreted was written in invisible writing, which had first to be brought to light and afterwards deciphered.

One research of great interest in which Professor Fowler had borne an important part was the interpretation of a series of hydrogen lines first noted in the spectrum of a somewhat faint star in the southern hemisphere. The hydrogen lines given by the great white or bluish stars, such as Sirius or Vega, here were supplemented by a second series interpolated between them, and the establishment of the significance of the relationship of the two series has been partly Professor Fowler's work.

A research of enthralling interest has been carried out within the last few years by Professsor Nicholson, and the work is still being carried on. If we may so express it, he has been constructing artificial elements in his study; that is to say he has been computing the spectrum which an atom of a given type of structure would yield. In this way he has been able to show that lines in the spectra of nebulæ, of the sun's corona, and of certain peculiar stars generally known from the names of their discoverers as Wolf-Rayet, are typical of elements more simple in structure than any with which we are acquainted in our laboratories. The structure of such an atom may be imagined by likening it to a sort of solar system in the infinitesimal. Round a sphere of positive electricity of relatively great mass a few electrons of negative charge but very small mass revolve rapidly; it is from their vibrations that the lines of the spectrum proceed. Thus the rainbow has given us a clue as to the most intimate structure of elements, some of which we have never yet met with on our own planet.

Colonel MACKINLAY had great pleasure in seconding the vote of thanks to Professor Fowler. There was one question which he would like to ask Professor Fowler. It was well known that there were some double stars of which one was visible to us and the other invisible; would it be possible to get the spectrum of the invisible star?

Professor FOWLER said that it was possible to detect the movements of stars in the line of sight by the displacement of the lines in their spectra, and in that way, in some cases, they had obtained evidence of the existence of non-luminous stars in association with visible stars. It was theoretically possible that such a non-luminous star might be hot enough to produce some thermal effect, to yield a spectrum in the invisible region in the infra-red, and such spectrum might give traces of absorption. At present, however, this was an excursion into the realms of romance; it was not within our present powers.

Mr. SUTTON proposed a hearty vote of thanks to the Astronomer Royal for presiding that afternoon. They had heard that afternoon about the possibility that an evolutionary process was going on in the starry universe. He would like to ask whether the evidence for that evolution was positive or merely negative; that is to say, had we direct evidence that this process was going on at the present time, or did the ascertained facts merely show that astronomical science revealed nothing which would render such a belief untenable?

Colonel ALVES seconded the vote of thanks to the Chairman.

The CHAIRMAN, in acknowledging the vote of thanks, said that unless we assumed an evolutionary process, we could give no explanation of the order that we recognized in stellar spectra.

The Meeting adjourned at 6.10 p.m.