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565TH ORDINARY GENERAL MEETING,

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

SIR FRANK W. DYSON, F.R.S., ASTRONOMER ROYAL, TOOK THE CHAIR.

The Minutes of the preceding Meeting were read and confirmed.

The SECRETARY announced the election of the Rev. Martin Anstey and the Rev. G. Campbell Morgan as Members of the Institute.

The Rev. Prebendary H. E. Fox, M.A., opened the Meeting and introduced the Lecturer, Professor Alfred Fowler, F.R.S.

THE SPECTRA OF STARS AND NEBULÆ. By Professor A. FOWLER, F.R.S.

[ABSTRACT.]

THE purpose of this lecture is to give some indication of the way in which the wonderful power of the spectroscope has been utilised in investigations of the chemistry of stars and nebulæ, and of the bearing of such knowledge upon the great question of celestial evolution.

The only intelligible message that a star sends to the earth is borne on its rays of light, and it is only by the analysis of such light that we can learn anything at all as to the chemical composition and physical condition of the star. Such an analysis has been rendered possible by the invention of the spectroscope in its various forms. Each element, and some compounds, has its own distinctive family of spectrum lines or bands, by which it can be identified wherever it occurs in the luminous condition. In opposition to earlier ideas, it is now known that the same substance may give different spectra when excited in different ways. Indeed, one of the most prominent landmarks in the recent history of the interpretation of solar and stellar spectra is the investigation of such changes in passing from the moderate temperature of the electric arc to the violent action of the condensed electric spark, which was first made by

Sir Norman Lockyer. Lines which are intensified, or which only appear, under spark conditions have been called "enhanced lines," and it is to the study of such lines that much of the progress of recent years has been due.

Kirchhoff's famous experiment of 1859 on the reversal of spectrum lines from bright to dark 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 proves 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.

In the spectrum of the Sun, which may be regarded as the nearest star, Rowland has catalogued some 20,000 dark lines, and the great majority of the more prominent have already been matched by spectra produced in the laboratory, largely from common substances such as hydrogen, sodium, iron, and calcium. Observations of eclipses of the Sun have shown that these gases and vapours exist chiefly in a shallow stratum, about 500 miles in depth, which has been called the "reversing layer" or "flash stratum." Hydrogen, helium, and calcium are the chief constituents of the overlying chromosphere, which has a depth of about 5,000 miles. The corona, which is the most striking feature of a solar eclipse, exhibits a few bright lines of at present unknown origin, and has apparently nothing to do with the dark lines of ordinary sunlight. Many of our chemical elements have not yet been traced in the Sun, but reasonable explanations of their lack of visible manifestation have been advanced, and there is no sufficient reason to suppose that the composition of the Sun is materially different from that of the Earth.

Our present extensive knowledge of stellar spectra has been made possible by the application of photographic methods of observation. All stars are alike in the sense that they are highly heated self-luminous bodies, but they are not all alike in the character of the light which they emit. Thousands of them resemble the Sun very closely, and what has been learned about the Sun in more favourable circumstances is equally applicable to stars of this class. It was early found that the number of distinct varieties of stars was by no means large. Father Secchi recognised four principal types of stellar spectra, which he numbered from I to IV, beginning with white stars and ending with red ones. It was not long before this classification came to be regarded as something more than a mere convenience of description, for it was found that the different types were not abruptly divided, but were connected by spectra representing well-marked transition stages.

Here we get the first definite indications 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 to be attributed primarily to differences in composition, but to their having reached different stages in an evolutionary process. Continuity of the spectral series practically compels us to believe, for example, that our Sun was once a star like Sirius, and that in due course Sirius will become a star like the Sun, the Sun meanwhile having become a red star with a spectrum of bands. We now speak quite freely of young or early-type stars, and of old or late-type stars. On the Harvard system of classification, the successive stages are designated O, B, A, F, G, K, M, N, in the order of early to later types.

The inclusion of solar, or G-type, stars in the evolutionary scheme necessarily implies that all the stars are similar in chemical constitution to the Sun, but independent evidence of the universal distribution of terrestrial kinds of matter is to be found in abundance in the analysis of individual stars. It is especially instructive to begin at the lower end of the stellar sequence, 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 of which they are characterised should present the minimum of difficulty. This expectation is completely realised. In the relatively cool stars of classes N and M, we find bands of carbon and titanium oxide respectively, together with such metallic lines as can be produced at comparatively low temperatures. As we go upwards in the series, from the red stars, through the yellow and white ones, to the Wolf-Rayet stars of class O, it has been found that while we continue to deal in the main with familiar elements, the reproduction of the stellar lines demands gradually increased energy of the exciting sources. Beginning with flames and electric discharges of low intensity, we end near the upper limit of the series with the most powerful discharges to which our spectrum tubes of glass or quartz will submit. The surprising thing is that the resources of our laboratories are already adequate to reproduce so many of the lines which occur in the spectra of the stars, even of those which are believed to be at the highest temperatures. There are still some celestial lines of unknown origin, but previous experimental success encourages the hope that they may yet be reproduced from terrestrial matter.

The generally accepted view that the ancestors of stars are represented by nebulæ requires that these bodies should contain all the materials of which stars are known to be composed. But the nebulæ have a very simple spectrum of bright lines, among which only those belonging to hydrogen and helium have been certainly identified. Hence the modern view, ably supported by the mathematical investigations of Professor Nicholson, that nebulæ consist largely of atoms of very primitive forms of matter, and that the stellar sequence may possibly indicate the order of evolution of the chemical elements as well as that of the stars themselves. However that may be, observations lately made at the Lick Observatory have shown a direct relation between the spectra of nebulæ and the Wolf-Rayet stars of Class O, which stand at the head of the stellar sequence and thus mark the first stage in the condensation of nebulæ. That nebulæ must contain matter other than that indicated by their spectral lines is also strongly suggested by observations of "new stars," which at one stage show lines of iron and other known elements, and at a later stage exhibit the lines characteristic of nebulæ.

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

⁂ A full report of Professor Fowler's lecture and of the discussion following it will be published in Volume XLVIII of the Journal of Transactions of the Institute.