spasm and takes up a new attitude, which is sustained for so long as the voluntary muscular act evoking it. The form, latency, and duration of this so-called 'associated movement' shows it to be a tonic reflex of the same type as those described by Magnus. Further, in favourable cases, a beautiful interaction between labyrinthine, neck and limb reactions may be observed if we combine changes in the position of the subject's head both in relation to space and to his trunk.

It is clear, in short, that the tonic reactions of Sherrington and of Magnus are present in the human subject. In a single personally observed case of complete decerebrate rigidity in the human subject, in which physiological 'decerebration' was performed by a tumour compressing the mid-brain, a perfect decerebrate rigidity with tonic neck reflexes and phasic flexion and crossed extension reflexes were obtainable.

These observations upon the subjects of disease and injury of the nervous system are of a double interest. They serve to correlate the work of the experimental physiologist with that of the clinical observer, they bring the human subject into line with animals lower in the scale. Further, they illustrate the value to the clinician of experimental physiology. For many years the labours of clinical neurologists have accumulated a vast mass of 'physical signs' of disease, which have been used empirically as aids to diagnosis; but so far as possessing other meaning was concerned they remained like the jumbled pieces of a mosaic. Thanks to the light received from the physiological laboratory, it is now possible to piece them together into a coherent and intelligible pattern, and they have become manifestations of a dissolution of nervous function, pregnant with physiological significance. Thus may the clinician not only derive information of inestimable value to him in his analysis of the phenomena of disease, but he may also, in a measure, repay some of his debt to the physiologist by carrying over the latter's animal observations to man.

Some Recent Advances in Astrophysics.[1]

By Prof. E. A. MILNE, F.R.S.

OF late years astronomers have become increasingly despairing as to what the stars are doing—in what direction they are evolving, how they produce the energy they radiate, whether (and if so why) some of them pulsate, how the stars are born and whether they die. At the same time astronomers have become increasingly confident as to what the stars are really like. It is proposed here to deal briefly with one province of this less speculative side of astrophysics, namely, that which is described, broadly speaking, as the subject of stellar temperatures and stellar spectra.

What are called the 'effective temperatures' of the stars have been determined by measurement of their colour, much in the same way as the temperature of a piece of red-hot iron may be estimated from its colour. With the piece of iron, we may measure either the total radiation leaving each square centimetre of its surface, or the ratio of the intensities of radiation for two different constituents of its spectrum. From either of these measurements we may infer the other. Both types of measurement are possible for the sun, and by the work of Abbot, Plaskett, and Fabry and Buisson, they have been shown to be in general agreement. For the stars in general, only the colour type of measurement is possible. It is true that of recent years the heat radiated by the stars has been measured directly, but such measures by themselves yield no more information than a determination of apparent magnitude. Colour-measures, however, by the use of Planck's law, yield the amount of radiation leaving each square centimetre of the star's surface—a quantity expressed parametrically by the effective temperature, or surface brightness.

The importance of this quantity lies in the fact that the total radiation leaving the surface per second is precisely the amount generated in the interior per second, assuming a quasi-steady state. Two examples of its employment in fundamental calculations may be mentioned. The amount of light from a star (a quantity given by the apparent magnitude) reaching the earth is equal to the product of the surface brightness into the solid angle subtended by the star. Hence a determination of surface brightness plus one of apparent magnitude is equivalent to a determination of the angular diameter of the star as seen in the sky from the earth. The confirmation of such estimates by the direct measurement of angular diameters at Mount Wilson by means of the Michelson interferometer affords a useful check on one of the steps in the reasoning, namely, the deduction of radiation per unit area per second from an observation of colour. The second example is that of the estimate of the densities of the components of a double star. The density-ratio of the components may be readily calculated in terms of the ratio of the surface brightnesses, the mass-ratio, and the difference of the apparent magnitudes. In this way it was inferred that the companion of Sirius must have a density some 60,000–70,000 times that of Sirius itself, and the verification of this by Adams at Mount Wilson, by measurements of the Einstein shift in the lines of the spectrum, has been one of the most sensational scientific events of the past year.

The effective temperature, however, is not the temperature of any particular portion of the star. The question arises, Is there any method of determining the actual temperature in the surface regions of a star, which alone we can directly observe? Have we a thermometer? The answer is in the affirmative. We can use the atoms volatilised in the atmosphere of a star as their own thermometer, by observing the absorption spectrum they produce.

The theory depends on the recent progress in atomic physics. It has long been known that the spectra of the great majority of stars fall into a single linear sequence, in which, as we pass by ascending effective temperatures from the red stars to the blue stars, some lines decrease in intensity, others increase, attain a maximum and decrease, others again only appear far on

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[1] Substance of a lecture delivered before the Manchester Literary and Philosophical Society on October 19.

in the sequence. Such a linear array of spectra could scarcely be due to differences in chemical composition, and it was emphasised by Russell and others that in some way the ordered sequence of spectra must be related to the sequence in effective temperatures. The true explanation, however, was only discovered in 1920, by Saha.

It was Saha who first pointed out that at high temperatures the atoms composing stellar atmospheres must dissociate into ions and free electrons according to the same laws of thermodynamics used by chemists to calculate molecular dissociations. Given the ionisation potentials of the atoms, the degree of dissociation is a function of temperature and pressure—to be precise, the partial pressure of the free electrons—and for a given pressure the ionisation increases with the increasing temperature. Consequently, for each element we shall have first the spectrum of the neutral atom, then that of the once-ionised atom, followed in turn by that of the twice-ionised atom, and so on. At the highest temperatures the spectrum of the neutral atom should completely disappear, in general. Further, the absence of an element from a stellar spectrum does not necessarily mean the absence of the element from the stellar atmosphere. It may only mean that the lines it is capable of producing in its then stage of ionisation are outside the accessible range of spectrum.

It is necessary to distinguish the ultimate lines of an atom in any given stage of ionisation from the remaining lines. The ultimate lines are absorbed only by the atom or ion in its normal, or unexcited stage. The theory shows immediately that the ultimate lines of a neutral atom should steadily decrease in intensity with increasing temperature: the ultimate lines of an ionised atom should increase at first, slowly attain a maximum and then decrease as further ionisation ensues. Calcium provides an illustration of both types of lines.

Intermediate between successive stages of ionisation we have atoms in excited states, with corresponding absorption spectra. Only a minute fraction of the atoms are in any given excited state at any instant, but the fraction is a definite one given the temperature and pressure, on the assumption of thermodynamic equilibrium. Moreover, this fraction has a comparatively sharp maximum. It is easy to see that a maximum must occur. At lower temperatures, comparatively few of the atoms are excited. As the temperature increases the excited fraction of atoms in the given state of ionisation increases, but the total number of atoms in the given state decreases owing to the next stage of ionisation setting in, and ultimately all the atoms pass into the next stage of ionisation. The number of excited atoms is thus practically zero at both low and high temperatures. In between it must have a maximum.

Following the method of Saha, it has been found possible to calculate at what temperature such a maximum should occur. We then identify the maximum in the number of excited atoms with the observed maximum of the corresponding absorption lines in the stellar sequence. We thus arrive at a truly thermometric scale of stellar temperatures. The most recent and detailed comparisons of observed and theoretical maxima are those contained in the researches of Miss Payne, of the Harvard College Observatory, and the following is her table of temperatures.

Class.	Temperature.	Class.	Temperature.
K_5	3,000°	A_0	10,000°
K_0	4,000°	B_8	13,000°
G_0	5,000°	B_3	17,000°
F_0	7,500°	$B_{1\cdot 5}$	18,000°
A_5	9,000°	B_0	20,000°

At present there still remains an empirical element in the temperature scale. It is necessary to assume a value for the pressure—the partial electron pressure—in stellar atmospheres, and to assume that the pressure is the same in all stars. The removal of this empiricism promises to open up a still more important line of work. A synthetic theory of the structure of a stellar atmosphere would not in fact deal with the pressure at any particular level. Starting with the value of gravity at the surface of the star, and the atomic absorption coefficients, it would proceed to calculate the distribution of atoms through the atmosphere, taking due account of the varying effects of selective radiation pressure on the individual atoms. Ultimate lines, for example, will give rise to much more intense radiation pressure than lines corresponding to excited states. Different classes of atoms will thus be at different horizons in the atmosphere, and so at different pressures. The nature of the spectrum itself controls the pressure, and so in turn the degree of ionisation. This double relatedness of spectra to ionisation, due to the intervention of radiation pressure, may lead after further study of stellar spectra not only to an improved temperature scale with the empiricism removed, but further to determinations of surface gravity and to astrophysical determinations of relative, perhaps even absolute, atomic absorption coefficients. The possibility of the latter type of determination serves to remind us that astrophysics contributes to atomic physics as well as borrows from it.

A further by-product of the theory is the determination of the relative abundances of the different elements in stellar atmospheres. Observations of maxima provide temperatures, and are independent of relative abundances: each maximum is a thing *per se*. But the places of first or last appearance of a line in the stellar sequence depend on the amount of the corresponding element available, and in the hands of Miss Payne have been used to estimate the relative abundances. It must suffice to state that the abundances bear a relation of rough similarity to the abundances of the same elements in the crust of the earth, with the exception of hydrogen and helium, the behaviour of which is anomalous.

It has already been mentioned that intensities of spectral lines are connected with the surface values of gravity. Empirical connexions of line-intensities with the absolute luminosities of the corresponding stars are now well known: they are another aspect of the same phenomenon. By a method originated by Kohlschütter, Adams and Joy, they are now used at many observatories to determine the parallaxes of stars spectroscopically. In conclusion, reference may be made to a similar method recently developed in the brilliant work of Ch'ing-Sung Yü at the Lick Observatory. He has investigated the continuous absorption spectrum associated with the limit of the Balmer series of hydrogen. This spectrum is produced by the ionisation of hydrogen atoms: its intensity is a measure of the fraction of hydrogen atoms remaining un-ionised. Yü has found empirically that it is a function of colour-temperature and of absolute magnitude. The method eliminates one unsatisfactory feature in the method of Adams and Joy, namely, the use of different empirical reduction curves for stars of different types. Yü's photometric measures determine colour-temperature and hydrogen absorption from the same spectrogram, and from these two quantities the absolute magnitude may be inferred. It is too early to estimate the ultimate value of the method, but it is at once a new weapon for the determination of parallaxes by calibration on known stars, and a challenge to theoretical investigators.

Obituary.

PROF. W. J. HUSSEY.

PROF. W. J. HUSSEY died suddenly in London on Thursday, October 28. He reached England on October 23 with Mrs. Hussey and with Mr. and Mrs. Rossiter. They proposed to leave for the Cape on October 29, taking with them a large telescope of 27 inches aperture and 41 feet focus. This was to be installed near Bloemfontein, Prof. Hussey remaining until the building was completed and leaving Mr. Rossiter in charge to carry out an extensive programme of double star observations. Prof. Hussey had only lately recovered from an attack of pleurisy, but seemed fairly well on October 27, when he gave an address to the British Astronomical Association.

William Joseph Hussey was born at Mendon, Ohio, on August 10, 1862, and graduated B.S. of the University of Michigan in 1889. For some years he taught mathematics in the University of Michigan, and was acting director of the Detroit Observatory. In 1892 he was appointed assistant professor of astronomy at the Leland Stanford Junior University, afterwards succeeding to the chair. From Leland Stanford it was a natural transition to the post of assistant astronomer in the Lick Observatory, not many miles away.

Hussey's knowledge and enthusiasm were such as to enhance the high traditions of this famous observatory. Barnard and Burnham had left, and their places were filled by Aitken and Hussey. The first important work Hussey undertook was the re-observation and discussion of the double stars observed by Otto Struve. The results form vol. 5 of the Lick Observatory publications. Hussey measured many close and difficult double stars which were only within reach of the largest telescopes. Among them may be instanced δ Equulei, which has an elliptic orbit, and the two stars are only separable when near elongation. He followed this star closely and found it to have a period of 5·7 years, one of the shortest known, while previous observers had supposed the period to be about double this length. It may be interesting to note that he determined the parallax of this star by a combination of line of sight determinations of linear velocity with the determinations of angular movement resulting from double star measures.

In 1899 Hussey joined Aitken in a systematic examination of all stars between the pole and -22° down to $9{\cdot}0^{\mathrm{m}\cdot}$ or $9{\cdot}1^{\mathrm{m}\cdot}$ to discover which of them were double. They worked on this programme from sunset to sunrise, and when Hussey left in 1906 to be professor of astronomy and director of the observatory of the University of Michigan, he had discovered so many as 1327 new double stars. Here he was engaged in spectroscopic work and in building and organising a new observatory. In 1911 the directorship of the observatory of La Plata was added to that of the University of Michigan. Before his resignation of this post in 1917, he had discovered 312 new southern double stars.

In 1902 Hussey was appointed to make telescopic tests of the suitability of sites in South California and Arizona for a solar observatory, and strongly advocated the selection of Mount Wilson. From 1917 he had in mind the possibility of the establishment of an observatory in the southern hemisphere specially for double star work. Three years ago he visited South Africa, and was very favourably impressed with the site of Bloemfontein. A personal friend from college days, Mr. Lamont, has recently provided funds for a telescope, designed and built under Hussey's direction, with an object-glass by Zeiss. This telescope was completed and was being taken to Bloemfontein at the time of Prof. Hussey's death. We understand that arrangements have been made to go forward with the establishment of this observatory, and that Mr. Rossiter left for South Africa on November 5. This, we may be sure, would have been in accordance with Prof. Hussey's wishes.

Prof. Hussey had many friends among English astronomers, who admired his gifts of industry and enterprise, and were always pleased when occasions like eclipse or other expeditions brought him to London and gave an opportunity of meeting him. He had been a foreign associate of the Royal Astronomical Society since 1903.

F. W. D.

WE regret to announce the following deaths:

Prof. F. M. Caird, emeritus professor of clinical surgery in the University of Edinburgh and a past president of the Royal College of Surgeons of Edinburgh, who worked as a student under Lister, on November 1, aged seventy-three years.

Dr. W. Romaine Newbold, Seybert professor of moral philosophy in the University of Pennsylvania, who wrote on suggestibility, automatism and kindred phenomena, on September 26, aged sixty years.

Dr. Francis E. Nipher, emeritus professor of physics in Washington University, St. Louis, whose work covered aspects of gravitating nebulæ, wind pressure, and the electric discharge, on October 6, aged seventy-eight years.

Dr. Franz Pfaff, formerly professor of pharmacology and therapeutics at the Medical School of Harvard University, on September 26, aged sixty-six years.

Dr. C. A. Waldo, emeritus professor of mathematics in Washington University, St. Louis, known for his work on warped surfaces, on October 1, aged seventy-four years.