Solar Research and Theoretical Astrophysics

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THE GREAT DISCOVERIES ASSOCIATED with the name of Hale—the spectroheliograph, the double reversal of the H and K lines of calcium in the spectrum of the flocculi, the magnetic field of sun spots and their laws of polarity, the general magnetic field of the sun—all belong to the earlier Kenwood period or the later Mount Wilson period. Hale's years at the Yerkes Observatory appear at this distance of time as an interim period of consolidation and study between years of great imagination and discovery. This may be disappointing to one who is looking back at the record of the Yerkes Observatory. Nevertheless, there is one romantic incident to which the University of Chicago (and the Yerkes Observatory) may lay lawful claim, namely, when Hale met the challenge of the spectroscopist, Carl Runge, that the bright yellow line discovered by the chemist, Sir William Ramsay, in the discharge through the gas occluded by the uranium mineral clevite cannot be identified with helium "unless the solar D_3 line were also double." On June 20, 1895, Hale succeeded in resolving the D_3 line of a bright solar prominence "into a delicate unequal pair" and "our possession of helium as a truly indigenous element was rendered incontrovertible."

Though the solar research carried out at Yerkes Observatory must take second place to the brilliance of the discoveries to be made only two or three years later at the Mount Wilson Observatory, the record of the Yerkes Observatory during the years between Kenwood and Mount Wilson is not insignificant. Indeed, Dr. Adams has written:

> As Hale moved onward to the wider field of work afforded by the Yerkes Observatory, he saw opportunities for extending his investigations with more powerful apparatus. A large spectroheliograph was one of the first requisites, and the Rumford spectroheliograph, when attached to the 40-inch refractor, has remained one of the most efficient instruments for certain types of solar research ever designed. With it dark hydrogen flocculi were discovered and the dark calcium markings which proved to be prominences seen in projection against the disk. The dispersion of the instrument was sufficient to make it possible to set the second slit upon different portions of the K line, and thus map the calcium flocculi at different levels through the solar atmosphere. A grating spectrograph supplemented the spectroheliograph, and with it Hale made the difficult visual discovery of the presence of the green carbon band in the spectrum of the chromosphere. He became fully aware at this time of the possibility of observing the chromospheric and much of the "flash" spectrum without an eclipse and in future years continued such work at Mount Wilson.
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> A strangely prophetic remark was made by Hale in an article published at the Yerkes Observatory in 1902: "The remarkable peculiarities of the spectra of sun spots seem to deserve more attention than they have hitherto received from spectroscopists." Widened lines in the spectra of spots had been observed visually by Young in 1872 and were studied systematically by the English astronomers Maunder, Cortie, and Lockyer. Hale made some attempts to photograph the spectrum of sun spots while at Kenwood Observatory, but his success was only partial because of the small size of the sun's image. With the larger image given by the 40-inch telescope at the Yerkes Observatory much better results were obtained, and not only were the widened lines measured but also many of the lines in a green band discovered by Maunder in 1880. Hale realized that for an adequate investigation of the spot spectrum greater linear scale in the spectrograph and a still larger image were needed. Accordingly he designed for the purpose a large spectrograph used in conjunction with a coelostat and long-focus concave mirror, thus planning to bring into regular astronomical use an instrument which had been relegated almost wholly to eclipse expeditions. This instrument finally took form in the Snow telescope with which in later years at Mount Wilson the first of the extensive sunspot investigations was begun.

After Hale's departure from the Yerkes Observatory, the Rumford spectroheliograph continued to be used systematically for many years. Of these later studies the most important are those of the late Philip Fox on "The Rotation Period of the Sun" and of Edison Pettit on "The Forms and Motions of Prominences." In the first of these two investigations Fox derived from some 4,000 measures of calcium flocculi on 285 plates the law of variation of the diurnal motion (ξ) in mean solar days at various heliographic latitudes (ϕ). He found that $\xi = 11^\circ.584 + 2^\circ.976 \cos^2\phi$. This law differs from those derived spectroscopically by Adams and presents a problem still awaiting solution.

In his investigations on the forms and motions of the solar prominences Pettit broke new ground, and his first study of the subject at the Yerkes Observatory still remains a classic. From this early study the remarkable fact already had emerged that the motion of a prominence measured along its trajectory is uniform, increasing suddenly at intervals as if by an impulse. This fact, confirmed by numerous later observations, still defies a satisfactory explanation.

After 1920 conventional solar research began to lag behind in the wake of the expanding interests in stellar astronomy and astrophysics, but occasionally some important investigations were carried out—for example, P. C. Keenan's careful photometry of the solar granulation. In one sense, however, interest in solar problems was never really lost. Indeed, as Hale has so often emphasized, "the student who would untangle the secrets of the universe recognizes in the sun a typical star." This is particularly true of the student of theoretical astrophysics: for, a theory of stellar constitution, to be satisfactory, must first account for the solar energy, and a theory of stellar atmospheres, to be satisfactory, must first account for the solar spectrum. Thus, a problem which has been studied intensively during recent years relates to the continuous spectrum of the sun.

It has long been known that the observed laws of darkening and the distribution with wave length in the continuous spectrum of the sun imply a source of continuous absorption in the solar atmosphere which varies with wave length in the following manner: The absorption coefficient increases by a factor of the order of two from 4,000 to 9,000 A.; beyond 9,000 A. it decreases by about the same amount until we reach 16,000 A. in the infrared; and the indications are that as we go further into the infrared, the absorption coefficient again increases. For many years one of the principal problems of astrophysics was to determine the source of continuous absorption in the solar atmosphere which will show the behavior we have described. On the basis of theoretical work done at the Yerkes Observatory it has now been established beyond any possible doubt that the negative ions of hydrogen are responsible for the continuous absorption in the solar atmosphere from 4,000 to 20,000 A. This identification of the presence of the negative ion of hydrogen recalls to one the case of helium, whose presence in the solar atmosphere was known a quarter of a century before its terrestrial existence was established. In the case of the negative ion of hydrogen, its stable existence was first established by Bethe and Hylleraas on theoretical grounds, and it was only 15 years later that its physical existence as a free atom was established in the solar atmosphere.

The brief reference to the continuous spectrum of the sun which we have made reminds us of the important role which problems of radiative transfer have played in the theory of stellar atmospheres. Until recently the solutions even for the simplest problems were not available. But the studies undertaken at Yerkes Observatory during the past few years have provided *exact* solutions for a great variety of problems. From one point of view the most important of these advances relates to the solution of transfer problems in which the polarization characteristics of the radiation field are properly taken into account. The importance of such considerations has been recognized since 1871, when Lord Rayleigh accounted in a general way for the distribution and polarization of the sunlit sky. Nevertheless, even the basic equations for the problem were not written down before the problem arose in an astrophysical context. We may briefly explain the particular astrophysical problem which gave the final impetus to formulating and solving transfer problems in which the polarization characteristics of the radiation field are incorporated and properly allowed for.

From the investigations of J. L. Greenstein and others it appears that in the atmospheres of stars with surface temperatures exceeding 20,000° K the transfer of radiation must be controlled predominantly by the scattering by free electrons. According to J. J. Thomson's laws for this process, scattering by free electrons must result in the partial polarization of the scattered radiation. If our belief in the important role played by the Thomson scattering in the atmospheres of the hot stars is correct, we should expect that the radiation emergent from the atmospheres of such stars should be partially polarized. The question of the degree of polarization to be expected under such conditions therefore becomes a matter of exceptional astrophysical interest. But before we can answer this question, the relevant equations of transfer distinguishing the different states of polarization must be formulated and solved.

The problem of radiative transfer in an electron-scattering atmosphere has now been solved exactly, and the theory predicts a degree of polarization to the extent of 12 per cent at the limb. It is apparent that if the predicted effect is present, the most favorable conditions under which the phenomenon could be observed are during phases close to the primary minimum in an eclipsing binary, one component of which is an early-type star. It is gratifying to be able to record that careful polarization measurements on RY Persei by A. W. Hiltner at the 40-inch telescope indicate that the effect of the predicted amount is very probably present.

The foregoing brief sketch is intended merely to give an impression of the kind of problems in solar and theoretical astrophysics which have been studied at the Yerkes Observatory. But it serves to underline a fact which Hale often emphasized, namely, that there is "no essential difference between the attitudes of a physicist and an astronomer."