Solar Observatory Work

SOLAR OBSERVATORY WORK. *

GEORGE E. HALE.

Spectra of Sun-spots.

In my last annual report, reference was made to the fact that photographs showing widened lines in the spectra of sun-spots had been obtained, and that steps would be taken to interpret these phenomena through experiments in the laboratory. The investigation which has grown out of this work has been alluded to in the introduction to the present report. The photographs of the spectra of sun-spots, made by Mr. Adams and Mr. Ellerman, after the Littrow spectrograph of the Snow telescope had been given its permanent form, proved so satisfactory that they have served as the basis of our studies. It should be remembered that the principal phenomena of spot spectra comprise: (1) Fraunhofer lines of the same intensity as those of the solar spectrum; (2) lines that are widened or strengthened; (3) lines that are weakened or replaced by bright lines. The photographs successfully register not only the more conspicuous lines of these types, but also the multitude of fine lines into which the spot spectrum was visually resolved by Professor Young many years ago. In my photographic work on spot spectra at Yerkes Observatory, which was done with the assistance of Mr. Ellerman, a few of the more conspicuous of these fine lines were recorded, but the scale of the spectrum was so small that their identity could not be determined with any certainty. The present photographs

* Report of the Director, 1907.
have a scale five times as great, with the result that thousands of the fine lines appear upon the plates, where their positions can be measured with precision. Measurements of these lines, by Mr. Adams, have shown that most of them are identical in position with the extremely faint lines recorded by Rowland in the solar spectrum. In other words, this feature of the spot spectrum is produced by a marked strengthening of the absorption of the solar atmosphere. However, the conclusion drawn by Dunér, from his visual observations, "that there is no fundamental difference between the general solar spectrum and that of the spots," is by no means warranted, for the intensities of the lines which are strengthened are not increased, in all cases, in the same proportion; on the contrary, the changes show the widest variations, some lines being unaffected, some enormously increased in intensity, and others greatly enfeebled.

The identification of the faint lines in the spot spectrum, although it cleared up the uncertainty as to their origin, by no means solved the problem regarding the cause of the characteristic spectral phenomena of spots. It seemed evident that extensive laboratory investigations might be needed for this purpose. The question was however, to find some logical basis for a plan of attack. I have long been impressed with the following characteristic features of spot spectra: (1) The diverse behavior of different lines of the same element; (2) the fact that all of the strengthened lines lie in the visible spectrum, and that the most conspicuous of them are in the red, yellow, and green, and (3) the relatively great intensity in the less refrangible region of the general background of the spot spectrum. In considering these peculiarities, I could not fail to recall: (1) That in the spectra of the elements some lines increase in intensity, while others decrease, when the temperature falls; (2) that in spectra observed at low temperatures, the most prominent lines are likely to appear in the less refrangible region; and (3) that in a continuous spectrum (as well as in a spectrum of bright lines) a reduction in temperature involves a shift of the maximum toward the red. The similarity of these two groups of facts led to the belief that the most characteristic phenomena could in all probability be accounted for on the hypothesis that the temperature of the vapors within the spot is below that of the corresponding vapors within the Sun's reversing layer. It was on this basis
that the laboratory investigations, described on another page of this report, were undertaken.

The results so far obtained in our study of spot spectra, while strongly confirmatory of the hypothesis outlined above, of course constitute only the first steps in the extended researches required to test it in a complete manner. The use of an electric furnace, for the vaporization of metals in a carbon tube, where no electrical phenomena, other than those which result in the production of heat, can influence their radiation, is a most important element in the general investigation. This work which is now in progress, will include all of the characteristic sun-spot metals that can be volatilized in the furnace. The solar side of the investigation will involve photographic and visual studies of spot spectra carried on through a period of several years. Further stellar spectroscopic investigations must be delayed until the completion of the 60-inch reflector, as the Snow telescope is not well adapted for this phase of the work.

It must not be supposed that our hypothesis is intended to account for all of the phenomena of spot spectra. The bright lines occasionally observed are probably due to the overlying reversing layer, or to the chromosphere, especially in cases where eruptive action is concerned. The hypothesis will serve a useful purpose if it provides a basis for the interpretation of the principal phenomena of strengthened and weakened lines, at the same time permitting an estimate of the approximate temperature of the vapors within the spot. Our work also appears to throw light on the much discussed question of the "enhanced" lines, favoring, as it does, the view that temperature alone is sufficient, in most cases, to account for these lines, though by no means precluding the view that high electrical potential, or sudden change of potential, may be capable of producing similar effects. Special attention will be given to these latter questions in our laboratory investigations.

**Radial Motion of the Calcium Vapor in the Flocculi.**

In connection with the study of the spectra of sun-spots, the work of Mr. Adams on the wave-length of the H and K lines in flocculi, and the motion of the calcium vapor in the Sun,* is of great importance. As the spectroheliograph so

* Contributions from the Solar Observatory, No. 6.
clearly shows, sun-spots are surrounded by extensive flocculi, consisting of cloudlike masses of calcium vapor, which sometimes overhang the smaller spots, so as to hide them completely. These calcium clouds rise from the facula, and they are presumably the effects of convection currents proceeding outward from the interior of the Sun. It is evident that the radial motion of the vapor should be measurable from the displacements of the $H_2$ and $K_2$ lines, which correspond to the lower and intermediate regions of the chromosphere, and those of the $H_3$ and $K_3$ lines, which are produced by the absorption of the cooler vapor at a somewhat higher level. Mr. Adams's investigation began with a redetermination of the wave-lengths of the $H$ and $K$ lines in the electric arc, since the available determinations were not in sufficiently close agreement to promise the necessary accuracy. The large scale of the photographs, which were made with the Littrow spectrograph, permitted them to be measured with high precision, and the resulting wave-lengths of the $H$ and $K$ lines are probably very close to the truth. Using the arc lines as standards, Mr. Adams determined the wave-lengths of the $H_2$ and $K_2$ lines, and those of the $H_3$ and $K_3$ lines, at various points on the solar surface, and also (for the latter lines) over sun-spots. The average displacement of $H_3$ and $K_3$, which amounted to 0.006 tenth-meter toward the violet, corresponds to a velocity of approach of the vapor amounting to 0.41 kilometer per second. The varying displacements obtained at different times, however, indicate that general conclusions should be based only on a very extensive investigation. The results given by the bright lines $H_2$ and $K_2$ also show a displacement toward the violet, so that it is probable that the calcium vapor in the flocculi may be regarded as moving upward. This would accord with the conclusions as to the nature of these objects based upon work with the spectroheliograph. As already stated, however, much more work along these lines must be undertaken, and special apparatus has accordingly been prepared for this purpose.