lengthy periods has been adopted before, as it must naturally have suggested itself as very desirable: but if so, it does not appear to have furnished the successful issues which it is so well calculated to bring about.

The plan of *direct observation* is of course vastly preferable in critical work on the Sun to any other method of viewing the spots. It is very convenient and useful in some respects to throw the Sun's image on to a white surface, and fair general views of the spots are obtainable in this way, but the plan utterly fails when we come to the study of the really difficult and delicate features of the solar disc.

Bishopston, Bristol,
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W. F. Denning.

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## *The Rumford Spectroheliograph of the Yerkes Observatory.*

The discovery by Prof. Hale in 1891 of the reversal of the centres of the dark lines H and K in scattered regions over the surface of the Sun's disk, as well as in the prominences, and his subsequent work at the Kenwood Observatory with the beautiful instrument he designed for recording these phenomena, are still fresh in the minds of astronomers. Of the recent developments at the Yerkes Observatory we now have (in vol. iii. of the 'Publications' of that Institution) a most interesting account, illustrated with a splendid series of half-tone plates.

The Rumford Spectroheliograph is designed to photograph, in monochromatic light, the seven-inch solar image at the focus of the 40-inch refractor, and its parts have of necessity to be built on a scale corresponding to that of the great telescope. The financial question naturally offered a serious obstacle to the construction of such an instrument at the outset, but this was finally disposed of by a grant from the Rumford Fund. Prof. Hale then proceeded to grapple with the many problems presented in designing an instrument which should be capable of dealing satisfactorily with so gigantic a primary image, and his account of the way in which the very formidable difficulties encountered have been faced and finally overcome affords exceedingly instructive and interesting reading.

The principle by which the spectroheliograph builds up a monochromatic image of the Sun with light from any selected line in the spectrum is very simple, and may be briefly described as follows:—When an image of the Sun is thrown on the slit plate of a spectroscope, the dark lines in the spectrum represent monochromatic images of a narrow section of the solar surface defined by the slit, and the lines belonging to the different elements may give different versions, so to speak, of this same section of the Sun. The function of the spectroheliograph is to isolate, by means of a second slit, any one of these monochromatic images and to build up with a number of such sections a complete image of the disk. This is effected by imparting a continuous movement to the first slit relative to the primary solar image, and by a simultaneous movement of the second slit relative to a photographic plate placed behind it.

It is obviously immaterial whether the slits themselves are made to move or the solar image and photographic plate are moved, the only essential condition being that the selected spectrum-line falls within the second slit and on to the plate throughout the exposure.

In the Rumford Spectroheliograph the slits are stationary, and the necessary movement of the image across the first slit, which is arranged to be parallel to the equator, is effected by the declination motor of the equatorial, a corresponding movement being imparted to the photographic plate behind the second slit.

No great dispersive power is needed for work with the very broad dark lines of the solar spectrum, and two simple prisms are found to be sufficient; these are, however, supplemented by a powerful grating for work with the finer lines. The method of correcting for the distortion due to the curvature of the lines of the prismatic spectrum (suggested by Prof. Wadsworth) is so simple and satisfactory that this drawback to the use of ordinary prisms in spectroheliograph design need no longer be considered.

Foremost among the rather numerous and exacting adjustments demanded by the spectroheliograph is the one whereby the second slit is made to coincide exactly and throughout its length with any selected line in the spectrum. This is not a very difficult matter if a sharply-defined line is chosen in a region of the spectrum that is easily visible to the eye. But in the case of the lines H and K, which give such interesting and beautiful images of the Sun's disk, as well as the prominences at the limb, the problem is a much more difficult one: these lines are at the limit of the visible spectrum and, especially K, are not at all easy to see; moreover they are broad indefinite bands, in which the slit must be set exactly at the centre where the bright reversals occur of those forms which Prof. Hale has appropriately named the *flocculi*.

If the slit is set to one side of the centre the picture obtained is much less brilliant in its contrasts, and the prominences are not shown at all. Interesting and very instructive results are nevertheless obtained with the slit in this position on the H or K bands, and Prof. Hale has made a special study and comparison of the photographs obtained with the slit set at the centre and at various points in the shading on either side.

The H and K lines in the solar spectrum consist of three distinct parts: first, a broad hazy band representing the absorption of the lowest and densest calcium vapour lying immediately over the mean photospheric level, but appreciably below and between the highest summits of the faculæ. This Prof. Hale designates $H_1$ and $K_1$. Next comes an interrupted bright line superposed on the centres of the bands, which he calls $H_2$ and $K_2$, representing the emission of the relatively hot calcium vapour rising immediately above the ordinary faculæ. Finally, there is a narrow dark line, $H_3$ and $K_3$, superposed upon the broader bright line, which is thereby mostly divided into two parts. This represents the absorption of the highest and relatively the coolest region of the chromosphere.

It would seem to be possible, therefore, by setting the second slit of the spectroheliograph successively upon the three different portions of, say, the K line, to obtain calcium images representing three different altitudes above the photosphere. It is, however, scarcely possible, without very great dispersion, to distinguish between the central absorption line and the underlying bright line, and when the slit is placed as near as possible to the centre the result is a photograph made up of light from the intermediate $K_2$ level, modified to some extent by the varying absorption of $K_3$.

But in the case of the broad $K_1$ band the slit can be set in more than one position which will be quite clear of the central $K_2$ line. When placed entirely outside the band upon the continuous spectrum, the image is the same as an ordinary direct photograph, showing the faculæ increasing in contrast towards the limb. But with the slit just within the borders of K, Prof. Hale considers that he obtains images of the very lowest level of calcium vapour. Farther within the band a higher level of calcium is reached, yet not so high as the $K_2$ level obtained with the slit central.

In discussing the results obtained in this way, Prof. Hale adopts this view as a "working hypothesis," namely, that the calcium flocculi are depicted sectionally in at least three different levels above the photosphere, and the evidence afforded by the photographs certainly seems to bear out this idea. A serious objection, however, would seem to follow from the fact that in photographs of the spectrum itself the true reversals of H and K seem to be entirely confined to the central $H_2$ and $K_2$ region of the lines. Only in the rare cases of violent eruptions are there ever any signs of lateral spreading of the bright lines; and the shading on each side appears almost always to be uniformly da[illegible] except only where it is crossed by the faintly bright continuous bands of the true faculæ. These bands, however, sometimes give a deceptive appearance of true reversal of the shading, as is well seen in plate ii. fig. 2.

An alternative hypothesis would be that the $K_1$ images really represent the true faculæ, and are photographed by the continuous spectrum superposed upon the K band. On this view they cannot be regarded as low-level *calcium* vapour. It is possible, however, that true calcium emission may become evident where shown up upon the dark background of a spot. The interesting comparisons given on plates v. and vi. would have been more instructive on this point had the region photographed been situated near to the limb, where the faculæ proper would have shown up in much greater contrast.

The increase in brightness of the flocculi with the slit set nearer the centre of the band, but still outside $K_2$, might be explained as an effect of contrast only. It is to be borne in mind, however, that in this position, so near to $K_2$, there is the possibility of partial reflection of the bright $K_2$ from one of the (highly polished) jaws of the slit itself.

Some of the most interesting plates are those showing the solar surface as depicted by the hydrogen line $H\beta$. This is a return to a very early phase of spectroheliograph work. In 1891 the present writer attempted, without success, to obtain photographs of the prominences projected upon the disk with a simple form of spectroheliograph, making use of the $H\beta$ line, with which it was not difficult to photograph them at the limb. The reason of this failure is now apparent: the ordinary prominences are less bright than the chromosphere from which they rise; consequently, if they are to be seen at all projected on the disk it is probable they would appear as *dark* forms, the cooler hydrogen in the prominence absorbing the light from the hotter region below. This appears actually to be the case; the photographs obtained by Prof. Hale and Mr. Ellerman with $H\beta$ show very curious dark forms distributed over the disk, and evidently due to absorption effects. Some of these seem to correspond in position with the prominences, although this relation is not made out with certainty. But there is a very evident correspondence in position of the larger dark masses with the bright calcium flocculi, and very interesting are the comparisons given of the $H\beta$ images and the calcium images in the neighbourhood of spots. These beautiful plates well illustrate the great possibilities of the spectroheliograph in extending knowledge of the intimate structure of the solar surface and of spots; for not only hydrogen and calcium, but many other elements having fairly strong absorption lines may be made to yield their own special versions of the interesting region lying immediately above the photosphere.

In concluding his discussion of the photographs, Prof. Hale draws attention to the fact that his results, so far as they go, are in accordance with the views expressed by the writer in attempting to explain the predominance of the enhanced lines in the flash-spectrum. In this connection it would be of great interest to compare the image given by any normal and isolated iron line with that yielded by an enhanced iron line. Enormous dispersion would, however, be needed to deal effectively with one of the latter lines, of which perhaps the line at $\lambda$ 4584·0 would be the most suitable.

But in this, as in many other lines of investigation for which the spectroheliograph is so well adapted, the persistent effort of many observers is imperatively needed, and it is to be hoped that Prof. Hale's appeal for cooperation in this work will meet with a wide response. The magnificent series of photographs of the great southern spot of October last should whet the appetite for further research, as they certainly emphasize our total ignorance of the real nature of sun-spots. J. Evershed.