VISUAL OBSERVATIONS OF THE SOLAR ATMOSPHERE

By George E. Hale

Mount Wilson Observatory, Pasadena, California

Communicated April 25, 1926

The spectrohelioscope, an instrument for observing the sun in monochromatic light, has been briefly described in a previous article.[1] The same optical parts employed in the preliminary work are now rigidly mounted in a vertical position in my new Solar Laboratory in Pasadena (a branch of the Mount Wilson Observatory). The second mirror of the coelostat, which stands at the summit of a low tower, sends the sun's rays vertically downward to a 30-cm. objective (kindly loaned me by the Yerkes Observatory) which forms a 5-cm. image of the sun on the slit of a spectroscope standing in a well excavated in the earth below the laboratory at the base of the tower. This spectroscope, like the one used for the study of the sun-spot spectra with the large tower telescope on Mount Wilson, has a focal length of 23 meters. It differs from that instrument, however, in having a skeleton tube running from the top to the bottom of the well, which carries at its upper end a reflecting spectroscope of 15 cm. aperture and 4 meters focal length, available for use as a spectrohelioscope or as a spectroheliograph. The oscillating slit-bar which served in the earlier work is still used, but by reducing the amplitude of oscillation to about 6 mm., single slits 0.08 mm. wide at each end of the bar are made to serve instead of the two sets of five slits previously employed. As the bar oscillates, the first slit moves back and forth over a part of the 5-cm. solar image, while the hydrogen line $H\alpha$, in the bright first order spectrum of a very fine plane grating ruled by Jacomini with 600 lines to the millimeter, moves alternately toward red and violet. When the second slit on the bar is set on this line, slit and line move exactly together. Thus the observer, looking with a low-power eyepiece through the rapidly oscillating second slit, sees a portion of the sun (about 6 mm. wide and 12 mm. long) in monochromatic hydrogen light. If the second slit (which with the dispersion employed is narrower than $H\alpha$) is set on the middle of the line, the sun is materially darkened, and the bright and dark flocculi, caused by increased radiation or absorption in various portions of the hydrogen atmosphere, are seen in projection against the disk. Prominences which extend beyond the limb appear dark against the disk and bright against the much less brilliant sky.

In general, therefore, the spectrohelioscope differs in its function from the spectroheliograph chiefly in rendering easily visible the phenomena long since discovered photographically with the latter instrument. Thus its usefulness might seem to be limited to service as a scouting auxiliary of the spectroheliograph or spectrograph. It will soon be evident that this is not the case. In fact, it seems probable that the spectrohelioscope may ultimately prove as generally useful as the spectroheliograph. Some of the reasons for this belief will appear from a glance at various possible applications of the spectrohelioscope in solar research.

Detection of Exceptional Phenomena.—As a guide to the most effective use of the spectrograph and spectroheliograph, the spectrohelioscope should be of great value. The impossibility of seeing against the brilliant photosphere the rapidly changing phenomena of the solar atmosphere has always been a serious obstacle in work with these instruments. A choice of the most interesting regions for study must be made and this can be done far more quickly and effectively by visual than by photographic means. Moreover, if the spectrohelioscope be provided with a device for indicating the exact position of the second slit on the Hα line, the precise setting of the second slit of the spectroheliograph required to show certain bright or dark flocculi moving with considerable radial velocity can be found in a moment. Finally, it is much easier and less expensive to glance at the sun with the spectrohelioscope several times a day, in order to detect the first indications of important phenomena, than to find them by the exposure and development of a long series of photographs.

Observations with Light of Different Wave-Lengths.—One of the most valuable qualities of the spectroheliograph is its power of singling out and recording either bright or dark flocculi moving rapidly in the line of sight. Remarkable effects of this kind were obtained by Ellerman and myself many years ago, by a method which permitted two photographs of the same region of the sun to be taken simultaneously with light from the red and violet sides of Hα, at points equidistant from the center of the line.[2] If it is desired to minimize this separating effect, and thus to obtain photographs integrating in a single image all bright and dark flocculi except the occasional ones moving with great radial velocities, this can be partially accomplished by using the lowest dispersion compatible with good contrast. But the discriminating power of high dispersion is very advantageous, and a method that permits it to be utilized, without the consequent limitations which confinement to one or two slit positions entails, is much to be desired. This is afforded by the spectrohelioscope, because of the extreme ease, while observations are in progress, of moving the second slit back and forth across the Hα line by means of a micrometer screw. Thus the flocculi can be studied in all of their varied aspects, and by moving the second slit beyond the edges of Hα the spots and faculae beneath them can be examined for comparison.

I shall not attempt to describe in this article the many interesting phenomena thus rendered visible, but some of them will be mentioned in the following paragraphs in order to render clear the various uses of the spectrohelioscope.

Chromosphere and Prominences.—By the aid of the electric slow motions of the second mirror of the coelostat, the entire circumference of the sun can be examined in a few moments. As compared with the customary spectroscopic method of observing the chromosphere and prominences with a wide slit, the spectrohelioscope not only permits their connection with phenomena on the disk to be clearly seen, but also offers two other advantages: a wider field of view and the use of strictly monochromatic light. It is frequently true that the hydrogen ($H\alpha$) light from prominences is by no means monochromatic, either because of physical conditions that produce great widening of the line (as in "bombs") or because of marked differences in the radial velocity of their various parts, some of which may be superposed. Thus when the slit of a spectroscope is widened sufficiently to show a prominence such effects are confused in its image, whereas the spectrohelioscope permits them to be separated.

The dark filaments, which have been extensively studied by Deslandres and d'Azambuja with the spectroheliograph and the velocity spectrograph at Meudon and by Evershed and Royds with the spectroheliograph at Kodaikanal, are beautifully shown by the spectrohelioscope. These interesting objects are prominences projected upon the disk, and with the spectrohelioscope I have observed many of them extending far beyond the limb. Some of these reached outward like the slender trunk of a tree, branching near the top. In one case, at a certain setting of the second slit on $H\alpha$, a still narrower dark column was seen superposed on the bright trunk. This was easily distinguished as an effect of absorption, as it disappeared, disclosing the bright hydrogen behind it, when the second slit was moved to a different position on the line. Inclined prominences of this slender type will repay careful study. They make a considerable angle with the solar surface, which could be approximately determined by the aid of stereoscopic photographs and by observations taken during their passage over the limb. In the case just mentioned the trunk of the prominence appeared dark against the disk, where it was best seen when the second slit was shifted from the position which displayed most clearly the outer part of the prominence projecting beyond the limb. The trunk continued across the disk toward a sun-spot group, but spread out into several dark branches before reaching it. On another occasion (February 17, 1926) the slender trunk of a similar prominence at the limb reached a small spot, where its greatly curved extremity plainly showed the absorbing gas entering the associated hydrogen vortex. Eighteen hours later this prominence no longer extended beyond the limb, but was seen as a diffuse object against the disk, greatly reduced in length, as though much of the slender trunk had been drawn into the spot vortex, which was still plainly visible.

Two other types of prominences are long narrow ridges and high arches. Both appear dark on the disk when the second slit is set near the middle of

$H\alpha$, but when it is moved toward the edges of the line the high dark masses are shown to rise from a wider luminous base, different in form and presumably representing the hotter gas at lower levels. I have previously studied such prominences on spectroheliograph plates, and determined their form stereoscopically. But the changes in their appearance seen while moving the second slit back and forth over $H\alpha$ are very illuminating, and suggest that much will be learned of their nature by careful visual observations.

A valuable feature of the spectrohelioscope is its power of rendering visible the spots and faculae (the latter when near the limb) by a quick displacement of the second slit sufficient to throw it off the $H\alpha$ line. Thus their exact position with reference to the hydrogen flocculi in the surrounding atmosphere can be determined. By using a single first slit and two second slits, one of the latter set on the $H\alpha$ line, the other on the continuous spectrum five or six millimeters away, two images of the same region of the sun appear side by side in the field, one showing the spots, the other the hydrogen flocculi. Such a comparison would be useful, for example, in classifying sun-spots by our magnetic method,[3] where it is often necessary to ascertain whether a single spot is followed or preceded by a train of flocculi. If the hydrogen flocculi exhibit any characteristic phenomena prior to the birth of a spot, or in association with the invisible spots described in the article just cited, systematic observations with the spectrohelioscope might reveal them.

Solar Eruptions and Terrestrial Phenomena.—In working with the spectrohelioscope, one is struck with the ease of detecting and observing eruptive phenomena on the disk. When these are violent enough to produce distortions of the $H\alpha$ line, their existence is readily detected with the spectroscope. The spectrohelioscope, however, not only permits their forms and rapid changes to be observed, but also reveals velocity differences too small to produce any perceptible distortion of $H\alpha$. Thus in eruptive regions near the center of the sun the maximum intensity of the bright flocculi usually corresponds with positions of the second slit on the violet side of $H\alpha$, indicating the ascent of the hot hydrogen. At high altitudes the gas cools sufficiently to produce absorption, and the resulting dark flocculi are shown in their descent toward the surface, when the second slit is moved toward the red. The mean velocities are readily determined by recording the exact positions of the second slit on the wide $H\alpha$ line.

The eruptions thus readily detected can also be followed through all their changes with the spectrohelioscope. Usually they are confined to small areas surrounding (for the most part following) the spots of active groups. Occasionally, however, they break out on a tremendous scale, as in a recent instance. On January 24, 1926, while testing the spectrohelioscope between $11^h\ 40^m$ and $12^h\ 15^m$ P.S.T., I observed a bright eruption in and following the great spot-group then visible (latitude about 22° N.). Its form changed rapidly and Hα was so much distorted in places that the rapidly descending dark flocculi could be seen when the second slit was displaced far beyond the line toward the red. On January 25th the eruption, then extraordinarily brilliant, continued throughout the morning and most of the afternoon. The sodium lines D_1 and D_2, and the helium line D_3 were brightly reversed in the large spot. At certain points following the spot D_3 appeared dark and greatly distorted toward the red. The next morning the great eruption seemed to be over, but at noon a small bright eruption was seen for a few minutes on the edge of the bridge in the large spot. On January 27th another small and short-lived eruption was seen near the largest spot. Subsequently I learned from Professor Störmer that he observed at Oslo on the evening of January 26th the brightest (red) aurora he had seen for years.[4] On January 26th the most intense magnetic disturbance in five years was recorded at the Royal Observatory, Greenwich. According to a note in *Nature* for February 6th, "the disturbance commenced at $16^1/_2$ h., rose to a considerable maximum, and subsided soon after 5 h. on the following morning."

Unfortunately, at the time of this eruption the spectrohelioscope was still in the experimental stage, and not suitable for observations of precision. I am convinced, however, that in its perfected form it will afford the best available means of studying the relationship between solar eruptions and terrestrial phenomena. It is well adapted, not merely for the observation of short-lived outbreaks, but also for the rapid measurement of the areas of all dark and bright hydrogen flocculi, including those which escape the spectroheliograph because of their motion in the line of sight.

Vortex Phenomena.—The law of sun-spot polarity, which presumably depends upon the direction of whirl in sun-spot vortices (within the photosphere), has been given in previous articles.[5] A first step in determining the law of storms in the overlying atmosphere of the sun was described in a later paper, in which it was shown that about 80 per cent of the hydrogen vortices above 51 sun-spots corresponded in direction of whirl with terrestrial cyclones and tornadoes.[6] A large number of observations will be required to determine this second law and to interpret the exceptions, and these can be made to advantage with the spectrohelioscope. Slight changes in the position of the second slit are often needed to render visible the vortex structure, and these are easily effected by the observer while examining the vicinity of each spot. The vortices thus far observed visually, like those previously studied on spectroheliograms, are in general harmony with the terrestrial law of storms. This indicates, as shown in the paper last cited, that the direction of whirl in a vortex above a spot may be opposite to that of the spot vortex below. But as Bjerknes has pointed out in a hydrodynamical study of sun-spot vortices soon to appear as one of the Mount Wilson Contributions, there is no objection to this in theory. The possibility of maintaining for some time a right- or left-handed vortex at a water surface by means of a paddle whirling in the opposite direction a few inches below, which I demonstrated experimentally many years ago, is another case in point.

The law of storms in the solar atmosphere may be derived from simple statistical studies, which merely require the direction of whirl in the hydrogen vortices to be recorded. More intimate understanding of these vortices, however, must be based upon observations of their detailed phenomena. An illustration of such observations, showing how the trunk of a long slender prominence, inclined to the solar surface, was apparently (though not certainly) drawn into a hydrogen vortex over a spot, has been given on a previous page. Another class of work for which the spectrohelioscope is especially fitted is the distinction between arched prominences near sun-spot groups and the typical vortex structure with which they may sometimes be confused. Some of these arches may arise from small jet eruptions of the type mentioned above, and the possibility of discriminating clearly between the ascending and descending hydrogen is important.

The hydrogen vortices can also be studied with the spectrohelioscope in cross section at or near the sun's limb. My records already contain some striking cases of this kind, in which small prominences on opposite sides of a spot were found to be moving in opposite directions in the line of sight. Thus on February 26th a small bright "spike" prominence near one side of a spot was visible alone when the second slit was set at the extreme red edge of $H\alpha$, while a similar spike, on the opposite side of the spot, appeared when the slit was moved to the center of the line, where a fainter arch, nearly uniting the two spikes, was also visible. At the extreme violet edge of $H\alpha$ the arch and the first spike had disappeared, and only the second spike persisted. Similar phenomena were observed when the spot reached the west limb on the following day, and the influence of the hydrogen vortex in drawing towards the spot the upper parts of three neighboring prominences was then beautifully seen. Another interesting phenomenon was the appearance near the spot of a small brilliant spike prominence, giving a greatly widened line, so that the spike could be seen when the second slit was well beyond both the red and the violet edges of the dark $H\alpha$ line. This object, because of its small size, brief duration (only a few minutes), and marked widening of $H\alpha$ thus closely corresponds in character with the "bombs" occasionally observed on the sun's disk near active spots in the course of the magnetic records on Mount Wilson.

Observations with Other Lines.—There is, of course, no reason why observations with the spectrohelioscope should be confined to $H\alpha$, though this line shows the most striking phenomena. The hydrogen flocculi have also been seen with $H\beta$, with such differences in general character as I have noted in previous papers.[7] Thus far I have tried only a few other lines, including the D lines of sodium, the *b* lines of magnesium, and a few of iron. The second order of the grating, used with the reflecting spectroscope of 4 m. focal length, serves very well for these lines, but I have also made some promising experiments with the grating at the bottom of the well, used as a Littrow spectroscope with an achromatic objective of 15 cm. aperture and 23 m. focal length: the arrangement primarily designed for the study of spot spectra with high dispersion. At the center of the D and *b* lines a structureless smoky veil appears to be drawn over the spots, obscuring the smaller ones and rendering the larger ones indistinct. But the details of these observations must be reserved for a later paper.

Magnetic and Electric Phenomena.—The spectrohelioscope offers a new means of searching for solar magnetic and electric phenomena. While it is less efficient than a high-dispersion spectroscope for most purposes of this kind, some methods which have suggested themselves may at least be of speculative interest.

Imagine a Zeeman triplet in the spectrum of a spark between the poles of a magnet. If observed along the lines of force, only the two outer components appear. In a spectrohelioscope, with the second slit set on either component, the form of the luminous vapor emitting this line will be seen. As the two components are circularly polarized in opposite directions, either one can be extinguished by means of a quarter-wave plate and Nicol prism. If these are used with a spectrohelioscope, the spark can be seen only when the second slit is set on the visible component.

In sun-spots which are not too near the sun's limb, the outer components of magnetic triplets are elliptically polarized to such a degree that they can be almost completely cut off in the same way. Thus if it were not for the continuous absorption in its spectrum, a spot could be made to appear and disappear by observing it with the second slit of a spectrohelioscope set on one of the outer components of such a spot triplet and rotating a quarter-wave plate above a fixed Nicol. With a fixed compound quarter-wave plate, such as we use in our magnetic observations, spots of north polarity would be seen through one set of strips and those of south polarity through the alternate strips. In practice this method of segregating according to their polarities the many members of complicated spot groups cannot be applied because of the continuous absorption and the wide range in field-strength of the large and small spots. But the method may not be without value.

Theoretically, it could be used to disclose the existence of the general magnetic field of the sun and to render visible the small invisible spots described in a previous article.[8] In both cases no continuous absorption would stand in the way, but the displacements due to the weak field of invisible spots and to the much weaker general field of the sun may be too small for detection. The procedure would obviously be to use the highest possible dispersion (probably the second order spectrum of the Littrow spectroscope of 23 m. focal length) and set the oscillating second slit closely against the edge of a suitable line and slightly overlapping it. A compound quarter-wave plate and Nicol should be mounted over the first slit, and above these a rotating half-wave plate. The presence of the general magnetic field would then be disclosed by a slight periodic darkening of one set of strips, while the intermediate strips would simultaneously become brighter. As for invisible spots, they might appear and disappear as the half-wave plate revolved, because of the local periodic widening of the line. But it is more than doubtful whether such slight effects could actually be seen.

I have not altogether abandoned the search for electric fields in the sun, though both theory and observation give little hope of finding them.[9] The most obvious method is to seek for signs of the Stark effect in suspected regions, by observations of favorable lines (notably Hα) and tests for plane polarization of their edges. In the case of lines asymmetrically affected by electric fields, slight shifts in position might also be found. The spectroheliscope method would be to set the second slit on the edge of a line and note any periodic change in the intensity of the region emitting it caused by the rotation of a half-wave plate above a Nicol. Thus it would be a question, not of detecting a slight change in the width of a line, plane polarized at the edges, but of perceiving periodic changes in the intensity of the object emitting it. In other words, the problem would become a photometric one, and this might conceivably prove to be an advantage. A recent test, made in a slightly different way, of a bright spike prominence showed no apparent change of intensity. But the available polarizing apparatus was not of the best type, and the dispersion was merely that of the 4 m. spectrohelioscope. More adequate tests will be made with high dispersion as soon as circumstances permit.

Laboratory Uses.—The spectrohelioscope should prove of service in the laboratory for the study of arcs, sparks and other light-sources with lines of various types. With low or moderate dispersion, differences in the distribution of the vapors emitting lines corresponding to various degrees of ionization could easily be detected. With high dispersion the regions giving the pole effect or producing pressure displacements or asymmetrical widening could also be examined.

Instruments and Accessories.—Thus far, most of my observations have been made with the oscillating bar, carrying a set of five slits at each end, which was used in the preliminary experiments two years ago. At first five slits or three slits were employed, but I now prefer to cover all but the central slits, though the increased brightening toward the edges of the field, caused by the effect of the reciprocating motion, is more conspicuous in this case. When using an amplitude of five or six millimeters, and cutting out the edges of the field with a suitable diaphragm, single slits give very satisfactory images and are much better adapted than multiple slits for work of precision, because of the disturbing effect of any slight errors of spacing. In the apparatus now under construction the oscillating bar will be replaced by either one of two disks, mounted on carefully made bearings and provided with improved motor connections. One of these disks, carrying several pairs of slits for special purposes mounted along different diameters, is designed for oscillation through amplitudes which will depend upon the brightness of the phenomena under observation and the dispersion and slit-width employed. The other disk, carrying 180 slits accurately spaced on diameters two degrees apart, will be used while in rapid rotation. If sufficiently well made, this rotating disk should give images free from flicker and uniformly bright from edge to edge. In the reflecting spectroscope of 4 m. focal length, with which these disks will generally be employed, the lines of the spectrum are slightly inclined. I have, therefore, devised a simple optical arrangement to bring them strictly into coincidence with the radial slits. An index showing at a glance the exact position of the second slit on Hα will also be provided. Another device will permit the forms of the flocculi corresponding to settings of the second slit on opposite sides of Hα to be compared (as in the "blink" microscope of a stereocomparator). Finally, it is hoped that it may ultimately prove possible to record all of the observed phenomena photographically.

Among the accessories provided to facilitate the use of the spectrohelioscope is a magnetoscope, showing variations in the horizontal component of the earth's field caused by solar phenomena, and a glass plate ruled with small squares, to be mounted just below the oscillating slit and used for measuring the areas and positions of bright or dark flocculi. A hydrogen vacuum tube, giving a sharp and narrow Hα line, is employed in determining the exact setting of the second slit corresponding to the true center of the lime.

A 5-cm. solar image is well adapted for most classes of work, but I have made a few observations under good conditions with a 15-cm. image,[10] in which I could see the finer structure of the vortices not visible in the small image with the eyepiece generally employed. This (positive) eyepiece, which magnifies about $2^1/_2$ diameters, is mounted in the binocular attachment of my Spencer microscope, an arrangement greatly superior, for my eyes, to monocular vision. As for the necessary dispersion, I have already tested a shorter focus spectroscope, in addition to the spectroscopes of 4 m. and 23 m. focal length. This consists of the optical parts of the old Kenwood spectroheliograph, mounted in the spectroscope well beneath the oscillating bar. I am indebted to Professor Frost for the loan of the two objectives which belong to the Yerkes Observatory. They have an aperture of 83 mm. and a focal length of 108 cm. The Rowland grating was used in the bright second order. Here the dark Hα line was narrower than the second slit, which was 0.08 mm. in width. Nevertheless the dark flocculi on the sun's disk were easily seen. I am, therefore, in hopes that small prominence spectroscopes, if provided with narrow oscillating slits, will ultimately permit most of the phenomena described in this paper to be observed by amateur astronomers.

[1] These PROCEEDINGS, **10**, 361–363, 1924.

[2] See Annual Reports of the Director of the Mount Wilson Observatory for 1910 and 1911. The Hα line widens towards the base of the chromosphere, so that to eliminate differences in form due to differences in level, the two second slits should be exactly equidistant from the center of the line.

[3] Hale and Nicholson, "The Law of Sun-Spot Polarity," *Mount Wilson Contributions*, No. **300**; *Astrophysical Journal*, **62**, 270–300, 1925.

[4] Miss Mary Proctor has since told me that she saw this brilliant aurora from a steamer in the North Atlantic.

[5] These PROCEEDINGS, **10**, 53–55, 1924; also presented in greater detail in *Mount Wilson Contributions*, No. **300**; *Astrophysical Journal*, **62**, 270–300, 1925.

[6] These PROCEEDINGS, **11**, 691–696, 1925.

[7] See, for example, "Solar Vortices," *Mount Wilson Contributions*, No. **26**; *Astrophysical Journal*, **28**, 100–115, 1908.

[8] These PROCEEDINGS, **8**, 168–170, 1922.

[9] Hale and Babcock, "An Attempt to Measure the Free Electricity in the Sun's Atmosphere," these PROCEEDINGS, **1**, 15–19, 1915.

[10] My new tower telescope is so constructed that by employing a 46-cm. concave mirror of pyrex glass in conjunction with either one of two convex quartz mirrors, I can obtain a 15-cm. or a 42-cm. solar image.

CAPILLARY CONDENSATION AND ADSORPTION

BY WILLIAM C. BRAY AND HAL D. DRAPER

DEPARTMENT OF CHEMISTRY, UNIVERSITY OF CALIFORNIA

Read before the Academy April 26, 1926

Sorption isotherms for water vapor on certain partially hydrated oxides in the form of porous granules have been found to be of the type shown in figure 1*A*. The adsorbents were the catalysts of Series 2 of Almquist and Bray,[1] and consisted of copper oxide, manganese dioxide and mixtures of these oxides. Weighed samples were evacuated for several hours at 200°, and the isotherms at 25° were determined by adding and withdrawing quantities of water measured as a gas at 45°. The data for copper oxide, corresponding to figure 1*A*, are shown in table 1, and those for one of the mixtures in table 2. In each case the data are arranged in the order in