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NO. 7.

THE FIVE-FOOT SPECTROHELIOGRAPH OF THE SOLAR OBSERVATORY

BY

GEORGE E. HALE AND FERDINAND ELLERMAN

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By GEORGE E. HALE and FERDINAND ELLERMAN

In a recent paper[1] we have described the spectroheliograph designed for use with the 40-inch Yerkes refractor. As stated in this paper, the most satisfactory form of spectroheliograph is that in which the instrument is moved as a whole, while the image of the Sun and the photographic plate are stationary. The first spectroheliograph of this type was constructed in 1893, from Mr. Hale's general design, by Toepfer, of Potsdam, and employed in some attempts to photograph the solar corona without an eclipse, from the summit of Mount Etna.[2] In the case of the Rumford spectroheliograph, it was necessary to produce the motion of the Sun's image across the first slit by driving the telescope tube at a uniform rate in declination, the photographic plate being moved at the same time across the second slit. From a mechanical point of view, such an instrument is not an entirely satisfactory one, but the Rumford spectroheliograph has nevertheless given good photographs, some of which are reproduced in our paper.

As soon as arrangements had been made to erect the Snow telescope on Mount Wilson, it became possible to design, for use with it, a spectroheliograph of the type employed on Mount Etna. We were fortunate in having the assistance of Professor Ritchey and Mr. Pease, whose skill in working out the details of construction has been demonstrated by the very satisfactory operation of the instrument.

A photograph of the spectroheliograph, mounted for use with the Snow telescope, is reproduced in Plate XI. A better idea of the general design may be obtained from Plate XII, which shows the spectroheliograph in our instrument shop before it was completed. It consists essentially of a massive cast-iron base, bearing four short Λ-rails at its four corners, on which the moving part of the instrument

[1] "The Rumford Spectroheliograph of the Yerkes Observatory," *Publications of the Yerkes Observatory*, 3, Part 1.

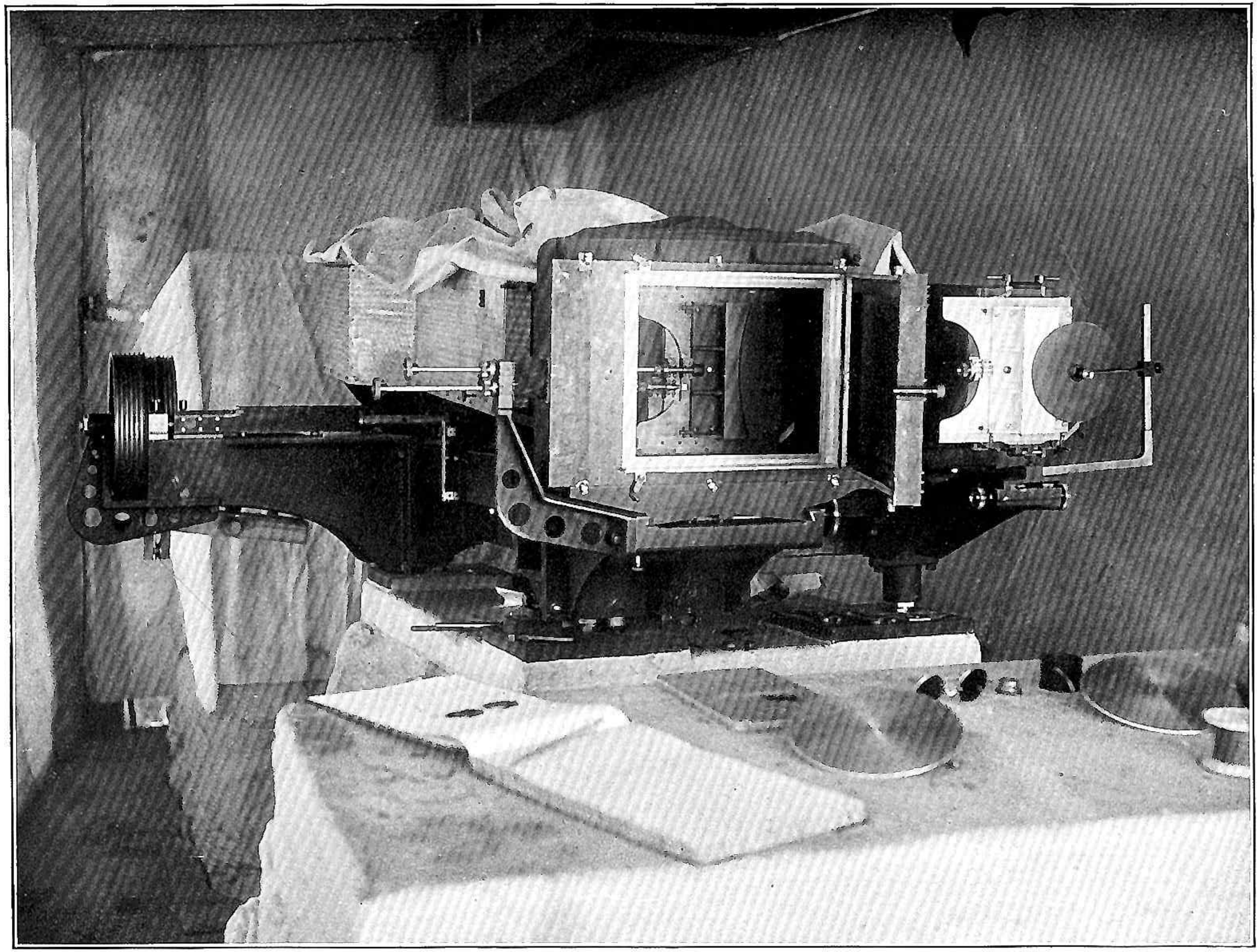
[2] *Astronomy and Astro-Physics*, 13, 662, 1894.

is carried by four steel balls. The cast-iron platform which bears the slits and optical parts has four inverted Λ-rails which rest on the steel balls, but almost its entire weight is supported by mercury, in three tanks formed by subdivisions in the base casting. Wooden floats extend from the lower surface of the iron platform into these tanks, reducing to a minimum the amount of mercury (about 560 lbs. = 254 kg) required to bear the instrument. The motion of this platform with respect to the fixed solar image and photographic plate is produced by either one of two screws of different pitch, driven by an electric motor arranged to give wide variation in speed.

Slits.—The first and second slits represent marked improvements over the slits employed in the Rumford spectroheliograph. They are each 8½ inches (21.6 cm) long; one jaw is fixed, and the other can be moved by a micrometer screw. The second slit can also be moved as a whole across the end of the camera, so as to permit it to be set accurately upon any spectral line after this has been brought near the center of the field by rotating a mirror in the optical train. Both slits are of very massive construction, so as to reduce the danger of flexure. The jaws are heavy castings of bronze, and the guides, in which one jaw of each pair slides, are very accurately made. The slits are so mounted that they can be rotated in their own plane by a screw, thus permitting the first slit to be placed parallel to the refracting edge of the prisms, and the second slit to be made parallel to the spectral lines. The iron castings which carry the slits can be easily removed from the collimator and camera tubes, when it is desired to substitute other slits of different curvature. The clamping screws, and the stops which determine the position angle of the slits, are so constructed that they can be released in a moment, while they define the position of the slits so accurately that no change in adjustment is required when the slits are returned to their places. The collection of slits already provided for the spectroheliograph includes one straight slit and five slits of different curvatures, required for use with either two or four prisms and for different spectral lines. Additional curved slits are constructed as the need for them arises.

The method of correcting the distortion of the solar image, which arises from the use of a straight first slit and a curved second slit

PLATE XI



The Five-Foot Spectroheliograph Mounted for use with the Snow Telescope is the same as that employed in the Rumford spectroheliograph: the curvature is equally divided between the first and second slits, in accordance with a suggestion made by Wadsworth some years ago. It must be borne in mind that this method is effectual only in cases where an odd number of reflections occur in the optical train (see p. 58).

It is important that the second slit should be provided with means of varying its width and changing its position when the photographic plate is in place. For example, it may be desired to make a series of photographs of the flocculi surrounding a sun-spot, corresponding to different widths of the second slit and to different positions of this slit on the H_1 band. For this purpose, as Plate XI shows, the micrometer screws are provided with extension rods, which can be turned from outside the light-tight box that incloses the plate-holder. These extension rods are furnished with micrometer heads, so that the exact position and width of the slit can be read without opening the box.

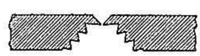


FIG. 1.—Section of Second Slit-Jaws

The jaws of the first slit are silver-plated, and when the instrument is in use a light screen of aluminium, pierced by a long narrow window, is mounted a short distance in front of this slit. Without these precautions, as our experience with the Rumford spectroheliograph showed, the heating of the jaws by the large solar image, 6.7 inches (17 cm) in diameter, would cause them to close by expansion during a long exposure.

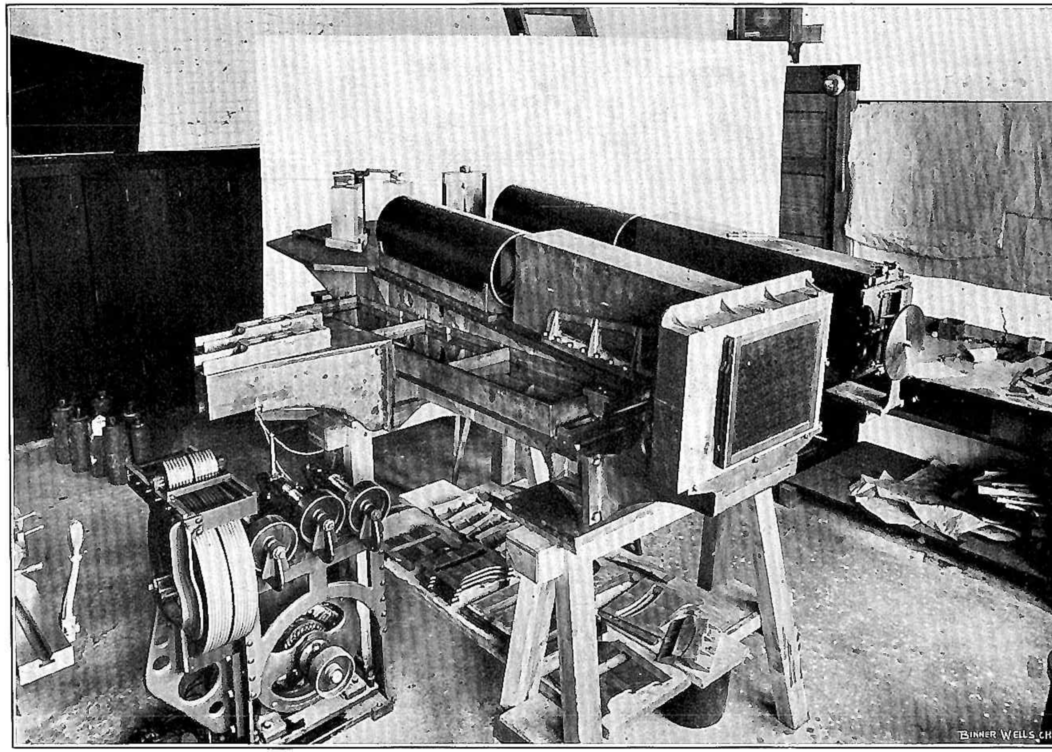
When the jaws of the second slit are of the ordinary form (beveled on the side away from the photographic plate), there is a possibility, as Mr. Evershed has suggested, that light falling on the beveled surfaces may be reflected through the jaws to the plate. In some experiments made during the past summer with a temporary spectroheliograph, the beveled surfaces were turned toward the photographic plate, to eliminate such reflections. In the present instrument a different plan has been adopted. As shown in Fig. 1, which represents the jaws in section, the lower (dead-black) surface is so formed in steps as to eliminate any possibility of appreciable reflection. In work with narrow dark lines, it is very important that all light be excluded from the plate except that which is due to the line itself. Under such circumstances the above precaution may prove of some value.

To cut off the light from the Sun's disk during an exposure on the chromosphere and prominences, circular metallic screens are provided, and mounted on an adjustable support, as shown in Plate XI. Several of these screens, corresponding to different diameters of the solar image, are available.

In order to give an accurate and rapid means of focusing the solar image on the first slit, a disk can be mounted in front of the slit, as shown in Plate XII. The support that carries this disk can be moved by a rack and pinion, and is provided with a millimeter scale, which defines its position with reference to a fixed mark. A piece of fine white cardboard is mounted on the disk, which is set in rapid rotation. By racking the whirling disk back and forth, the Sun's image (seen through dark glasses) can be very accurately focused on the white surface, which does not show such inequalities of texture as trouble the eye when an image is examined on a stationary surface. When a satisfactory focus is secured, the position of the disk is read on the millimeter scale. The distance from the zero position gives a correction by which the concave mirror of the Snow telescope can be set, with the aid of a millimeter scale attached to the rails on which it slides, so as to bring the solar image exactly in focus on the slit-jaws.

Optical parts.—The collimator and camera objectives, which are of the portrait lens type, were made by the John A. Brashear Co. Their aperture is 8 inches (20.3 cm.), their focal length five feet (152 cm). They seem to meet our specifications in every particular, including sharpness of definition, flatness of field, and equality of focal length. They can be focused from the eye-end, by milled heads, provided with micrometer scales (not visible in the photograph). The tubes, of rectangular section, which unite the first and second slits with the collimator and camera objectives, are provided with a very complete system of diaphragms, which seem to do away with all difficulty from diffuse and reflected light. The tubes of the portrait lenses themselves are also lined with diaphragms, which must

PLATE XII



THE FIVE-FOOT SPECTROHELIOGRAPH WHEN UNDER CONSTRUCTION be numerous in order to prevent reflection of light from the ends of the long slits.

On account of the desirability of being able to suit the dispersion employed to the work in hand, the prism-train is so designed that either one, two, three, or four prisms may be used. The prisms are of Jena glass, No. O.102, with faces $8\frac{1}{4}$ inches (21 cm) high and $4\frac{15}{16}$ inches (12.5 cm) wide. The angle of each prism is 63° 29′. The arrangement of prisms and mirrors ordinarily employed for work with the calcium lines is shown in Fig. 2. When it is desired to obtain a circular image of the Sun, two slits of equal and opposite curvature are used, and the prism-train is arranged to work with one mirror, as indicated by the solid lines in the figure. In this case, as shown by Newall, each point in the solar image will be drawn out

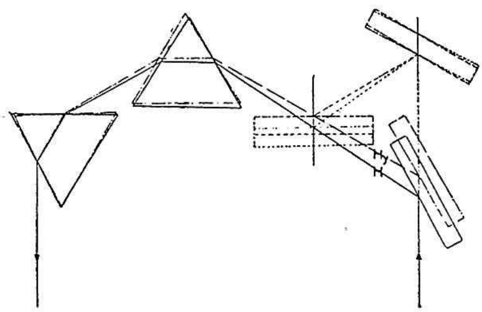


FIG. 2.—Arrangement for Calcium Lines

in the direction of dispersion into a short line. Under ordinary circumstances the slits are so narrow that the distortion resulting from this cause is entirely negligible. It sometimes happens, however, that important advantages may result (in the case of the H and K lines) from the use of slits so wide that this distortion would be injurious. In such a case, a straight first slit is used with a highly curved second slit, and two mirrors are introduced into the optical train, as shown by the dotted lines. The solar image as a whole will then be distorted, but all of the points in the image will be sharp and well defined. The use of wide slits tends to decrease the contrast, but during the past summer we have obtained excellent photographs of the calcium flocculi and prominences with wide slits, which greatly reduce the exposure time.

In order to bring any part of the spectrum upon the second slit, a mirror immediately in front of the collimator objective can be rotated from the eye-end, by means of a tangent screw. As mentioned above, the final adjustment of the line is made by moving the second slit as a whole. The two prisms are provided with a minimum deviation device, so that they may be brought at once to the position of minimum deviation for any line by setting a pointer at the corresponding reading on a scale. The mirrors may be moved parallel to the optical axis of the collimator, so as to make the light central on the prisms. The position of each mirror is given by a pointer

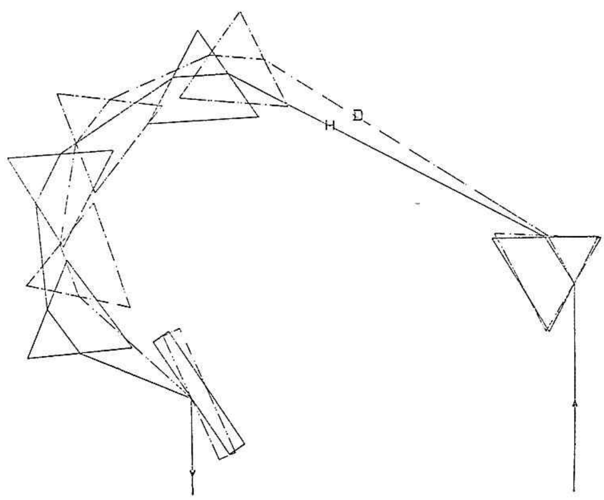


FIG. 3.—Arrangement with Four Prisms

moving over a millimeter scale. When four prisms are used, the arrangement of the train is as shown in Fig. 3. In this case two mirrors cannot be employed, but they are not needed, since the narrow dark lines used with high dispersion require the use of narrow slits.

Plate-carrier.—As shown in Plate XI, the photographic plate-holder is carried in a light box of cast aluminium, in close contact with the second slit. After the plate-holder has been inserted, the hinged aluminium cover of the box is closed and the slide drawn through a door on the side away from the first slit. This door is then closed and the entire plate-carrier moved forward by rack and pinion until a conical pin (seen in Plate XI under the iron bracket) drops into a hole in the casting on which the plate-carrier is mounted. In this position the film is almost in contact with the jaws of the second slit.

The plate-carrier is connected with the moving part of the spectroheliograph by a flexible bag, which effectually excludes the light from the plate.

When it is desired to replace the second slit with one of different curvature, the aluminium box can be removed in a moment, by turning the six buttons visible in the photograph.

The driving mechanism.—The moving platform that carries the slits and optical parts of the spectroheliograph is mounted, as already stated, on four steel balls, one inch (2.5 cm) in diameter, running in V-rails. The V's are made of hardened steel, and are ground perfectly true and parallel. As the total weight of the moving parts is approximately 1400 lbs. (636 kg), the system of mercury flotation already referred to was provided to decrease the friction on the steel balls. The result has been extremely satisfactory, the instrument moving with an ease that is surprising when its great weight is considered.

The motion of the platform is produced by either one of two screws, mounted on a strong cast-iron bracket bolted to the iron base. Both screws have hardened and ground end-thrust bearings. The finer screw is of 18 pitch, while the coarser screw, with double thread, is of 3 pitch. The long nuts are split on one side, and can thus be adjusted to take up wear. They are held between the arms of stiff bronze forks, which are connected with the moving platform by steel shafts. The shafts slide freely through cast-iron sleeves bolted to the moving platform. By inserting a conical steel pin, which passes through the sleeve and the shaft, either screw can be made to drive the platform. If neither of the two shafts is fastened to the platform, the instrument can be freely moved across the solar image by hand.

The 1 H.-P. Westinghouse direct-current motor which furnishes the motive power is mounted in a cast-iron frame, shown at the left in Plate XII. By shifting the belt of the motor, any one of three worm gears may be driven by it. Thus either of the screws that move the spectroheliograph may be driven at speeds ranging from 3 to 36 revolutions per minute. The motion is transmitted from the pulleys on the worm-gear shaft to the corresponding pulleys on the heads of the two screws by means of a series of small round belts. Braided fish-line has been found to give more satisfactory results than round leather belting. A single belt of fish-line is sufficient to drive the platform at the highest speed. In practice, however, seven belts of fish-line will be used on each pulley. The driving mechanism is mounted on a pier at some distance below the spectroheliograph,[1] and by moving the idler pulleys shown above the large driving pulleys in Plate XII, the belts corresponding to either the fine-pitch or coarse-pitch screw may be tightened, thus bringing either screw into use.

Current is supplied from a storage battery of 26 cells. The results of the preliminary work indicate that the motion will be very smooth and uniform when all the adjustments have been perfected.

The principal advantages of the new instrument over the Rumford spectroheliograph are: the larger aperture of the collimating and camera objectives, obviating loss of light at the Sun's limb; the possibility of photographing the entire disk with high dispersion; the ease of attaching slits of different curvatures; the possibility of using from one to four prisms, and either one or two mirrors in the optical train; the wide range of speed afforded by the driving mechanism; the elimination of the danger of distortion arising from imperfect synchronism in the motion of solar image and plate; and the ease of manipulation due to the general design and the improvement of details.

RESULTS

The new spectroheliograph, which has been in regular use since October 10, has already yielded some interesting results. On account of the high dispersion of the prisms, and the considerable focal length of the collimator and camera objectives, the $H\delta$ line and the line λ 4045 have been successfully used with two prisms in photographing the hydrogen and iron flocculi. Three photographs of the same region of the Sun, made on November 18, 1905, in quick succession, with the lines λ 4045, H_1 and $H\delta$, are reproduced in Plate XIII. At that time a straight first slit and curved second slit were in use,

[1] In the preliminary work the driving mechanism has been used on a pier north of the spectroheliograph.

PLATE XIII

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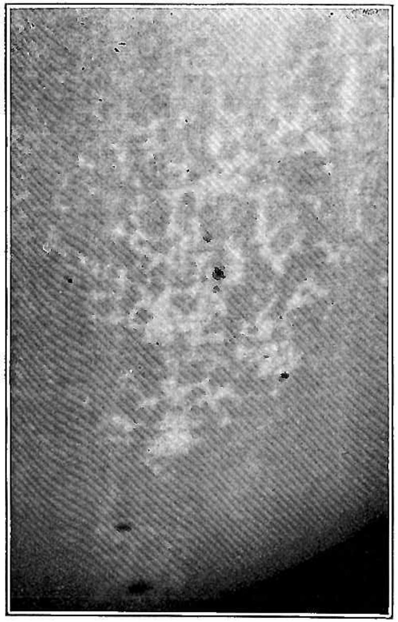

FIG. 1.—Iron Flocculi
Slit set on $\lambda 4045$

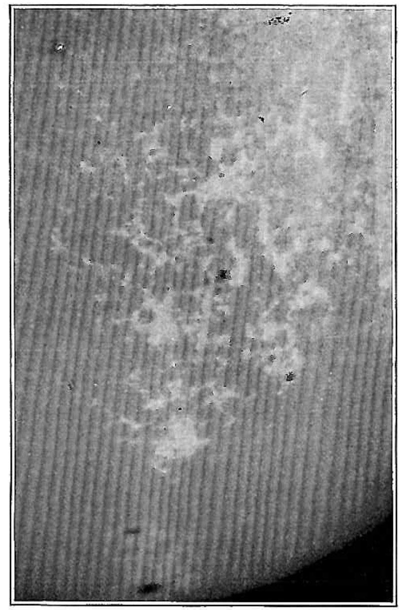

FIG. 2.—Low-Level Calcium, Flocculi
Slit set on H_1.

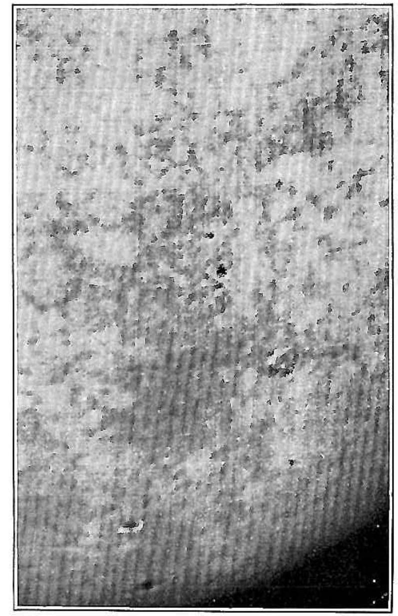

FIG. 3.—Hydrogen Flocculi
Slit set on $H\delta$

N

and consequently the solar image is distorted. Since the distortion is the same in all three photographs, however, they are strictly comparable with one another. It will be seen that the iron flocculi agree very closely in form with the low-level calcium flocculi. Further remarks on this subject are reserved for a future paper, which will contain the results of comparisons of iron and calcium flocculi now being made with a Zeiss stereocomparator. At present we wish to call attention to the photograph of the hydrogen flocculi, which presents some interesting features.

It will be noticed, in the first place, that the photograph confirms our results obtained with the Rumford spectroheliograph, in showing that most of the hydrogen flocculi are dark, as distinguished from the bright flocculi of calcium and iron. It will also be seen that these dark flocculi correspond roughly in form with the bright flocculi of calcium and iron, though they show certain important divergences. For example, dark flocculi may be found on the hydrogen photograph at points where no bright flocculi appear on the other plates. The H_2 (higher-level) calcium photograph, taken at the same time, also fails to show flocculi at some of these points. These differences in the distribution of hydrogen and calcium in the solar atmosphere will warrant much careful study in the future.

The most interesting feature of the hydrogen photographs, however, which was indicated to a certain extent on some of the plates taken with the Rumford spectroheliograph, is the presence of narrow bright rings, partially or completely encircling certain sun-spots. Fig. 2, Plate XIII, in our paper on the Rumford spectroheliograph, shows a neutral region in the calcium flocculi surrounding the sun-spot; for it cannot be said that this region is materially brighter or darker than the general disk of the Sun in this photograph. In our present plates, however, as may be seen from Fig. 3, Plate XIII (if the reproduction is successful), this region is in some cases distinctly brighter than the general background.

Such rings should be distinguished from the bright eruptive phenomena also frequently shown on hydrogen photographs. The bright eruptions change rapidly in form, whereas these bright rings, which are usually much less brilliant than the eruptions, do not change materially in the course of several hours. They may probably be taken to indicate the existence of comparatively hot regions in the chromosphere closely encircling certain spots. It will be a matter of great interest to study such regions in connection with other phenomena, such as the radial motion of the calcium vapor, and the intensity of radiation as measured with the bolometer. We have already convinced ourselves that the bright rings are due to hydrogen, and are not caused by any effect on the plate of light from the continuous spectrum of underlying faculæ. Indeed, the faculæ are sometimes faint or absent at the very points where the hydrogen rings are brightest.

Mount Wilson, California,
December 1905.