The Measurement of Solar Photographs made with the Spectroheliograph.

By George E. Hale.

Papers on monochromatic solar photography have devoted much attention to methods of photographing the sun, but comparatively little to the reduction of the results. It goes without saying that the value of the plates depends upon the means they afford of increasing our knowledge of the sun, and that much attention should be devoted to their measurement and discussion. In the present paper only two phases of this extensive subject will be touched upon: (1) the determination of the heliographic coördinates of the flocculi, with special reference to the problem of the solar rotation; (2) the measurement of the areas of the flocculi, to provide a new index to the solar activity.

Heliographic Positions of the Flocculi.

The method ordinarily employed to determine the latitude and longitude of sun-spots involves the measurement of their position angle and their distance from the centre of the sun, together with a simple computation, facilitated by the use of tables. In the reduction of direct photographs, like those of the Greenwich series, this method has been satisfactorily used for many years. Photographs of the flocculi, however, show such a very large number of points suitable for measurement that the expense of the computations becomes a serious matter. For this reason a simple device for obtaining the heliographic coördinates without computation was brought into use at the Yerkes Observatory, where it was first applied to the measurement of the calcium flocculi photographed with the Kenwood
spectroheliograph. Without giving the details of the process, which will be described elsewhere, it suffices to say that the solar photographs are projected optically upon the surface of a globe, ruled with meridians and parallels one degree apart. When the axis of the globe is fixed at an angle determined by the date of the photograph, the latitude and longitude of the flocculi selected for measurement may be estimated (to the nearest tenth of a degree) with reference to the meridians and parallels of the globe. An important requirement is that the angular diameter of the globe, as viewed from the projecting lens, must be equal to the angular diameter of the sun for the date in question.

This simple method gave excellent results in the reduction of the Kenwood plates, and is now regularly used by Fox for the measurement of photographs made with the Rumford spectroheliograph. It is also in daily use, in the modified form represented by the "heliomicrometer," at the Mount Wilson Solar Observatory. In this instrument, designed to give results of the highest precision, the globe and plate are observed with two 4 inch telescopes, the images being superposed in a single eyepiece. Settings on a flocculus are made with the aid of cross-wires, mounted immediately in front of the plate, and moved vertically or horizontally by the observer at the eye-piece. While setting on the flocculus, light from the illuminated surface of the globe is excluded by a swinging screen, controlled by a cord, which exposes the object-glass of one telescope, and covers the other. As soon as the wires have been set on the flocculus, the globe is brought into view. It is then only necessary to estimate the position of the cross-wires with reference to the nearest meridian and parallel.

On account of the large proper motions of the flocculi, longitudes obtained in this way are sufficiently accurate for the determination of the solar rotation. If, however, a greater degree of precision is required, it may be ob-
tained by providing the globe with graduated circles, one for latitudes, the other for longitudes, in lieu of meridians and parallels ruled on its surface. After the cross-wires have been set on the flocculus, the globe is turned by the observer at the eye-piece until a small black dot, at the point of intersection of the equator and central meridian, coincides with the wires. One circle then gives the latitude of the flocculus, the other its distance in longitude from the centre of the sun.\textsuperscript{1} The instrument in use at the Solar Observatory is so constructed that it can be used in either of the two ways described above.

In selecting flocculi suitable for the determination of the solar rotation, only those should be chosen which undergo very slight change in form from day to day. If the time interval between two successive photographs is too great, the identification of the point to be measured may be uncertain. In our studies of the motions of the flocculi preference is given to negatives obtained during the summer season, partly because the definition is better at that time and also on account of the long periods of unbroken clear weather, permitting many plates to be obtained on successive days. Large flocculi are liable to great change of form. For this reason we almost invariably select such small isolated flocculi as persist without much change of form, from three to six days. As many as eighty flocculi suitable for measurement may frequently be found on a single plate. It is important that they should be well distributed in latitude, so as to give the greatest possible uniformity in weight to the results for the different zones. A large number of points is also needed, to smooth out the effects of proper motion.

The heliomicrometer offers a very satisfactory means of selecting flocculi for measurement. Two negatives, corresponding to successive days, are mounted in the instrument,

one in the ordinary position, the other immediately in front of the globe. Both are illuminated by electric light, and observed with the eye-piece common to the two telescopes. It is usually best to arrange the occulting screen as in the case of measurement with the globe, i.e., so as to permit the same flocculus on the two plates to be observed in quick succession by pulling a cord. In this way the flocculi which undergo least change of form may readily be picked out.

In the solar rotation work now in progress Fox, at the Yerkes Observatory, is giving special attention to the larger calcium (H₂) flocculi, while at Pasadena we are measuring the smaller H₂ flocculi, and are about to take up a systematic study of the motions of the hydrogen (Hγ) flocculi. The latter offer special difficulties, on account of their lack of contrast and their rapid change of form. It is frequently impossible on account of the difficulties of identification, to measure a very large number of these objects on a single plate. For this and other reasons it is greatly to be desired that at least one other observatory should systematically photograph and measure the hydrogen flocculi.

Areas of the Flocculi.

In many comparative studies of solar and terrestrial phenomena, a numerical measure of the sun's activity is required. Such a measure is equally essential for the interpretation of various classes of solar phenomena. For example, if it is found that the solar "constant" of radiation is not constant, but undergoes irregular or periodic changes, it is important to learn whether manifestations of the sun's activity show similar fluctuations.

Hitherto the principal quantities whose variations have been studied are the mean number of sun-spots or prominences, or the areas of the spots or faculae. Another index to the state of the sun should be given by the areas of the flocculi, as recorded on spectroheliograph plates.
The remarks in the present paper are confined to the calcium flocculi photographed with the \( H_2 \) or \( K_2 \) lines. The study of the flocculi which appear on plates made with the \( H_1 \) line of calcium, the \( H_\gamma \) line of hydrogen, etc., will be discussed in a subsequent paper, though the methods here described may be applied, with little or no modification, in some of these cases.

The problem, then, is to determine the areas of the flocculi, both as a measure of the solar activity, and in such a way as to bring out irregular or periodic changes in the heliographic latitude and longitude of these objects. On examining a good photograph of the calcium flocculi, one is immediately impressed with the wide range in size and brightness of these objects. The smallest flocculi hitherto photographed are less than one second of arc (geo-centric) in diameter; the largest ones consist of groups covering immense areas of the sun's disk. The range in brightness is no less striking. Eruptive regions are characterised by flocculi of dazzling brilliancy, while the faintest objects are barely distinguishable from the background on which they lie. Since it is manifestly impossible to measure the areas of all the flocculi, the difficulty of selecting objects suitable for measurement presents itself at the very outset.

As compared with the faculæ shown on direct photographs of the sun, the calcium flocculi offer two principal points of difference: they are far more numerous and they may be equally well seen in all parts of the disk. The faculæ are well shown only in the neighbourhood or the limb, and fade into invisibility as they approach the central meridian. Their areas must therefore be measured under the most unfavourable conditions, in a region where the effect of fore-shortening is very marked. The gradual manner in which they become invisible, after being carried by the sun's rotation out of this region, renders it extremely difficult to select objects for measurement.

The flocculi, on the other hand, may be measured in the
central part of the sun, where errors due to foreshortening are of no importance. The choice of objects for measurement, however, is not facilitated by this fact; on the contrary, the great diversity in the size and brightness of the flocculi renders selection quite as difficult as in the case of the faculae. Variations in the density and contrast of the negatives are further complications, to which may be added the effect of bad "seeing," which blurs the image, reducing the contrast of the larger flocculi, and causing the smaller ones to disappear.

In my first studies of this problem, I felt that the brightness of the flocculi, as well as their area, might be considered to have a bearing on the solar activity, and should therefore be taken into account in the measures. A photometric method was thus suggested. On account of the great variation in the density of the photographs, it was also believed that the effect of the background should be eliminated. An instrument was accordingly constructed in which both of these conditions were met. A set of three photometric measurements, made by a process which need not be described here, gave data from which a quantity proportional to the amount of light transmitted by a given region of the negative, after eliminating the background, could be computed. The background necessarily included all of the smaller flocculi rejected in the process of selection employed. Unfortunately, the quantities thus determined were so small that they could not be depended upon to bring out the much smaller effects due to variations in area or brightness.

It therefore seemed necessary to fall back upon a less rigorous method in which the brightness of the flocculi is not taken into account in the measures, though it still affects, quite as much as before, the selection of these objects. The photometric apparatus for determining their areas is retained, and applied as follows: Each of the original negatives chosen for measurement shows a solar image, about 6.7 inches (17 cm.) in diameter, photographed
with the calcium line \( \text{H}_2 \).* One of these negatives is first placed in the heliomicrometer, and the intersections of the meridians and parallels ten degrees apart on the globe are marked by ink dots on a sheet of glass held in contact with the negative. The central region of the image is thus divided into a series of areas, each ten degrees on a side, extending north and south of the equator to latitude 40°, and east and west to meridians differing 40° in longitude from the central meridian. In this way the measurements are restricted to the central part of the sun, where the effect of foreshortening is least.

The next step is to select the flocculi for measurement. This is, of course, an arbitrary process, in which the experience of the observer counts for much. A glass plate is placed in contact with the negative, and the brighter and larger flocculi are selected, one by one, for measurement. Each flocculus, as soon as selected, is painted out on the glass with a small camel’s hair brush dipped in black paint. Thus the area of each flocculus is matched by that of an opaque black region on the glass plate. Blue prints of the plates thus marked are preserved for reference. The sum of the areas of the selected flocculi in each ten degree region is measured with a simple photometric apparatus, which gives the ratio of the light transmitted by a marked region to that transmitted by clear glass. The sum of the areas included in all of the squares serves as a measure of the solar activity for the date. The mean value for an entire rotation period is the quantity adopted for comparison with the records of terrestrial magnetism, etc.

The process here described has been used, by Miss Smith, at the Solar Observatory for the past year, with results which may be regarded as fairly satisfactory. The same plate, when marked and measured quite independently

* These photographs are taken with the Snow telescope and the 5-foot spectroheliograph of the Mount Wilson Solar Observatory.
at different times, gives results which sometimes differ as much as 10 per cent. for the total area. Such differences appear large, but I am told that the results nevertheless compare very favourably with those obtained at Greenwich for the spots and faculae. Moreover, since the quantities to be compared with the magnetic records will be mean values, sometimes representing as many as twenty-five plates, the precision of the results should prove to be sufficient. While I am still endeavouring to find a better means of selecting the flocculi for measurement, I nevertheless believe that the total area of the flocculi, as now measured, will be of value, especially in the correlation of solar and terrestrial phenomena.