OBSERVATIONS OF INTENSITY WITH A SPECTROHELIOSCOPE.

R. v. d. R. Woolley and H. W. Newton.

(Communicated by the Astronomer Royal)

1. This paper describes auxiliary apparatus attached to the Hale spectrohelioscope at Greenwich by means of which it is possible to measure the light intensity of bright flocculi and prominences. The intensities of flocculi are referred to the intensity of the undisturbed solar disc at the same distance from the Sun's centre as the flocculus, and the intensities of prominences are referred to the intensity at the centre of the solar disc, in both cases in wave-lengths outside the absorption line $H\alpha$ or $H\beta$. Intensities of both flocculi and prominences can accordingly be made absolute if the solar constant and solar energy curve are known. The paper also presents the results of observations made at the Royal Observatory, Greenwich, during the period 1934 August to 1935 October. During the winter months observations of this nature are rarely possible at Greenwich.

The auxiliary apparatus is set up as follows (fig. 1). A motor-headlight filament lamp (12 v., 60 w.) is placed off the axis of the spectrohelioscope, at A in the plan. A prism C placed immediately below the main spectrohelioscope beam reflects the light from A on to the upper mirror D. This beam is dispersed by the grating E, and passes on to the lower mirror F which reflects light of the same wave-length as that in which the Sun is viewed in the spectrohelioscope. This reflected beam passes immediately above the line-shifter G and into the eyepiece H. The observer sees a small part of the spectrum of the lamp (drawn out into a band by the rotating prisms of the spectrohelioscope) immediately above the field containing that part of the solar surface which is under examination. A stop behind the first slit considerably reduces the amount of scattered light and also limits the field of view to a strip about equal in extent to that of the comparison band. An optical wedge is inserted at B, and the brightness of the lamp spectrum seen at H can be altered by adjusting this wedge. An object on the Sun—flocculus, prominence or part of the undisturbed disc—can accordingly be matched with the lamp. Observations comparing the brightness of two objects viewed in the *same* wave-length have previously been made at Greenwich simply by moving a wedge over the brighter until a match is obtained; but with the present apparatus a comparison between two objects viewed in slightly *different* wave-lengths can be made by using the lamp as an intermediary. The comparison wave-length is chosen clear of the absorption line ($H\alpha$ or $H\beta$). It is assumed that neither the brightness of the lamp nor the transparency of the sky vary during the measurement; by making observations in the order disc—flocculus—disc (the three observations being completed within two minutes) any regular variations in lamp and sky are eliminated; the observations must be rejected if the sky is so poor that it is not possible to get steady readings on the undisturbed disc. The lamp,

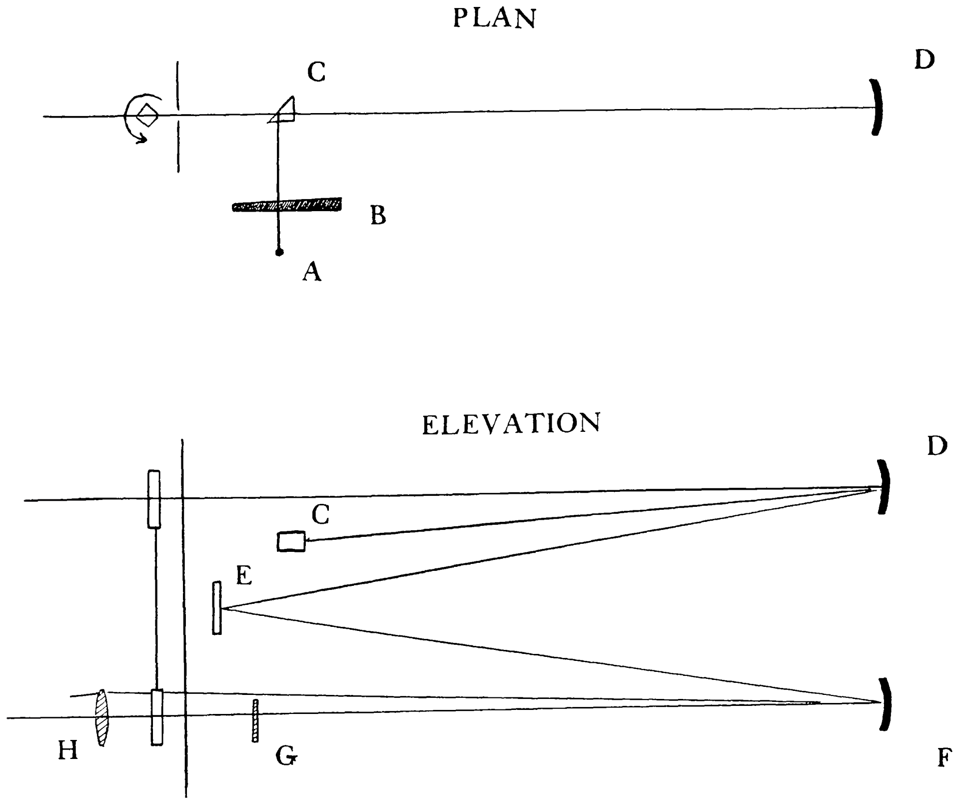

FIG. 1.—*Arrangement of Apparatus.*

which is fed by a transformer run off the mains, has given no trouble, and when the sky is moderate observations agreeing to within 7 per cent. at intervals of two minutes may be commonly obtained.

2. *Method of Measurement and Instrumental Corrections.*

(1) *Calibration of the Wedge.*—Let the wedge reading be x, the density of the wedge D, and the fraction of incident light transmitted by the wedge be f. Then the calibration curve of the wedge supplied by the makers is $D = Ax$, where A is some constant and $D = \log 1/f$. The value of the constant A (supplied by the makers, Messrs. A. Hilger, Ltd.) was checked by an application of the half-aperture method employed by Greaves, Davidson and Martin. Measures of the centre of the disc against the comparison lamp were taken (1) with the object-glass forming the solar image unobscured, and (2) and (3) with the top and bottom halves of the object-glass covered.

Let L be the brightness of the solar disc, *i.e.* the amount of light from the Sun received in the eyepiece per unit solid angle, and $B \times f$ the amount of light received from the lamp. Then in the half-aperture experiment, $L_1 = L_2 + L_3$ so that $f_1 = f_2 + f_3$. Now if the true calibration is $D = (A + \alpha)x$ it can be shown that

$$\alpha = \frac{1}{2\cdot3}\,\frac{f_1 - f_2 - f_3}{x_1 f_1 - x_2 f_2 - x_3 f_3},$$

where x_1, x_2 and x_3 are the three settings. In practice f_1, f_2 and f_3 are taken from the old calibration of the wedge, *i.e.* $f_1 = \text{antilog}\,(-Ax_1)$, etc. A large number of observations were made on eight different dates by two observers with the object of determining the value of the correction α. The weighted mean result was $\alpha = +0{\cdot}004 \pm 0{\cdot}0014$, and the correction $\alpha = +0{\cdot}004$ was adopted. The makers' calibration being $D = 0{\cdot}149x$, the adopted calibration is accordingly $D = 0{\cdot}153x$.

(2) *Correction for Reflections by the Line-shifter.*—Now consider a patch on the solar disc a, having a brightness L_a, viewed in a wave-length λ_a. It is to be compared with a patch at the centre of the Sun's disc at a wave-length λ_0 (brightness L_0). Let the two settings of the wedge be x_a and x_0, and let the line-shifter be set at angles θ_a, θ_0 to the normal. The light from the comparison lamp does not pass through the line-shifter,* but the light from the Sun does so, and suffers a loss by reflection dependent on θ. Let $g(\theta)$ be the ratio of the light transmitted when the line-shifter is set at an angle θ, to the light transmitted when the line-shifter is normal.

Then

$$\frac{L_a}{L_0} = \frac{g(\theta_0)}{g(\theta_a)}\cdot\frac{f_a}{f_0} = \frac{g(\theta_0)}{g(\theta_a)}\,\frac{\text{antilog}\,(-Ax_a)}{\text{antilog}\,(-Ax_0)}.$$

The correction $g(\theta)$ used is computed from Fresnel's formula assuming a refractive index of $1{\cdot}5$ for the line-shifter (Table I). This formula was tested by comparing the apparent brightness of the solar disc in two wave-lengths 6576 A. and 6579 A., the former through the line-shifter in the normal position and the latter through the line-shifter inclined at an angle of 56° to the normal. The result found was $0{\cdot}94 \pm 0{\cdot}01$ in good agreement with Fresnel's formula which, for $\mu = 1{\cdot}5$, gives $0{\cdot}93$. It should be pointed out that differences in intensity on the solar energy curve over a range of 10 angstroms in the

Table I

Transmission through a Thin Plane Parallel Glass

Angle of Incidence	Relative Transmission
0° – 30°	100
40°	99
50°	96
52°	95
54°	94
56°	93
58°	91
60°	89

* It is necessary to make the lamp brighter than the $H\alpha$ image of the Sun. This could only be done by bringing the lamp beam through a slit wider than that of the spectrohelioscope proper.

neighbourhood of $H\alpha$ may be neglected; the present observations cannot aim at an accuracy as great as one per cent., and the change in the energy due to a change of wave-length of 10 A. is only 0·04 per cent.

3. *Measurement of the Contour of $H\alpha$*

If we confine our attention to the centre of the Sun's disc, undisturbed by any phenomenon, and make a series of comparisons with the lamp determining $L\lambda/L\lambda_0$ distributed over various wave-lengths we shall obtain the contour of $H\alpha$. It is of interest to record observations of line contour which have been made without photographic photometry, but the spectrohelioscope is not the ideal instrument for the development of visual observations of line contour. (It is by now well known from experience with photographic methods that a monochromator should be used and that glass prisms give better results than a grating. It is intended to develop visual observations of line intensity at Greenwich using glass prisms and a monochromator.) The central intensity of $H\alpha$ found in the present series of observations is 0·23, and is undoubtedly too high, the error being due to scattered light. The general method of making the observations has already been described. In detail, since the line-shifter gives a workable range of only 4 A., a wave-length 4 A. from the centre of $H\alpha$ is taken as a secondary reference point, and every observation of intensity between this point and the centre is made between a pair of observations of the intensity of the reference point. Only one side of the contour is observed at a time, *i.e.* either the long wave-length side of $H\alpha$ or the short wave-length side is observed. The intensity of the secondary reference point is compared with the intensity at a point 10 A. from the centre of $H\alpha$—adopted as standard—in a separate experiment. Observations on the long wave-length side of $H\alpha$ were carried out on 1934 October 22, 26, 29, and 1935 September 12 and October 12: and on the short wave-length side on 1934 September 28 and October 22 and 1935 October 21 and 23. The mean contour of $H\alpha$ given by the observations is shown in Table II and fig. 2. It may be said that it agrees well with good photographic observations—those of Thackeray * and Minnaert—except that the central intensity is higher than that which Thackeray obtained with a monochromator. No correction has been applied for the distortion of the contour due to finite resolving power of the grating. It may be noted that the scale of the first order spectrum used in the present observations is 1 A. = 4·35 mm.; the grating is one ruled by Rowland and has 14,438 lines to the inch. The spectrohelioscope beam does not fill this grating, but an area containing about 43,000 lines is illuminated. The width of the slits is about 0·1 mm. The selecting agent is of course the second slit which is sampling a spectrum whose purity is determined by the grating and by the first slit. Successive points on the contour were obtained by making a series of settings with the line-shifter, the scale of which is 0–10 divisions = 0·37 A.

The curve shown in fig. 2 represents smoothed values of 186 comparisons

* *M.N.*, **95**, 293, 1935.

between various wave-lengths inside the line and the secondary reference points 4 A. on either side of the centre. An individual determination may differ by as much as 10 per cent. from the mean value. The long- and short-wave halves of the contour are completely independent of each other. Depressions occur in the neighbourhood of 6560·6 A. and

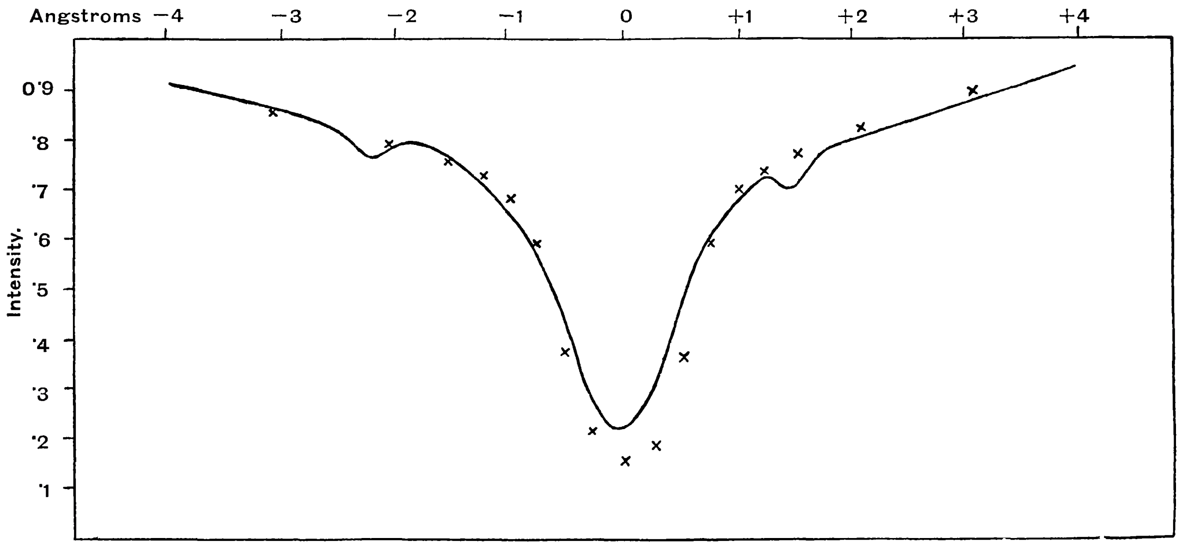

FIG. 2.—*Contour of Hα.*

Continuous curve : smoothed values of Greenwich visual observations, 1934–35.

Crosses : observed photographically by Thackeray (*M.N.*, 95, 296, 1935).

6564·2 A., where there are respectively lines of intensity 1 *Nd*?, and 0 and −1 blended, all due to atmospheric water vapour according to *Revision of Rowland's Table.* In the present observations, insufficient points were taken accurately to determine the contour of these secondary lines.

TABLE II

Contour of Hα Observed Visually

Distance from Centre of *Hα*	Intensity: Short Wave-length Side	Intensity: Long Wave-length Side
4·0 A.	92	95
3·5	89	91
3·0	86	87
2·5	(81)	83
2·0	(78)	78
1·5	75	(71)
1·0	64	66
0·5	42	46
0·0	23	23

4. *Intensities of Flocculi*

(1) *Hα Flocculi.*—The intensities of 62 bright patches of *Hα* flocculi associated with sunspots have been compared with the intensity (= 100) of

the undisturbed disc, in a wave-length 10 A. from the centre of $H\alpha$, at the same distance from the centre of the disc as each flocculus respectively. The observations are summarised in Table III. All the observed intensities of bright flocculi stand in need of some correction for scattered light. It seems probable that most scattering takes place in the form of a transfer from one wave-length to another and not from one point of the field to another. The image of the solar disc is perfectly sharp, but the light which is viewed in the eyepiece is not solely that of the wave-length indicated by the line-shifter, but contains a small percentage of light of other wave-lengths perhaps not very far removed from that of the line. Consider a continuous spectrum crossed by a single absorption line. Let I_1 be the intensity of the spectrum at some wave-length within the line and I_2 the intensity of the continuous background near the line. Let us suppose that the grating removes the fraction α of the light of any particular wave-length and scatters it uniformly in directions proper to other wave-lengths. Then the intensity given by the imperfect grating instead of I_1 is

$$I_1(1-\alpha)+\alpha I_2,$$

so that if r' is the observed intensity of a flocculus and r its true intensity (on the scale disc $=1$) we shall have for the true intensity

$$r=\frac{r'-\alpha}{1-\alpha}.$$

Taking Thackeray's value of the central intensity, $r=0{\cdot}15$ where our instrument gives $r'=0{\cdot}23$; from these values we find $\alpha=0{\cdot}09$. Returning to the mean intensity (uncorrected) of the flocculus, we have $r'=0{\cdot}36$, so that with $\alpha=0{\cdot}09$, $r=0{\cdot}30$. On account of the uncertainty of the exact nature of the scattering, we have shown all the values in this paper both uncorrected and corrected.

It is to be noticed that the correction to be applied to a prominence is quite different, as the prominence has no continuous spectrum. In this case we have simply $r=r'\,.\,\frac{1}{1-\alpha}$, and the observed brightness of prominences should be increased by about 10 per cent. In this case also, both uncorrected and corrected values will be shown.

The eruptive flocculi entered in the fourth column refer to small, very bright patches which arise suddenly within the confines of a normally bright area; the duration of enhanced emission is of the order of a quarter to half an hour.

Table III indicates that during the period of observation the measured light intensities of normal $H\alpha$ flocculi were most frequent between 30 and 40 per cent. uncorrected (or 23 and 34 per cent. corrected), that of the continuous spectrum 10 A. away from the centre of $H\alpha$; the mean is 36 per cent. uncorrected and 30 per cent. corrected. It should be pointed out that there is probably a tendency for the observer to omit very faint material from his survey, though the faintest flocculi appear to be those in which

TABLE III

Intensities of Bright Hα Flocculi associated with Sunspots, 1934–1935

Intensity		Number of Flocculi	
Uncorrected	Corrected	Normal	Eruptive
20–24	12–16	0	
25–29	17–22	3	
30–34	23–27	21	
35–39	28–33	25	
40–44	34–38	10	1
45–49	39–44	3	3
50–54	45–49		2
...			
75–80	73–78		1

the associated sunspot has died out. It is thought, therefore, that the material included in Table III is fairly representative of flocculi associated with sunspots during the period covered.

The data for eruptive flocculi are meagre at present but may be taken to indicate the order of magnitude of the enhanced emission shown by this class.

It is of interest to compare Table III with other data given in Table IV derived by the simple method * referred to previously, of a neutral wedge inserted in the field of view of the spectrohelioscope ; a wedge measure of equality affords a direct comparison between the brightness of a flocculus and that of the adjacent background at the *same* wave-length—normally that of the centre of $H\alpha$. This table presents the data obtained at Greenwich in this manner for normal and for eruptive flocculi for the period 1932–35 † as a whole and also for the period 1934–35, during which the new method of measuring intensities has been employed.

Table IV shows that a maximum frequency for the normal flocculi occurs at a light intensity of 1·4, *i.e.* the ratio of intensity of flocculus to that of the adjacent background at the same wave-length is 1·4. The mean of the second column (data for normal flocculi, 1934–35) is 1·46. Since the maximum intensity of the normal bright flocculi occurs within ·05 A. from the centre of $H\alpha$,‡ a factor of 23, taken from our contour of $H\alpha$, multiplied by 1·46 gives a mean value of 34 per cent. that of the continuous spectrum ; this value is in good agreement with the mean value derived quite independently from the corresponding column in Table III, viz. 36 per cent. (both figures uncorrected).

(2) *Hβ Flocculi.*—The spectrohelioscope can be fairly rapidly adjusted for observations in $H\beta$. Normally, however, $H\beta$ flocculi corresponding

* *M.N.*, **93**, 172, 1933.

† It may be noted that Table VI given in the previous paper, *loc. cit.*, includes measures of light intensity of $H\alpha$ flocculi both for areas in which sunspots were present and those in which the associated spot had died out.

‡ *M.N.*, **93**, 170, 1933.

TABLE IV

Intensities of Bright Hα Flocculi associated with Sunspots (Simple Wedge Method)

Intensity	Number of Flocculi: Normal 1932–35	Normal 1934–35	Eruptive 1932–35	Eruptive 1934–35
1·1	7	2		
1·2	23	17		
1·3	42	24		
1·4	59	29		
1·5	41	20		
1·6	20	9		
1·7	16	8	1	1
1·8	8	4	1	0
1·9	7	3	1	0
2·0	5	3	5	0
2·1	2	1	2	0
2·2	1	1	6	3
2·3	0	0	1	1
2·4	0	0	1	0
2·5	2	1	2	2
2·6–2·9			2	2
3·0–3·4			2	1
3·5–3·9			0	0
4·0–4·4			1	1
4·5–5·0			1	1

in place to the bright $H\alpha$ areas are dark * and not bright, but when there are bright eruptive flocculi in $H\alpha$ or in H or K, bright $H\beta$ flocculi also appear. Future observations should decide whether this is an invariable rule of eruptive flocculi. The short life of these eruptive phenomena makes it difficult to obtain accurate comparative measures in $H\alpha$ and $H\beta$, but it is hoped to accumulate data during the coming sunspot maximum. A measure on a small bright flocculus in $H\beta$ on 1935 June 30 gave 49 per cent. that of the continuous spectrum, the corresponding measure in $H\alpha$ being 44 per cent.

5. *Intensities of Prominences*

(1) *Prominences in $H\alpha$.*—During the period of observation, intensity measures were made of 101 prominences visible in $H\alpha$. The comparison of intensity was made between each prominence and the continuous spectrum 10 A. away from the centre of $H\alpha$ at the centre of the Sun's disc. The prominences were mostly between 1′ and 2′ in height and, with the exception of five, were relatively stable in nature. The frequency of the measured intensities is indicated in Table V, the five eruptive prominences being tabulated in a separate column.

* Illustrations of this statement are given in *Publications of the Yerkes Observatory*, **3** (I), Plates 8 and 9 (1903). Characteristic phenomena visible respectively in $H\alpha$ and $H\beta$ are summarized in *Annales de l'Observatoire de Paris* (Meudon Section), **8** (II), 42, 1930.

TABLE V

Intensities of Hα Prominences Compared with the Centre of the Sun's Disc, 1934–35

Intensity		Number of Prominences	
Uncorrected	Corrected	Quiescent	Eruptive
1– 4	1– 4	10	
5– 9	5–10	51	
10–14	11–15	25	
15–19	16–21	10	1
20–24	22–26		1
25–29	27–32		1
30–34	33–37		0
35–39	38–43		1
50–60	55–66		1

The mean observed intensity of quiescent prominences summarized in Table V is 9 per cent. uncorrected (or 10 per cent. corrected) that of the continuous spectrum. The few observations that have been made of eruptive prominences (characterized by rapid changes and motions in the line of sight) indicate the greater brightness of this class of prominence. It is hoped that a large number of eruptive prominences will be measured as the present sunspot cycle develops.

As an example of the measures of intensity of an eruptive prominence, we may refer to one observed at Greenwich on 1935 May 11 at the west limb. This prominence appeared to originate from a bright eruptive flocculus which contained a sunspot passing around the limb. As the line-shifter was turned from positions indicating radial velocities of +50 to −80 km./sec. the shape and apparent brightness of the prominence changed very considerably, and the following measures of intensity were made :—

Time 1935 May 11 U.T.	Radial Velocity km./sec.	Intensity (Uncorrected)
h m		
10 44	−45	44
10 50	0	24
10 55	−80	39
11 00	−25	18
11 15	+50	58
11 20	+50	54

The association of high emission with large radial velocity at the limb is interesting and worth future investigation.

(2) *Prominences in Hβ*.—In general, the observation of intensity of prominences in $H\beta$ is difficult with the present equipment on account of their relative faintness as compared with their $H\alpha$ images. Observations were made, however, when suitable prominences presented themselves, in order to obtain a measure of their relative intensities, $H\beta/H\alpha$, and the results of comparisons of 22 prominences are given in Table VI. These prominences were, with two exceptions, indicated with an asterisk, stable

and ranged in height from 0′·5 to 2′·5. In making the reductions it was assumed for a first approximation that the contour of $H\beta$ was similar to that of $H\alpha$.

TABLE VI

Comparison of Intensities of Prominences in $H\alpha$ and $H\beta$, 1934–35

Date 1934	Ratio of Intensity $H\beta/H\alpha$	Date 1935	Ratio of Intensity $H\beta/H\alpha$
Aug. 26	·24	May 2	·40
28	·25	June 21	·33
31	·20	22	·31*
31	·33	22	·33
Sept. 28	·10	23	·11*
28	·12	30	·15
Oct. 4	·27	Aug. 5	·20
11	·20	5	·14
11	·28	Sept. 2	·17
12	·53	11	·40
		Oct. 23	·49
		23	·20
Mean	·25		·27

Table VI shows that the ratio of the brightness of a particular prominence in $H\beta$ to its brightness in $H\alpha$ varies from 0·10 to 0·53 (mean 0·26). The probable error in the measured brightness in $H\beta$ is of order 10 per cent., and the probable error of the measure in $H\alpha$ is less, so that we conclude that the variations in the ratio $H\beta/H\alpha$ from one prominence to another are probably real, *i.e.* the Balmer decrement varies substantially from one prominence to another. This variation is shown by measurements from $H\beta$ to $H\delta$ made by Schwarzschild on prominences which he observed at the eclipse of 1905 (*Ast. Mitt. Gottingen*, **13**, 53, Table XIX, 1906). It is hoped to obtain more information on this point by extending the observations if possible to include measurements in $H\gamma$, but visual work with the spectrohelioscope in this region of the spectrum is very restricted.

6. *Future Work with the Instrument*

It is not proposed to attempt to introduce any refinement into the measures of line contours, because it is hoped to obtain better contours with a new instrument embodying a monochromator. But the spectrohelioscope being peculiarly well adapted to the observation of transient phenomena on the disc, work on the flocculi and prominences will be continued.

The simple wedge method for comparing the intensity of a flocculus with that of the adjacent background at the same wave-length appears to give satisfactory results and is more rapid in operation—a definite advantage when the sky is variable.

In both methods we have hitherto measured the brightness of each prominence or flocculus at maximum contrast with the disc. An attempt