The Solar Rotation derived from the H and K Lines in Prominences. (Second Paper.) By J. Evershed, F.R.S.

In *Monthly Notices*, 88, 126, I summarised the results of measures of 92 spectra of prominences obtained in the years 1926–27. These yielded values of the solar rotation in four zones of heliographic latitude which are remarkable for the very large angular motion in each zone, as compared with values derived from spectra of the reversing layer, or from the motion of sunspots. In addition, the general shift towards red of the H and K lines was found to exceed the predicted relativity shift by about 0·003A, in approximate agreement with measures previously obtained with the same lines in the chromosphere, and with iron lines in the reversing layer in the same spectral region.

During 1928 the work has been continued on the same lines, but one change has been made in the method which greatly simplifies the process of measurement and reduction of the spectra. Owing to this change, and to the favourable season, a much larger number of plates

* It should be noted, however, that this is a rather erratic set of residuals, and the comparison of the observations with theory was direct in 1923 but indirect in 1921 and 1922. The data are taken from *Yale Transactions*, vol. iii., part 6.

has been dealt with, and the results now obtained, both as to the rotation and the general shift, are, I think, of considerable interest.

In the 1927 series the Fe arc spectrum was impressed on all the plates, and the positions of the prominence lines H and K were determined with reference to the terrestrial iron lines 3969·262 and 3930·300 respectively. This involved the measurement of two more Fe lines, in order to derive accurate factors for computing the positions of the prominence lines. For the estimate of the Einstein effect it was necessary to assume that the wave-lengths of terrestrial H and K, as determined by St. John, correctly represented the positions in air to the third decimal in angstroms.

In the new series of plates a comparison spectrum in which the calcium lines are prominent was employed, and the small shifts directly observed between the terrestrial and solar H and K lines were measured. This involves no subsidiary measures. The scale of each plate is given by the distance separating H and K, and the factors at H and at K are easily derived with sufficient accuracy from the mean factor as determined midway between H and K.

The substitution of the Ca^+ lines for Fe can have no appreciable effect on the values obtained of the solar rotation, except possibly a very small systematic error in the direction of increasing the displacements, due to the fact that the shifts are directly observed, and past experience has shown that in measuring small displacements there is an unconscious tendency to exaggerate them.* While every effort has been made to minimise this source of error, there remains the possibility that the values obtained are too large by an amount which would not exceed 5 per cent.

The 1927 results are entirely free from this source of error, because during the measures nothing is known or seen of the shifts, which are determined later by calculation.

The general shift towards red of the lines is not affected by this error, which does not increase in proportion to the amount of the shift, so that in taking the difference of shifts west – east it is eliminated. The direct observation of solar and terrestrial lines should yield a more satisfactory value of the Einstein effect than the indirect method involving assumed wave-lengths of the terrestrial H and K lines.

The carbon arc provides the source of Ca^+ radiation, but the character of the lines varies in carbon rods of different make, and it is necessary to select material that gives sharp narrow lines and as free as possible from iron lines. One particular set of rods 5 mm. in diameter was used throughout. The yellow flame of the arc from these yielded extremely narrow Ca lines, as well as the D lines of sodium and the aluminium lines.

The observed shifts converted into angstrom units are corrected for the annual and diurnal motions of the Earth in the direction of the Sun, computed for the date and time each spectrum was photographed. The heliographic latitudes of the prominences and the heights above the limb of the spectral images are determined as explained in my previous paper.

* *Kodaikanal Observatory Bulletins*, **8**, 23.

Rotation Results.—About 380 prominence spectra were photographed during the year, many of the plates having more than one measurable image impressed. Of these, 289 prominence images were measured, the others having ill-defined or greatly distorted lines due to violent motion in the line of sight. Those selected vary in quality, and I divide them into two classes, viz., 180 of class A, which have straight narrow lines, and 109 of class B with more or less ill-defined or wavy lines. In analysing the results these classes have been treated separately, with the result that the B spectra yield values of the rotation shift 15 per cent. larger than the A spectra, and the general shift nearly 14 per cent. larger.

I give first the result of a general average of all the east and west spectra of class A only, as in this series it so happens that the distribution in latitude is identical for the east and the west.

TABLE I.

Mean Shifts from all Measures of Class A Spectra.

	Mean Latitude.	K.	H.
West	21°·0	+0·0408A	+0·0409A
East	21°·1	−0·0152	−0·0164
Half sum		0·0280	0·0286

Mean of H and K		0·0283A = 2·150 km./sec.
Mean correction for revolution of Earth . . .		+0·136 ,,
Mean correction for inclination of Sun's axis . .		+0·013 ,,
Sidereal rotation	= V	= 2·299 km./sec.
Daily rotation at mean height 34″ . . .	= ξ	= 16°·9

Comparing this result with the value obtained from the 1927 series, a reduction of daily angular motion from 20° to 16°·9 is shown. There is still, however, a large excess over the corresponding motion for sunspots, which for latitude 21° would be 14°. If the B spectra are included, 0·1 km./sec. is added to V, and ξ becomes 17°·6.

Considering that quantity rather than quality is important in measures of this kind, where large deviations from the mean values are found, I have included all the measures of class B spectra in the further analysis into zones of latitude, which are given in Table II.

TABLE II.

Solar Rotation in Different Latitudes.

No. of Measures.	φ.	h.	V.	ξ.
	°	″		°
99	9	41	2·48 km./sec.	17·1±0·8
51	18	28	2·36 ,,	17·1±0·9
78	25	33	2·66 ,,	20·2±0·7
37	35	32	1·98 ,,	16·6±1·7
24	51	35	1·59 ,,	17·3±2·4

The symbols used in this table have the following meanings :—

ϕ = mean latitude of each group of spectra.
h = mean height of each group of spectra.
V = mean velocity corrected to its sidereal value and for mean inclination of the Sun's axis.
ξ = daily angular motion in degrees.

The formula used for computing ξ takes account of the mean height in each zone, whereby the Sun's radius is increased 3 per cent. or more. The probable errors are derived from the residuals of the individual measures in each group, taking the mean values given by H and K. These probable errors are rather arge considering the large number of measures, and indicate the large departures from the mean values due to the random motions of the prominences, and not to the measuring errors, which are relatively small.

These values of ξ are in surprisingly good agreement with those obtained from the 1927 series. They do not indicate any diminution of angular speed, except in the 9° zone. In other zones the figures are much the same for the two years.

A curious feature is the large value of ξ for the 25° zone, showing strongly in both years, and this region in 1928 gave more consistent values than any other zone, as is indicated by the probable error. There were 53 spectra of class A and 25 of class B in this zone, but each class gives the same mean value. If the north and south hemispheres are treated separately, it is found that this high value of the angular speed occurs in the southern 25° zone but not in the northern, where the maximum value of ξ is found in the 18° zone. It would be interesting to learn whether these features have any relation to sunspot frequency, or are purely accidental.

There is no evidence in this series of a polar retardation of angular motion, and excepting for the large value in the region of 25° the figures indicate a remarkable constancy.

The prominence spectra have been photographed at various heights above the chromosphere, ranging from 5″ to 150″, and from the large number of measures now available the effect of height on angular motion may be estimated. Dividing the prominence spectra of each zone into two series, in which the mean heights are about 20″ and 60″, I find the values obtained are extremely irregular in the different zones, some giving larger velocities for the higher prominences, and others the reverse. Yet on the whole, counting the two years together, there is a mean excess for the high prominences, amounting to about +0·17 km./sec., or an increase of 7 per cent. in the mean observed velocity. The increase of height from 20″ to 60″ demands a 4 per cent. increase in velocity for the same angular motion. The evidence therefore favours an increase of angular motion with height, but I do not consider that much weight can be given to this result.

General Shift of the H and K Lines in Prominences.—The mean shift of the lines towards red in the class A series may be taken from the differences west–east in Table I. These give :—

	K.	H.
$\frac{W-E}{2}=$	+0·0128	+0·0122

Mean	+0·0125
Add for pressure effect .	+0·0017
Sun–arc in vacuum . .	+0·0142A ± ·0007

The results for the different groups of latitude, in which spectra of class B are included, are shown in Table III.

TABLE III.

φ.	Mean of H and K.	No. of Measures.
9°·2	+0·0137 ± ·0016	99
18	+0·0140 ± ·0017	51
25	+0·0127 ± ·0013	78
35	+0·0120 ± ·0027	37
51	+0·0190 ± ·0029	24
Weighted mean	+0·0137 ± ·0009	
Add for pressure effect . . .	+0·0017	
Sun–arc in vacuum	+0·0154A	

Omitting the discrepant value at latitude 51° the mean is

	+0·0132 ± ·0003
Add for pressure effect	+0·0017
Sun–arc in vacuum	+0·0149A

The most reliable result is perhaps that given by the A spectra alone, which is, omitting the last figure, +0·014A. My previous result from the 1927 spectra was +0·011A. I am unable to account for this large difference. It would seem to imply that the H and K arc lines in my spectra were displaced to violet by 0·003A, or that the assumed wave-lengths of these lines are in error by this amount, the larger shift being nearer the truth.

I had rather confidently expected that with the much larger amount of material dealt with the shift would be brought into better agreement with the Einstein effect, that is to say, it would be reduced by something of the order of 0·003A. Instead, it is increased by this amount, making the discrepancy 0·006A. A redetermination of the wave-lengths of H and K, as produced in the carbon arc and with very high dispersion, is now on my programme, and an attempt will be made to redetermine the shift given by the H and K lines in the chromosphere.

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