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Radial Movement in Sun-spots. By J. Evershed.

Displacements of the absorption-lines of hydrogen and calcium are frequently observed in all spot disturbances where there is active change in progress, and during the genesis of a spot. These line-shifts may amount to several Ångstrom units in either direction in the spectrum, indicating velocities towards or away from the observer of one or more hundred kilometres per second. Only the elements of the higher chromosphere seem to be affected as a rule, and the movements are seldom maintained for more than a few minutes at a time; also they are rarely found within the penumbral area of a spot.

Recently line-shifts of quite another character have been photographed here. These are permanent, affect most, if not all, of the Fraunhofer lines, and are greatest in the penumbræ.

In some spectra obtained by me this year, in the fourth and fifth orders of a Rowland plane grating of 3·2 inches ruled surface and 14,428 lines to the inch, the lines crossing the spot-band were found to be slightly bent, or inclined one or two degrees as compared with the lines in the neighbouring photosphere. The first plate showing this feature clearly was exposed on January 7, 1909, in the fourth order of the grating. It covers the region $\lambda 4650$ to $\lambda 4790$, and the scale is 1Å = 1·08 mm. The total displacement of the lines measured on each side of the penumbra amounts to 0·027Å, indicating a receding velocity on the north-west side of the spot of 0·85 km. per second, and an approaching velocity of the same amount on the south-east side. The spot was in latitude 9° north and longitude 31° west of the central meridian, and the position-angle of the north end of the spectrograph slit was 314°.

The appearance of the lines on this plate at once suggested a rotation of the absorbing gases in the penumbra—not a vortex motion, but a rotation of the spot as a whole about a point at its centre. The lines are quite straight over the spot, although inclined to the undisturbed lines; and in the centre of the umbra there is no displacement. The hypothesis of circular motion of any kind has proved, however, to be certainly untenable. From an examination of about 150 spectra, obtained since January 7, and representing seven different spots in the northern hemisphere and four in the southern, the following definite results have been obtained:—

1. All the spots examined show line-shifts of about the same order of magnitude when at the same distance from the centre of the Sun's disc.

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2. The displacements disappear when the spot is within 10° of the centre.

3. The displacements are most marked when the spot is between 30° and 50° east or west of the meridian.

4. The displacements are of opposite sign on opposite sides of the central meridian.

5. The displacements are invariably towards the violet on the preceding side of a spot and towards the red on the following side, when the spot is east of the central meridian; the reverse when west.

6. Southern spots show the same directions of movement as northern.

7. No displacements are obtained when the slit bisects a spot in a direction at right angles to a line joining the spot and the centre of the Sun's disc.

A hypothesis which seems in harmony with all the facts here stated is one which attributes the displacements to a radial movement outwards from the spot centre. The motion must be essentially horizontal, or parallel to the Sun's surface; this is shown by the total disappearance of the line-shifts when the disturbance is near the centre of the disc. The hypothesis of a vortex, or rotation of any kind, about an axis perpendicular to the Sun's surface, is negatived by the fact stated in paragraph 7, for it is evident that for a circular movement a nodal point should be found when the slit bisects the spot in a direction passing through the centre of the Sun's disc, the maximum displacement occurring in a direction at right angles to this. This position of the node, however, differs from that actually found by about 90°.

To obtain evidence on this crucial point, advantage is taken of the rotation of the solar image, due to the action of the heliostat. Thus, in the interval between 8 A.M. and 5 P.M. the position-angle of the slit, which is fixed truly vertical, changes through about 100°, the north end of the slit passing from position-angle 300° through 0° to 40°, being at 0° at solar noon. Different sections of a spot can therefore be obtained by simply taking a succession of photographs at intervals throughout the day. Now, it has invariably been found that the displacements diminish in amount from 8 A.M. up to about 11, when they usually disappear entirely, reappearing with opposite signs in the afternoon; but the time of no displacement does not occur exactly at solar noon, and the evidence so far obtained shows that the line of nodes coincides with the direction at right angles to a line joining the spot and the centre of the disc, as it should do if the motion is radial. The whole of the evidence obtained up to the time of writing will be published in Bulletin No. 15 of this observatory, and need not be detailed here; but, in view of the importance of the determination of the line of nodes, I give a table showing the results of seven independent determinations.

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Date.	Kodaikánal Spot No.	P.A. of Spot.	P.A. of Node.	Angle between Node and Centre of Disc.
Jan. 18	1588	82° E.	20° W.	102°
,,	1591	74° E.	2° W.	76°
20	1591	60° E.	23° W.	83°
25	1594	87° E.	8° W.	95°
,,	1591	84° W.	0°	84°
26	1591	88° W.	9° E.	97°
27	1595	60° E.	31° W.	91°
			Mean	90°

The estimate of the time when there is no shift must necessarily be extremely uncertain, considering the small amount of the displacements, even when at their greatest; and the accordance in the above table is really surprising, and testifies to the sensitiveness of the eye in estimating very minute deviations from straightness in the spectrum lines.

Since these determinations were made, a device has been added to the spectrograph, by which the Sun's image can be made to rotate on the slit plate through 90°, and the results obtained by this means leave no doubt whatever as to the position of the line of nodes; for wherever a spot may happen to be situated on the disc, outside the limit of 10° from the centre, at which the shift becomes inappreciable, the displacement is always found to be greatest when the slit bisects a spot in the direction of the centre of the disc. If the image is turned through 90°, so that the bisection is at right angles to the direction of the centre, no shift is obtained, the lines remaining absolutely straight across the spot-band.

The constancy of the displacement in all the spots examined is most remarkable; and the fact that it has not, to my knowledge, been observed previously is difficult to explain, except by supposing that spot spectra are usually obtained when near the central meridian, or with the slit approximately in the line of nodes.

It may be well, perhaps, to mention that a test of the reality of these minute line-shifts was made by photographing the spot spectrum in the red, in the region including the well-known group of solar and telluric lines used by Dunér and Halm in their determinations of the solar rotation. In this group, the telluric oxygen lines are very narrow and well defined, whilst the solar iron lines are comparatively broad, and are indeed much widened in spots. Since the displacements are much more conspicuous in the finer lines of the spectrum, the oxygen lines should show the effect strongly if spurious, but in the photographs they are found to be absolutely straight, whilst the iron lines beside them are inclined.

The maximum total displacement obtained with the slit in the direction of the centre of the disc for a spot 40° west of the central

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meridian and 9° north is 0·040 Ångstrom units at λ4850. The component of velocity in the line of sight from this is 1·24 km. per second towards and away from the observer, on the following and preceding sides of the penumbra respectively. Dividing this by the sine of the angular distance of the spot from the centre of the disc ($\sin 42° = \cdot 67$) gives an actual motion parallel to the Sun's surface of 1·9 km. per second each way. But the motion seems to vary directly as the distance from the spot centre, and the value found is for the outer limits of the penumbra, or at an actual distance of about 32,000 km. from the centre of the spot. At intermediate distances, the motion will be less in proportion.

It is somewhat disappointing, perhaps, that the hypothesis of a radial movement, which is so strongly supported by these observations, seems entirely out of harmony with the splendid discovery of the Zeeman effect in sun-spots, made by Professor Hale. This seems to demand a vortex, or at any rate a circular movement, in sun-spots; and it was only after a considerable amount of evidence had accumulated that the preconceived conviction that the motion must be circular was abandoned.

A consoling feature of this new theory of spot movement is that it seems to explain the radial structure of the filaments in the penumbræ of spots, and the radial disposition of the calcium flocculi immediately surrounding a well-developed symmetrical spot. It also harmonises with the well-known tendency of the principal spots in a group to separate, the leader advancing and the follower receding.

A difficulty should also be mentioned. When the slit centrally bisects a symmetrical spot in a direction approximating to that giving the greatest shift, the displaced lines appear quite straight, as before mentioned, and inclined to the undisturbed lines, the greatest shift occurring at the outer limits of the penumbra. This seems to imply an accelerating movement from the centre of the spot outards; yet at the limits of the penumbra the motion apparently ceases abruptly. It is hoped that further research will throw light on this and other obscure points.

Kodaikánal:
1909 *February* 6.

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The Brightness of Saturn with Ring Invisible.

By J. M. Baldwin, M.A.

(*Communicated by Sir David Gill, K.C.B.*)

In a paper on photometric measurements of Saturn which appeared in *Monthly Notices*, vol. lxviii. p. 368, owing to an unfortunate mistake, a factor 2 had been omitted in obtaining the correction to be applied to the observed brightness to reduce it to the brightness in mean opposition, and in consequence the correction given is only half as great as it should be. In the following table the correct values are given, the observations being arranged in order of phase angle, the columns being respectively date of observation, phase angle, observed difference of magnitude Saturn $-\alpha$ Aquilæ, correction to mean opposition, and the magnitude reduced to mean opposition, the magnitude of α Aquilæ being taken as 0·96 (Müller, *Potsdam Publ.*, viii. p. 235, 1893). Further particulars of the observations are given in the paper above cited, the first four observations in the former table having been omitted, for reasons there mentioned.

Date.	α.	ΔM.	Corr.	M_0.	Corr.	M.
1907	°					
Sept. 18	0·28	− ·01	− ·02	·93	+ ·02	·95
13	0·53	+ ·02	− ·02	·96	+ ·03	·99
22	0·59	+ ·02	− ·02	·96	+ ·01	·97
12	0·63	− ·02	− ·02	·92	+ ·03	·95
11	0·73	+ ·06	− ·02	1·00	+ ·03	1·03
Sept. 24	0·80	+ ·03	− ·02	·97	·00	·97
10	0·83	+ ·13	− ·02	1·07	+ ·02	1·09
25	0·90	− ·09	− ·02	·85	·00	·85
27	1·11	− ·04	− ·02	·90	− ·01	·89
28	1·21	− ·04	− ·02	·90	− ·01	·89
Sept. 29	1·32	− ·10	− ·02	·84	− ·02	·82
4	1·46	+ ·12	− ·03	1·05	+ ·01	1·06
Oct. 2	1·63	+ ·02	− ·03	·95	− ·02	·93
3	1·74	·00	− ·03	·93	− ·02	·91
8	2·25	+ ·13	− ·03	1·06	− ·02	1·04
Oct. 11	2·55	− ·04	− ·04	·88	− ·03	·85
20	3·39	+ ·16	− ·05	1·07	− ·03	1·04
24	3·74	+ ·01	− ·06	·91	− ·04	·87
Nov. 3	4·51	+ ·19	− ·09	1·06	− ·04	1·02
27	5·69	+ ·20	− ·17	·99	− ·06	·93
Dec. 1	5·78	+ ·13	− ·19	·90	− ·06	·84

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