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ON THE DISPLACEMENTS AT THE SUN'S LIMB OF LINES SENSITIVE TO PRESSURE AND DENSITY.

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In a discussion of the displacements of spectrum lines at the sun's limb[1], Messrs. Evershed and Royds have shown that iron lines displaced to the violet by increased pressure are shifted, in common with the majority of lines, to the red of their position at the centre of the disc. The hypothesis that the pressure of the effective level of absorption at the limb is greater than that at the centre of the disc, requires that these lines should be shifted to the violet and not to the red. From the small relative shift of these lines compared with the shift of those displaced to the red by pressure, they concluded that the difference of pressure of the effective levels of absorption at the sun's limb and at the centre of the disc was small.

It should be remembered that, in the reversing layer, the vapour density of any element will vary proportionately with the total pressure if the relative amounts of the various elements remain constant, and therefore any increase or decrease of pressure at the limb compared with the centre of the disc will be accompanied by a corresponding increase or decrease of vapour density.

Now, certain lines, particularly of calcium and sodium, are much more sensitive to pressure and density than iron lines. The limb shifts of these lines, therefore, provide a more rigorous test than the iron lines as to whether there is a large difference of pressure and density between the sun's limb and the centre of the disc. The lines available as being sensitive to pressure or to density are as follows :—(1) the sodium pairs at λλ 5680 and 6150, (2) the calcium triplets at λλ 3950, 4580 and 6120 and (3) the magnesium lines at λλ 4352 and 4703. All these lines are unsymmetrically widened towards the red and undergo, with increased pressure or density, large displacements to the red. It will be shown in the following paragraphs that a comparison of the limb shifts of these lines with those of other lines of the same level shows that the difference of pressure and density between the effective levels at the limb and at the centre of the disc must be very small.

Experimental Details.[2]

The spectrograph has been already described in Kodaikanal Observatory Bulletin No. XXXVI. The method of making exposures of the centre and both the limbs simultaneously is the same as that given in Kodaikanal Observatory Bulletin No. XXXIX. In the region λ 6150 some of the plates were also obtained by alternate exposure of the centre and each limb separately. Observations were made between latitudes 0° and 75° at a distance of one-thirtieth of the sun's radius inside the limb. The higher latitudes were in the regions λλ 5680 and 6150. In the region λ 6150 the second order spectrum was used ; in the other regions the third order was employed.

[1] Kodaikanal Observatory Bulletin No. XXXIX. [2] The photographs were taken by the Director and Assistant Director.

The following table contains the limb — centre shifts of all the lines measured :—

TABLE I.—LIMB — CENTRE SHIFTS.

[Lines most sensitive to pressure and density are marked ur, being unsymmetrically widened towards the red]

λ (Rowland)	Intensity	Number of measures.	Limb — centre		λ (Rowland).	Intensity.	Number of measures	Limb — centre.	
			Kodaikanal	Mt. Wilson				Kodaikanal	Mt. Wilson.
			A/1000	A/1000				A/1000	A/1000
3940·039 (*ur*)	Ca 1	3	+ 7	...	4733 779	Fe 4	2	+ 7	+ 10
3950·102	Fe 5	4	+ 6*	+ 6	5655·715	Fe 2	2	+ 10	...
3956 819	Fe 6	5	+ 6*	+ 7	5659·052	Fe 4	5	+ 9	...
3966·212	Fe 3	3	+ 4*	.	5662 744	Fe 4	5	+ 8	...
3969·413	Fe 10	5	+ 4*	.	5667·739	Fe 2	1	+ 8	.
3977·891	Fe 6	6	+ 7*	+ 6	5679·249	Fe 3	4	+ 8	...
4076·792	Fe 4	2	+ 4	.	5682·869 (*ur*)	Na 5	5	+ 1	+ 7
4078·515	Fe 4	2	+ 5	..	5684·710	Si 3	5	+ 7	+ 10
4081·033	Fe 2	2	+ 4	.	5688·436 (*ur*)	Na 6	5	+ 3	+ 6
4085 161	Fe 4	2	+ 5	.	5690 646	Si 3	4	+ 8	+ 8
4089 374	Fe 3	2	+ 4	.	5691·715	Fe 2	1	+ 9	.
4091·711	Fe 3	2	+ 6	.	5701 323	Si 1	1	+ 6	+ 7
4095·094 (*ur*)	Ca 4	4	0	+ 4	5701 772	Fe 4	4	+ 7	
4096·129	Fe 3	2	+ 4	..	5706·215	Fe 3	1	+ 6	...
4098·689 (*ur*)	Ca 4	4	+ 2	.	5708 622	Si 3	4	+ 9	+ 9
4337 216	Fe 5	2	+ 7	+ 8	5709·601	Fe 5	4	+ 7	..
4352 083 (*ur*)	Mg 5	4	+ 4	+ 4	5709 775	Ni 5	4	+ 12	+ 12
4352·908	Fe 4	1	+ 6	+ 6	6065·709	Fe 7	4	+ 4	+ 12
4527 101 (*ur*)	Ca 3	7	+ 4	+ 7	6079·227	p Fe 2	8	+ 4	+ 12
4528 798	Fe 8	4	+ 6	+ 5	6102 392	Fe 6	7	+ 3	+ 13
4531 327	Fe 5	4	+ 8	+ 7	6102·937 (*ur*)	Ca 9	7	+ 3	+ 8
4548 024	Fe 3	4	+ 6	+ 8	6122·434 (*ur*)	Ca 10	8	+ 3	+ 7
4549 642	p Fe 2	4	+ 6	+ 8	6136·829	Fe 8	8	+ 5	+ 13
4556 063	p Fe 3	4	+ 8	+ 11	6151·834	Fe 4	8	+ 3	+ 12
4560 266	Fe 2	3	+ 7	...	6154 438 (*ur*)	Na 2	6	+ 3	+ 11
4578·732 (*ur*)	Ca 3	5	+ 3	.	6160 956 (*ur*)	Na 3	8	+ 2	+ 12
4581 575 (*ur*)	Ca 4	6	+ 3	..	6162·390 (*ur*)	Ca 15	8	+ 2	+ 8
4584·018	p Fe 4	4	+ 8	+ 12	6166·651	Ca 5	8	+ 4	+ 9
4586·047 (*ur*)	Ca 4	6	+ 2	+ 6	6169·249	Ca 6	8	+ 3	+ 10
4592·840	Fe 4	2	+ 8	..	6169·778	Ca 7	8	+ 4	+ 9
4595·540	Fe 2	2	+ 8	..	6173·553	Fe 5	8	+ 5	+ 14
4598·303	Fe 3	2	+ 6	.	6175·584	Ni 3	8	+ 3	+ 11
4603·126	Fe 6	2	+ 6	...	6191·393	Ni 6	8	+ 2	+ 11
4607 831	Fe 4	2	+ 8	..	6191 779	Fe 9	8	+ 5	+ 14
4679·027	Fe 6	1	+ 4	...	6213·644	Fe 6	8	+ 4	+ 14
4703·177 (*ur*)	Mg 10	3	+ 4	+ 8	6219·494	Fe 6	4	+ 6	...
4707 457	Fe 5	3	+ 5	...					

* These values are taken from Kodaikanal Observatory Bulletin No. XXXIX.

For comparison, Dr. Adams's values are also given under the heading "Mount Wilson." Generally there is a fair agreement except in the region λ 6150, where my values are much smaller than Adams's. The cause of this is not clear. As stated above, the plates in this region have been obtained both by comparison of each limb separately with the centre of the disc and also by simultaneous exposure of both limbs and the centre in a manner identical with that of photographs in other regions giving good agreement with Adams. My experience agrees with that of other workers, who have found that the value for the limb shifts vary considerably from plate to plate in an apparently arbitrary manner; in a particular plate, while the majority of lines may have their average values some may have abnormal values, notwithstanding the fact that they give correct values for the rotational velocity of the sun. Whether these variations are due in some way to the photographic process, such as the unequal shrinking of the film in drying, or are real phenomena having their origin in the sun is a matter for investigation.

Comparison of the shifts of sensitive lines with those of other lines.

In Kodaikanal Observatory Bulletin Nos. XXXVIII and XL, Dr. Royds has shown that an increase of density displaces unsymmetrical spectrum lines in the direction of their greater widening. So far as we know, the pressure displacements are also in this direction. Consequently, the limb—centre shifts of lines unsymmetrically widened towards the red will be greater or less than those of symmetrical lines at the same

level according as the pressure and density at the limb are greater or less than at the centre of the disc. The lines chosen for comparison with these sensitive lines should be symmetrical lines originating at the same level as the sensitive lines in order to eliminate differences of velocity depending on level in the reversing layer.[1] According to St. John's values for the radial motion in sunspots, the level of the sensitive lines λλ 3949 (Ca), 4095 (Ca), 5682 (Na), and 5688 (Na) is the same as that of the iron lines of intensity 2 to 4, and the level of the magnesium lines λλ 4352 and 4703 is the same as that of the iron lines of intensity 6 to 7. The average limb—centre shifts of these lines are compared in the following table :—

TABLE II.—AVERAGE LIMB DISPLACEMENTS OF SENSITIVE LINES COMPARED WITH THOSE OF IRON LINES AT THE SAME LEVEL.

Sensitive lines	Mean shift.	Iron lines at the same level	
		Mean shift.	Intensity.
3949, 4095, 5682 and 5688	+ 0·0035 A ...	+ 0 0070 A*	2 to 4
4352 and 4703	+ 0·0040 A	+ 0 0047 A*	6 to 7

* These values are from Kodaikanal Observatory Bulletin No. XXXIX, Table II.

It will be apparent from the above table that the limb shifts of lines sensitive to pressure and density are smaller than those of iron lines at the same level.

The shifts of all the sensitive lines measured, compared with those of iron lines on the same plates, are given in Table III.

TABLE III.—AVERAGE DISPLACEMENTS (LIMB — CENTRE) OF SENSITIVE LINES, COMPARED WITH THOSE OF IRON LINES ON THE SAME PLATES.

Sensitive lines.	Mean shift.	Neighbouring iron lines.		
		Mean shift.	Number of lines.	Mean Intensity.
3949·039 Ca	+ 0·0070 A ...	+ 0·0054 A	5	6·0
4095·094, 4098·689 Ca	+ 0·0010 ...	+ 0·0046	7	3·3
4352·083, 4703·177 Mg	+ 0·0040 ...	+ 0·0058	5	4·8
4527·101, 4578·732, 4581·575, 4586·047 Ca	+ 0·0030 ...	+ 0·0070	9	4·1
5682·869, 5688·436 Na	+ 0·0035 ...	+ 0·0080	9	3·2
6102·937, 6122·434, 6162·390 Ca	+ 0·0026 ...	+ 0·0044	8	6·4
6154·438, 6160·956 Na				

Here again it is seen that the shifts of sensitive lines are generally smaller than those of iron lines which are less sensitive. The line λ 3949 is the only apparent exception, which may probably be accounted for by the higher level of the iron lines with which it is compared, as judged by their mean intensities.

[1] See odaikanal Observatory Bulletin No. XXXVI, page 52.

We are led to the same conclusion if we compare the unsymmetrical calcium lines with the symmetrical calcium lines.

These results seem to point to slightly lower pressure and density at the limb than at the centre of the disc, since lines displaced most to the red by pressure and density have a slight *relative* shift to the violet.

Absolute limb—centre shifts of sensitive lines.

According to Humphreys, the mean pressure shift for the sodium lines λλ 5682 and 5688 is +·055 A per atmosphere and that for the calcium lines λλ 6102, 6122, and 6162 is +·024 A per atmosphere. The mean limb—centre shifts for these two groups of lines are +·004 A and +·003 A respectively. Even assuming that the absolute limb—centre shift is entirely due to pressure, it is interesting to find that the difference of pressure between the limb and the centre can only be a fraction of an atmosphere.

Conclusion.

We see, therefore, that, even taking the limb shifts of lines much more sensitive to pressure and density than the iron lines, the difference of pressure and density between the limb and centre is very small, in agreement with the conclusions of Messrs. Evershed and Royds for iron lines. The balance of evidence is in favour of slightly lower pressure and density at the limb than at the centre of the disc.

I take this opportunity to express my thanks to Dr. Royds, at whose instance the work was taken in hand and whose many suggestions at various stages have been of invaluable help to me.

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