

# Kodaikanal Observatory.

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## THE DISPLACEMENTS OF THE ENHANCED LINES OF IRON AT THE CENTRE OF THE SUN'S DISC.

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The general displacement of the solar lines towards the red has been interpreted in Bulletin No. XXXVI as due to movements of the solar gases in the line of sight, and not to pressure as had been formerly believed. The movement is one of recession from the earth, or a falling movement at the centre of the sun's disc. This would suggest a circulation of the solar gases in a radial direction, the cooler gases falling from the higher parts of the sun's atmosphere, and these being replaced by hotter gases ascending from below. In discussing some eclipse spectra obtained in 1900 it was suggested that a circulation of this kind might account for the relatively great intensity of the enhanced lines of iron and other substances in eclipse spectra, as compared with their intensities in the Fraunhofer spectrum, "The highly heated ascending gases giving the predominant features to the flash spectrum, whilst the cooler more diffused gases slowly subsiding determine the character of the absorption spectrum." \*

With a view to detecting the rising movement of the hotter gases, a special study has been made of the enhanced lines of iron in the sun and in the electric arc. The spectrograph used is the same as was described in Bulletin No. XXXVI, but for most of the work a new grating ruled by Anderson was employed. This has a ruled surface 5 by 4 inches with a total of 75,080 lines. The third order spectrum was used in the green and blue parts of the spectrum, and the second order in the red. As in previous investigations of this nature the electric arc and the centre of the sun's disc were photographed simultaneously, using a reflecting device placed in front of the slit. The enhanced "spark" lines of iron were obtained by using a very short arc between iron electrodes, carrying a current of 10 to 12 ampères. Under these conditions the enhanced lines are readily photographed, and they appear all to be of the same character, narrow symmetrical lines, but neither very intense nor very sharp. They are nevertheless excellent lines for measurement when a sufficient exposure has been made. As the exposures required were generally much longer than is necessary for the sun, the latter spectrum was impressed at the middle time of the exposure on the arc, or, if several minutes were required for the sun, a succession of short exposures was distributed throughout the much longer arc exposure. As temperature changes in the grating have been found to be a source of appreciable errors in long exposures, even when the exposure on the sun is made at the middle time, the further precaution was taken of observing the temperature with a sensitive thermometer placed inside the grating chamber. If the temperature was found not to vary more than 0.2° Fahrenheit during a 30-minute exposure, the plate was considered safe for measurement.

The group of seven enhanced lines in the region 4508-4584 required ten minutes on the arc, and one minute on the sun, with the Michelson 5-inch grating. With the Anderson grating the lines 4924 and 5018 required fifteen minutes on the arc and three on the sun. The line 5169 could be photographed in five minutes in both arc and sun, but the fainter lines 5234, 5276 and 5316 required twenty to twenty-five minutes on the arc and four to five minutes on the sun. At the red end of the spectrum, using dyed "lantern" plates and the second order of the Anderson grating, nearly thirty minutes was necessary for the arc and two minutes for the sun.

The scale of the plates varies from 1.2 mm. per angstrom to 1.6 mm. per angstrom between 4500 and 5300, and in the second order red it varies from 0.84 to 0.89 mm. per angstrom between 6100 and 6400.

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\* J. Evershed, Phil. Trans. A. 201, 477.

The measures were made and reduced in the same manner as those detailed in Bulletin No. XXXVI. The residual shifts, sun — arc, after eliminating the shifts due to the earth's movements relative to the sun, are given in the table following :—

TABLE I.—SHIFTS OF ENHANCED LINES AT CENTRE OF SUN'S DISC.

	Intensity in sun.	Mean shift $\odot$ — arc in angstroms /10,000.	Number of plates measured.
4303'337 ... ..	2	+ 39	} 1
4508'455 ... ..	4	+ 60	
4515'508 ... ..	3	+ 44	
4520'397 ... ..	3	+ 3	
4522'802 ... ..	3	+ 19	
4549'642 ... ..	2	+ 21	
4556'063 ... ..	3	+ 10	} 6
4584'018 ... ..	4	+ 26	
4924'107 ... ..	5	+ 53	
5018'629 ... ..	4	+ 136	
5169'220 ... ..	4	+ 62	
5234'791 ... ..	2	+ 2	
5276'169 ... ..	3	+ 63	} 4
5316'790 ... ..	4	+ 2	
6042'315 ... ..	3	+ 39	5
6456'603 ... ..	3	— 19	1
			4

This list of sixteen lines includes only those which are of sufficient intensity in the arc for accurate measurement, and which appear in the solar spectrum as single lines sufficiently separated from neighbouring lines to admit of accurate measurement. As in previous determinations when  $\text{A}/10,000$  is taken as the unit there is a considerable variation of shift for the same lines on different plates, some lines being more consistent than others. This may be largely, but we think not wholly, due to errors of measurement.

The general result is obvious : the enhanced lines give positive shifts in every case but one. They cannot therefore represent ascending gases, as was supposed. The relation of shift to intensity found in discussing the much more numerous measures given in Bulletin No. XXXVI holds also in this series ; thus, the mean shift of the six lines of intensity 5 and 4 is  $+ 0\cdot0056 \text{ A}$ , and the mean shift of the ten lines of intensity 3 and 2 is  $+ 0\cdot0022 \text{ A}$ . If the displacement is interpreted as movement in the line of sight, it is clear that the iron vapour giving the enhanced lines shares in the descending movement of the iron vapour giving the arc lines, and the enhanced lines show also the retardation of this movement in the lower levels of the reversing layer.

There is one line in the list which gives an appreciable negative shift, the line 6456'603, but it would obviously be unsafe to conclude that this indicates rising movement in the sun. Besides this line there are two others, which, considering their intensities in the sun, give anomalous shifts. The line 5316 gives a practically zero shift, and the line 5018 gives an abnormally large positive shift. An attempt has been made to discover whether these three lines are shifted in the arc as in the case of unsymmetrical lines, when comparing the centre of the long arc with the short arc, and comparison spectra have been obtained of the central portion of an arc 3 to 4 mm. in length and a current strength of 4 ampères with a short arc 1 to 2 mm. in length and a current strength of 10 to 12 ampères. The enhanced lines at the centre of the longer arc are reduced to exceedingly fine lines, but in each case they are found to coincide in position with the much stronger lines due to the short arc. The test is a severe one, and in the green regions a large proportion of the ordinary arc lines of iron show very marked displacements to red or violet in the short arc, according to the nature of the unsymmetrical widening.\*

It is concluded that the enhanced lines generally are symmetrical in character and well suited for sun — arc measurements. The anomalous shift of the line 5018 might be accounted for if it is assumed that this line represents a considerably higher level in the reversing layer than any other of the enhanced lines, and similarly the small shift of the line 5316 would be explained if it represents a very low level. This line however, in common with the other enhanced lines, has always been regarded as a high level line from the evidence of eclipse spectra. Anomalies of this kind of course can always be explained if a compound origin for the solar line is assumed, the wave-length being affected by an unresolved component.

\* T. Royds, Kodaikanal Observatory, Bulletin No. XL.

In order to find out whether there was any relative shift between the enhanced and the ordinary lines, and also to guard against any systematic errors which might affect this particular set of plates, measurements were also made of many of the best defined and apparently symmetrical arc lines of iron. In table II we give the mean results, grouping the lines according to the colour of the spectrum where they occur :—

TABLE II.

Region.	Number of lines measured.	Mean intensity in sun.	Mean shift sun - arc in angstroms.
Blue	{ 8 enhanced lines	3.0	+ 0.0028
	{ 7 arc lines	3.9	+ 0.0039
Green	{ 6 enhanced lines	3.7	+ 0.0053
	{ 20 arc lines	3.7	+ 0.0053
Red	{ 2 enhanced lines	3.0	+ 0.0010
	{ 10 arc lines	6.0	+ 0.0041

This table shows an essential agreement of shift between the enhanced lines and the arc lines, such differences as occur being accounted for by differences of mean intensity, and by the anomalous shift of one of the two red lines.

The enhanced lines of iron in the sun give therefore no evidence of a radial circulation of the solar gases, nor of any relative movement compared with the arc lines. An upward compensating movement is of course not excluded by this result; it may be that the hotter ascending gases do not give appreciable absorption lines, the emission being of the same intensity as the background of continuous spectrum. The enhanced lines in eclipse spectra may in fact represent the ascending gases, while the enhanced absorption lines in the Fraunhofer spectrum, in common with the arc lines, represent the falling gases. If this were so, each enhanced absorption line would have an emission line on its more refrangible side when observed at the centre of the sun's disc; but it would be difficult or impossible to detect this if it were nearly equal in intensity to the continuous spectrum.

The question whether there is such a radial circulation of the solar gases, and whether the general movement of recession is radial to the sun or radial to the earth, can probably be determined by observations made across the disc from the centre towards the limb, since if the movement is radial to the sun, and part of a general circulation, the line-of-sight component of this motion should decrease to zero at the limb, the wave-lengths of the lines decreasing proportionately with the cosine of the angular distance from the centre. Observations of this kind are now being made, and the results will be published in a subsequent Bulletin.

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