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ANOMALOUS DISPERSION IN THE SUN,

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In a recent number of the Astrophysical Journal Dr. Sebastian Albrecht claims to demonstrate the effect of anomalous dispersion in the sun [1] Employing the test of the mutual influence of neighbouring dispersion bands he has obtained the solar displacements of the iron lines and finds that those lines which have a close companion on one side or the other are displaced in the sun in the direction predicted by the theory of anomalous dispersion. According to Albrecht's results lines with a companion on the red side are, on the average, displaced to the violet in the sun by 0·007 A, for a mean ratio of intensities of 3 : 4 and a mean separation of 0·24 A ; those with a companion on the violet side are displaced to the red by 0·005 A, for a mean ratio of intensities of 8 : 9 and a mean separation of 0·21 A. There is, therefore, a relative shift of 0·012 A between the two groups of lines.

The method by which Albrecht has arrived at the solar displacements must, in my opinion, be regarded with suspicion. The displacements were deduced by comparing the solar wavelengths determined by Rowland [2] with the wavelengths in the iron arc determined in the laboratory. The process was to plot the differences between the solar wavelengths in Rowland's Table and the arc wavelengths and to draw a mean curve through them to represent the systematic errors of Rowland's table ; the residuals between the actual difference for each line and the curve were regarded as the relative solar displacements of the iron lines. There are sufficient examples in the history of spectroscopy to show the danger of attempting to derive displacements from differences in wavelength tables. Certainly one would expect this to be so in comparisons with Rowland's Table. Rowland claims only an accuracy of ± 0·01 A in his standards, [3] and there are reasons to believe that this is an under-estimate of the errors. Kayser thinks that quite apart from the mistake in the absolute values, the error is generally about ± 0·02 A,[4] and that the systematic error cannot be determined within ± 0·01 A.[5] It therefore seems to me that residuals generally less than 0·01 A cannot have much real meaning and I think the comparison with displacements given in this paper shows that even the average of a fairly large number of residuals has little significance.

The solar displacements can be obtained in a direct and simple manner by comparing the solar and arc spectra simultaneously on the same plate and measuring directly the shift between the two ; after eliminating the motion of the earth relative to the sun, the true sun-minus-arc displacement is given. There can be no cavil against this procedure and the superiority, if not absolute necessity, of direct comparison methods in order to obtain displacements need not be elaborated here. If, then, Albrecht's residuals, containing perhaps innumerable unknown errors, evidence a real relative shift of 0·012 A between solar lines according to the side on which the companion lies, it is clear that the direct method of observing displacements, free from the errors involved in wavelength determination, must render the shift unmistakeable and free from doubt.

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[1] S Albrecht, Astrophysical Journal, XLI, 333, 1915.
[2] Rowland, Preliminary Table of Solar Spectrum Wavelengths.
[3] Rowland, Physical Papers, p. 557.
[4] Kayser, Handbuch der Spectroscopie, Vol. VI, p. 887.
[5] Kayser, Handbuch der Spectroscopie, Vol. VI, p. 888.

The sun-minus-arc displacements of the iron lines have been measured by various observers. Using the determinations of Evershed and Royds,[1] the sun-minus-arc displacements were compared with Albrecht's residuals for all lines common to their and Albrecht's lists. As all the data on which this comparison is based has already been published in the papers referred to it will suffice to list the lines used. They are given below .—

TABLE I.

Fe lines with companion to the red		Fe lines with companion to the violet.	
3705·708	4707 457	3680 069	4592·840
3735 014	4938 997	3737 281	4787·003
4191·595	4957·480	3887·196	4789·849
4210 494	5005·896	3895·808	4872·332
4337·216	5107 619	3969 413	4957 785
4454·552	5139·427	4132·235	5006·306
4461 818	5195 113	4134 840	5098·885
4637·685	5328·236	4144·038	5107 823
4679 027		4191·843	5139 644
		4227·606	5167·678
		4233·772	5227 362
		4308·081	5371·734
		4315·262	5447·130
		4427·482	5455·834
		4531·327	5615·877

The sun-minus-arc displacements were obtained using an arc in air at a pressure of three-quarters of an atmosphere, whilst Albrecht has made use of wavelengths in the arc in air generally at atmospheric pressure, reducing them to wavelengths at half an atmosphere which he supposes to approximate to the solar pressure.[2] It is immaterial for the present purpose to whichever of these pressures the arc wavelengths are reduced, for the *relative* shift (column 4 in Table II) of the two groups of iron lines remains practically unaffected.

The means for the iron lines listed in Table I are given below in Table II.

TABLE II.

Relative Shift of the two groups of Iron Lines.

	—	17 Fe lines with companion to red.	30 Fe lines with companion to violet.	Relative shift.
Straight means.	Albrecht's residuals [3]	— 0·0059 A	+ 0·0052 A	+ 0 0111 A
	Sun-arc displacements	+ 0·0039 A	+ 0·0068 A	+ 0 0029 A
Weighted means.	Albrecht's residuals [3]	— 0·0086 A	+ 0·0079 A	+ 0·0165 A
	Sun-arc displacements	+ 0·0032 A	+ 0·0079 A	+ 0·0047 A

The first section of the table gives the straight means and the last section the weighted means according to the weights assigned by Albrecht to each line. It is seen that whilst Albrecht's indirect method gives a relative shift of 0·0111 A (straight mean), or 0·0165 A (weighted mean), the direct method gives values only one quarter of these amounts but in the same direction. Consequently the results of Albrecht showing a large effect of anomalous dispersion in the sun are mainly, if not entirely, fictitious. It should be pointed out that the lines used in the above comparison are not those least favourable to Albrecht's conclusions since the relative shift according to the residuals is not less for the lines used than that obtained by using the whole number of lines in his tables, which was 0·009 (direct mean), or 0·0160 (weighted mean).

[1] Kodaikanal Observatory Bulletin, Nos. XXXVI, XXXVIII and XXXIX The experiments with the short arc have not been taken into account

[2] This value for the solar pressure results from ignoring the density effect. See Kodaikanal Observatory Bulletin, No. XXXVIII

[3] Albrecht's signs have been reversed to agree with the direction of the supposed displacement.

There is, however, even in the sun-minus-arc displacements a small relative shift amounting to 0·0029 A (direct mean), or 0·0047 A (weighted mean) in favour of the anomalous dispersion theory. Whether this small amount has any real significance is doubtful. It is larger than the shift to be expected from the difference in the average solar intensity of the two groups of lines, but so small a shift unless based on a large number of measurements cannot be regarded as independently establishing a physical property of the sun's atmosphere.

Although Albrecht's complete discussion of the systematic differences between Rowland's Table and the International System has not been published, it is already possible to enunciate some objections to the procedure on which his recent article depends. In reducing the arc wavelengths for comparison with solar lines Albrecht has ignored all solar conditions producing changes in wavelength except pressure. Firstly and most important, there are at the centre of the sun's disc, Doppler displacements discovered by Evershed [1] which are not constant but vary from line to line according to the effective depth of its origin in the reversing layer. How far this fact has affected the curve of systematic errors it is impossible to say without a detailed examination. Secondly, it has been shown that lines widened unsymmetrically in the arc are displaced in the sun relative to the symmetrical lines in a way which cannot be explained on pressure hypotheses. [2] However, this fact probably does not seriously affect the *relative* shift of the lines with close companions, as was pointed out previously.

Again, Rowland's exact procedure in deriving the wavelength of a particular solar line is not definitely known. In the extreme case of lines unresolved in the solar spectrum it is manifestly impossible to obtain the exact solar wavelengths of the components Yet these lines are assigned high weights by Albrecht. One can only conceive that Rowland has in these cases determined the arc wavelengths, applying an uncertain correction to reduce to the solar standards. If so, how is it possible to attach any significance to Albrecht's residuals for such lines ? If Rowland's values for unresolved lines really represented their true solar values the relative separation of the cyanogen lines between $\lambda\lambda$ 3872 and 3880 in Rowland's Table and in the arc would be an excellent test for anomalous dispersion in the sun, since the lines are very close together, of equal intensity and not complicated by pressure shifts ; but since we do not know what Rowland's values really represent it seems to me useless to make the comparison.

There are many difficulties in the way of accepting claims to demonstrate the existence of anomalous dispersion in the sun. It has been pointed out that if a Fraunhofer line is really enveloped in a dispersion band there should be, where the effect is expected to exist, a dissymmetry of the two edges of the line, producing a distortion which is not to be seen in the sun. [3] Further, Albrecht claims to show that the mutual influence of Fraunhofer lines exists when the separation amounts to as much as 0·5 A. The limit of any dispersion band present in the solar spectrum must extend less than 0·1 A from the centre of the line for the majority of lines and less than 0·05 A for many ; it is difficult to see how two such lines brought to 0·5 A apart could possibly influence each other.

The following conclusions are drawn from the above :—

(1) The residuals between Rowland's Table and arc wavelengths cannot be trusted to represent relative displacements.

(2) When the actual sun-minus-arc displacements are substituted for Albrecht's residuals the relative shift between the two groups of solar lines having a close companion on one side or the other is too small to establish anomalous dispersion in the sun.

I wish to express my indebtedness to the Director, Mr. J. Evershed, F.R.S., for many suggestions.

THE OBSERVATORY, KODAIKANAL,
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[1] Evershed, Kodaikanal Observatory Bulletin, No. XXXVI

[2] Royds, Kodaikanal Observatory Bulletin, No. XXXVIII.

[3] Evershed, The Observatory, 37, 388, 1914.

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