ON AN APPARENT CHANGE OF WAVE-LENGTH IN SOLAR IRON LINES

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Summary

The telluric oxygen lines in the solar spectrum have been used to test the stability of four solar iron lines, 6280, 6297, 6301 and 6302, interspersed within the α group. In the interval of about twenty years the absolute wave-length of each of these lines photographed at the centre of the Sun's disk appears to have decreased by measurable amounts. 6280 representing a low level in the reversing layer, is the least affected, decreasing by only 0·002 A., whilst the line 6301 representing a relatively high level, has decreased by 0·008 A. Table I shows the various yearly values of wave-lengths obtained, and the differences from the " Recommended " values of the International Astronomical Union.

At the Sun's limb, the wave-lengths of the four lines appear also to have diminished. In Table II the increase of wave-length at the limb compared with the centre spectra is shown, and this quantity for the lines 6301 and 6302 appears not to have changed materially from the earlier measures of Halm and Adams.

An investigation of the constancy of wave-lengths of atmospheric and solar lines was made by St John and Babcock * with the result that they found no reason to question the stability of the telluric lines of oxygen in the B group, and in the α group in spectra taken at intervals from sunrise to sunset, and in different years, indicating the absence of high-velocity currents in the Earth's atmosphere.

Of the constancy of the solar lines at the centre of the Sun's disk they also found that, taking the means of groups of from 13 to 21 lines in different regions of the blue, no appreciable changes were found in the years 1917 and 1921.

On the other hand, when investigating the constancy of wave-length of individual lines in "sunlight" spectra, that is light mainly derived from the central region of the Sun's disk, ruling out any local disturbances which might affect a small region at the centre, I found some marked variations amounting to several thousandths of an angstrom in the region 4337–4531, using for comparison lines in the iron arc not subject to "pole effect."† A. Hunter ‡ has called attention to an apparent change in the solar "limb effect", that is the increased wave-length of lines at the Sun's limb as compared with those at the centre of the disk, in the region 6280–6322. The redward shift at the limb appeared to have changed from +0·012 in the older measures of Halm in 1907 and Adams in 1910, to +0·008 in 1932. This may indicate a change of wave-length at the limb, or at the centre, or both.

These results and the marked instability of the sodium line D_1 at the centre of the Sun, shown in recent measures of this line § suggested the desirability of testing the stability of the stronger iron lines representing relatively high levels in the reversing layer of the Sun. The α group of telluric oxygen lines form ideal

* C. E. St John and H. D. Babcock, *Ap. J.*, **55**, 36, 1922.

† *Annual Report Kodaikanal and Madras Observatories*, 1919.

‡ A. Hunter, *M.N.*, **94**, 594, 1934.

§ " New Measures of the Sodium Line D_1 in the solar spectrum," *M.N.*, **105**, 200, 1945.

standards of reference for testing the stability of the solar lines interspersed among them. I therefore undertook, between 1940 and 1948, to make an extended series of measures in this region. The spectra were obtained with the liquid prism spectrograph, using the equivalent of ten or fifteen prisms by multiple transmission through two prisms and one reflecting half prism. The linear dispersion varied from about 1 mm./A. to 1·5 mm./A. The spectra were measured by two methods, those of lower dispersion but having the best contrast mainly by the positive-on-negative method; the rest by an accurately engraved glass plate fixed above and almost in contact with the negative to be measured, instead of the usual scheme where it is placed in the eyepiece of the microscope. The negative is attached to the long nut of the micrometer screw, and moves with it—a great improvement on the old scheme of dragging the microscope along oiled ways over a fixed negative.*

The graphical method of the reduction of the measures has been adopted; it is sufficient to state here that the wave-length of each one of the four iron lines measured in this region was determined from an oxygen line on each side of it. These O lines are based on interferometer comparisons with neon lines, and assuming that these ultimately depend on the cadmium standard, absolute values of the solar iron lines are obtained, after correcting for the orbital and diurnal motions of the Earth. These values may therefore be compared with the wave-lengths of iron lines in terrestrial sources for finding the gravitational effect of Einstein.

Unfortunately these particular lines do not appear to have been measured in the vacuum arc with sufficient accuracy for this comparison; but in any case the telluric lines, whatever wave-lengths are assumed for them, can be used to find any changes in the solar lines, assuming only their constancy, which appears to be justified.

In the year 1940, I had already measured four spectra in this region, and obtained marked deviations from the "Recommended" wave-lengths published in *Trans. I.A.U.*, **3**, 99, 1928. In the later years, I have confined attention to the following four solar iron lines, 6280, 6297, 6301 and 6302, using the O lines more or less symmetrically placed on either side of each, and using also a series of five O lines from 6279 to 6306 for determining the varying scale of the plates. I have omitted the strong *Fe* line 6290, as it is not well-enough defined in most spectra to admit of very accurate measurement. It is perhaps necessary to state that the Sun's image, of about 60 mm. in diameter, was accurately centred on the middle point of a shortened slit, and would not deviate from that position appreciably even during the comparatively long exposures of one or two minutes required for the 15-prism spectra.

The line 6280, intensity 2, excitation potential 0·855, probably represents a low level in the reversing layer, and the other three a higher level, especially the line 6301, intensity 7, e.p. 3·6, and this is confirmed by the fact that the former always gives a rotation value about 3 to 5 per cent smaller than the others in measures of limb spectra, in accordance with the remarkable rule that the angular speed of rotation increases with height above the photosphere.

In the table which follows I give in four columns the fractional wave-lengths of the lines measured, beginning with the "Recommended" wave-lengths of the

* For a full description of the micrometer and the method of reduction of the measures, see *M.N.*, **99**, 120 and 122, 1938.

I.A.U., and followed by my recent measures of two old Kodaikanal grating spectra of a central section across the whole disk of the Sun. These are in very close agreement with the "Recommended" values. Next follows the mean of three Edinburgh grating spectra, photographed by Storey in the year 1934, and kindly sent to me by Dr Ellison. Following this are the yearly mean values of the Ewhurst prism spectra from 1940, with the means of each of the four years up to 1948 May 18.

TABLE I

Decrease of Wave-length of Solar Iron Lines

Year	Source of the Measures	6280	6297	6301	6302
1928	International Astronomical Union	0·622	7·799	1·508	2·499
1914	Kodaikanal from a paper print	0·620	7·785	1·508	2·496
1915	Kodaikanal from a negative	0·622	7·799	1·508	2·498
1934	Edinburgh mean of 3 spectra	0·622	7·795	1·504	2·497
1940	Ewhurst mean of 4 spectra	0·623	7·796	1·503	2·497
1946	Ewhurst mean of 43 spectra	**0·620**	**7·793**	**1·500**	**2·495**
1947	Ewhurst mean of 14 spectra	0·622	7·794	1·501	2·496
1948	Ewhurst mean of 11 spectra	0·621	7·795	1·502	2·498
Decrease of wave-length of the 1946 spectra		−0·002	−0·006	−0·008	−0·004

It appears that the minimum wave-lengths for all the four lines was reached in 1946, and this is followed by a tendency to increase. These minimum values are in heavy type in the table, and the differences from the International values are given at the foot of the columns. The low-level line 6280 is the least affected, having diminished by two units only in the third decimal, while the high-level line 6301 decreases by eight units. In the year 1947 August, I was able, with the cooperation of Dr Thackeray, to secure two grating spectra at the Cambridge Observatory and measures of these confirm very closely the results of the prism spectra, giving an even lower value for the line 6301.

It is unfortunate that I have only two spectra from earlier years to compare with the recent values, but these agree closely with the International values. It must be stated, however, that the interferometer measures of these lines, given in the last column of Table IV of Vol. 3 of the *Trans. I.A.U.* differ slightly from the "Recommended" values, and if these are substituted the decrease would be less, except for the first line, as follows :—

6280	6297	6301	6302
−0·003	−0·005	−0·005	−0·002

As regards the accuracy of the measures, the mean yearly values are not likely to be in error by as much as one unit in the third decimal, except perhaps the 1940 measures of only four spectra. The low-level line 6280 is remarkably constant in wave-length, and has therefore a smaller uncertainty than the others, which occasionally show rather large changes from plate to plate, indicating real changes. The line 6297 is the best for the accuracy of measurement.

General shift to red of the lines at the Sun's limb

I now give some results of measures of limb spectra showing the general increase of wave-length at the limb compared with the centre of the disk. This increase can be measured directly when the spectra have been photographed at the same time both at the centre and at the limb. This has been done in the case of the Edinburgh spectra of 1934 already alluded to. These photographs include, in addition to the three spectra of the centre of the disk, three of the east limb and three of the west limb. The results are given in Table II, following the earlier measures of Halm in 1907 and Adams in 1909 for two of the lines. In the case of the Ewhurst spectra obtained in subsequent years, the east and west limbs were photographed simultaneously by the method described in *M.N.*, **93**, 165, 1933, whilst the centre of disk spectra were obtained separately, and at different times. The true wave-lengths of both the limb spectra and the centre spectra were determined by applying the appropriate corrections for the orbital and diurnal motions of the Earth. The centre wave-lengths were then subtracted from the limb wave-lengths; and as the differences are liable to rather wide changes on different dates, due probably to bad definition of the Sun's limb, I have in Table II given the means of several spectra in the different years.

For all the limb spectra from 1940 to 1943 inclusive I used the very consistent values obtained in the centre spectra in 1940 and in the 1946 series I used the slightly smaller wave-lengths obtained from 43 centre spectra in that year.

TABLE II

Mean Shifts, Limb—Centre

Year	Source of the Measures	6280	6297	6301	6302
1907	Halm			+0·012	+0·012
1909	Adams 0·99 from centre			+0·012	+0·012
	No correction to limb applied				
1934	6 Edinburgh spectra 0·97 from centre	+0·008	+0·010	+0·011	+0·009
	Correction to limb +0·002				
1940	20 Ewhurst spectra 0·97 from centre	+0·007	+0·008	+0·011	+0·009
	Correction to limb +0·002				
1941	18 Ewhurst spectra 0·94 from centre	+0·007	+0·009	+0·011	+0·010
	Correction to limb +0·003				
1943	6 Ewhurst spectra 0·94 from centre	+0·008	+0·006	+0·010	+0·010
	Correction to limb +0·003				
1946	20 Ewhurst spectra 0·98 from centre	+0·007	+0·010	+0·011	+0·008
	Correction to limb +0·001				

It is very necessary in all these measures to correct for the distance within the limb at which the spectra were secured. In Table II these corrections have been applied to the Ewhurst and Edinburgh measures: they are estimated from my measures of the change of wave-length between centre and limb, given in Kodaikanal Observatory Bulletin No. 49. The mean results for the four years of the

Ewhurst spectra, when so corrected, are in better agreement than was anticipated, and those of the year 1946 agree very closely with the mean of the three Edinburgh spectra of the year 1934 measured directly from the centre spectra impressed on the same plate.

As to the earlier results of Halm and Adams, there appears to be only a slight decrease in the later years, but if I had used the "Recommended" values of the I.A.U. for the centre of the disk, the limb-centre shifts would have been very much smaller.

These results of the limb spectra appear to show that the wave-lengths at the limb must also have diminished, if anything, even slightly more than at the centre.

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