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THE RED SHIFT OF THE D LINES OF SODIUM IN THE SUN.

J. Evershed, F.R.S.

In the *Observatory* for 1923 October (**46**, 303) I have recorded the results of some measures of the shifts of the D lines of sodium at the centre of the Sun's disc and at the limb. These were obtained with the large grating spectrograph of the Kodaikanal Observatory, using a 45-mm. image of the Sun and the sharp sodium emission lines given by a carbon-iron arc containing some crystals of a potassium salt.

The results, corrected for the air pressure at Kodaikanal and assuming zero pressure in the Sun, indicated shifts towards red slightly in excess of the Einstein relativity effect, both at the centre of the Sun and at the limb. Unlike the lines of iron, there was no increase of wave-length in passing from centre to limb. At both positions the mean value of D1 and D2 was +·015 A. But this value depends very largely on the reliability of measures of pressure shift. According to Humphreys (*Astrophysical Journal*, **6**, 210), the pressure shift for 1 atmosphere is approximately +·011 A. both for D1 and D2.

During the year 1937 I have redetermined the shift for the D1 line only, using the liquid prism spectrograph with ethyl cinnamate or methyl naphthalene as the dispersing agent. This last has a slightly greater dispersive power than cinnamate; with 10 transmissions through the prism it gives nearly double the linear dispersion of the grating plates, with about half the exposure time on the Sun.

The comparison spectrum is produced by a low-pressure sodium lamp made by Messrs. Philips. This lamp contains solid sodium metal and neon gas at a pressure not exceeding 4 cm. of mercury at room temperature. When the electric current is first applied the red light of neon appears, but as the tube warms up sodium evaporates, and after five minutes fills the tube with a dazzling yellow light. The neon spectrum then is replaced by the D lines of sodium. At the working temperature of about 270° C. the pressure in the tube would be raised to about 1/10th atmosphere. The D lines are remarkable for their sharpness and brilliance, never exceeding in width the solar absorption lines, and of an intensity comparable with the continuous spectrum near D of the Sun itself. This has the great advantage that equal and simultaneous exposures can be made on Sun and lamp. With 10 transmissions through the prism an exposure of 30 seconds is sufficient for process panchromatic plates.

The lamp is placed near the slit of the spectrograph and to one side of it, the light entering the slit through two small reflecting prisms. The Sun's image, 60 mm. in diameter, falls directly on the slit, and any part of it, centre or limb, is directed between the two prisms, which are separated by an interval of 2 mm. The collimator-camera lens of the Littrow spectrograph is completely filled with light from both sources.

The linear dispersion obtained with 10 transmissions through methyl naphthalene in a 63° prism and a lens of 16 feet focus is ·69 A. per mm. at D1, the two sodium lines being separated by nearly 9 mm. D2 in the moist climate of England cannot be used in this research, owing to a water-vapour line which broadens it on the red side, more or less according to the humidity of the air, the altitude of the Sun, and the relative motion of Earth and Sun. It is seen separated from D2 only at the Sun's east limb in an autumn morning, when the solar line is shifted nearly the maximum amount towards blue.

Confining attention therefore to D1, the following results have been obtained, using the positive on negative method of measuring, for which the spectra are well adapted.

Red Shift of the Sodium Line D1.

No. of Spectra measured	Position	Sun − Sodium Tube	
12	Centre of disc	+·0123 ± ·0003	
12 pairs	Equator	+·0115	Mean of limb spectra +·0123 ± ·0002
22 pairs	12° to 24°	+·0130	
10	North pole	+·0120	
10	South pole	+·0120	

The spectra of the Sun's equator and between latitude 12° and 24° were taken in pairs, east limb and west limb, the shift being derived from half the difference W.–E. to eliminate the solar rotation effect.

The differences here shown at different positions on the limb are probably of no significance, and the mean of 54 estimates from all the limb spectra agrees with the centre shift.

These are the observed values of the shifts, corrected for the orbital and diurnal motions of the Earth relative to the Sun, but not corrected for difference of pressure in the two sources. Assuming a zero pressure in the higher parts of the reversing layer, represented by the D line, and a pressure of 1/10th atmosphere in the sodium lamp, then, from Humphreys' measures of the pressure shift of D1, ·0011 A. must be added to the figures given above, and the mean shift then becomes +·0134 A., both at centre and limb, the relativity shift equivalent to ·634 km./sec. being +·0125 A.

Whether this small correction for pressure is applied or not, it is evident that D1 gives a close approximation to the theoretical shift both at the centre and limb, as had previously been found from 33 grating spectra of less dispersion but in which D2 was included.

The sodium lines therefore differ from the iron lines, which give shifts at the limb nearly twice the relativity effect, and a marked increase of shift between centre and limb for the lines representing lowest levels. They differ also from the calcium lines H3, K3, which give the same displacements as iron at the limb, but a change of wave-length between centre and limb in the opposite sense, the redward shift increasing from limb towards centre, where it becomes actually three times the relativity effect.

These changes of wave-length between centre and limb are most readily explained by movements of the solar gases radially outward in the case of low-level iron, and inward (that is, a motion of descent) for calcium in the higher chromosphere.

It is true that such measures as have been made of low-level lines at intermediate points between centre and limb give a law of increase of wave-length differing from the simple theoretical relation on the assumption of uniform radial streaming; but this I think is to be expected from the fact that near the limb the absorption lines represent a higher level than at the centre, and the velocity of outflow probably accelerates, as it does in the case of eruptive prominences and in the outflow from sunspots.

The constancy of the limb shift, or of the difference of wave-length between centre and limb, has been called in question by A. Hunter (*M.N.*, **94**, 600, 1934) from the results of measures of two solar rotation plates from the Edinburgh Observatory obtained in the year 1932. These gave much smaller values limb – centre than had been observed in previous years, especially by Halm in 1907.

It is uncertain whether this apparent change is due to a temporary variation of wave-length at the centre of the disc or to a secular change of wave-length at the limb, as Hunter appears to assume. My own experience is that temporary changes of the shift limb – arc or limb – centre frequently occur, but innumerable measures of limb shift over a series of years give no certain evidence of long-period changes. To test this possibility, however, four pairs of east and west limb spectra in the H and K region were obtained in November last, and these were found to yield limb – arc shifts for the iron lines in close agreement with previous values—that is, nearly twice the Einstein prediction. It cannot be supposed therefore that the smaller limb shift of the sodium line D1 indicates a general change.

Sodium, and probably also aluminium, represented by the two lines of that element between H and K, occupies an intermediate position between the calcium of the higher chromosphere and the low-level iron, a position where there appears to be no radial movement outward or inward. A similar intermediate position is taken by sodium in sunspots, where low-level iron lines show outward motion and high-level calcium lines inward motion, the D lines of sodium being undisplaced. But in this case the motion is parallel to the Sun's surface, not radial to the Sun. It is as if the normal radial outflow at low levels and inflow at high levels were increased in sunspots and changed in direction from vertical to horizontal, the intermediate zone represented by the D lines remaining undisturbed.

But in whatever way we interpret the changes of wave-length across the disc of the Sun, or in sunspots, and the large shift of the iron and calcium lines at the limb, amounting to nearly twice the predicted shift, it is evident that the sodium lines do not share in these changes, and a factor of 2 is not required to bring theory into line with observation; for the measures herein recorded indicate a close approximation to the prediction of Einstein, both at the centre of the disc and the limb.

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Summary.—By means of multiple transmission through a liquid prism containing methyl naphthalene, measures have been made of the shift of the line D1 in high-dispersion spectra of the Sun compared with similar spectra of a low-pressure sodium lamp. A table is given showing the shifts, corrected for the motion of the Earth, at the centre of the Sun, at the equatorial and polar limbs and in spot latitudes. Unlike the lines of iron or calcium, the sodium line is found to give the same shift towards red at the centre of the disc as at the various points on the limb, and this shift agrees very closely with the Einstein relativity effect. The constancy of the shift of the solar lines was tested by photographing the iron lines in the H and K region, and these spectra were found to yield the same values for the shifts as had been observed in former years, namely, nearly twice the relativity effect, at the Sun's limb.