Some Problems of Astronomy.

XIV. The Displacement of the Lines of the Solar Spectrum towards the Red.

When the spectrum of the Sun is directly compared with that of a metal in the electric arc, such as iron, so that the spectra may be seen side by side in the field of view of the spectroscope, the observer is immediately struck with the wonderfully exact way in which the bright lines of the arc correspond with many of the dark solar lines. In regions of the spectrum where the iron lines are numerous this marvellous "fit" of the two spectra is most impressive and convincing; even with very high dispersive power the bright lines seemingly form precise prolongations of the dark lines.

Exact measurements of the bright and dark lines show, nevertheless, that when the sunlight is taken from the centre of the Sun's disk so as to eliminate the small displacements due to a component in the line of sight of the Sun's rotation movement, there yet remains a minute shift of one spectrum with reference to the other; the solar lines may be either slightly on the red side or slightly on the violet side of their terrestrial equivalents.

This discrepancy is largely due to movements of the Earth itself, the component of the diurnal rotation in the direction of the Sun, and the orbital movement of the Earth as a whole, approaching the Sun in autumn and receding from it in spring. There is also a small monthly oscillation of the Earth in the direction of the Sun due to its revolution round the centre of gravity of the Earth-Moon system. All of these movements and their line-shift equivalents can be readily computed and applied to the measures of the solar lines as corrections to reduce them to the normal positions they would occupy were the Earth at rest relatively to the Sun.

When this is done it is still found that the fit of the solar and terrestrial spectra is not perfect, there is a very small residual shift which, unlike a motion shift, affects some lines much more than others. This shift is in general towards the red, the solar lines having slightly increased wave-lengths, or a plus shift, compared with the arc lines. Not only are the shifts very variable from line to line, but the *sign* of the shift is not the same in all the lines, even of the same element, some giving a minus shift.

This residual shift was first observed by Jewell when engaged under Rowland in studying the solar and arc spectra. Rowland himself did not believe in the reality of such small displacements, which he considered to be due to instrumental causes. Their reality has, however, been confirmed by later work; and since the discovery that the wave-length of a line is to a small degree dependent on the pressure of the radiating gas, the discrepancies have been ascribed to a difference of pressure in the radiating gases in the Sun and in the electric arc. By comparing the residual shifts, Sun − arc, with the shifts produced at known pressures, Jewell estimated the pressure in the reversing layer to be of the order of 7 atmospheres for certain regions of absorption.

Subsequently, Messrs. Fabry and Buisson took up the enquiry and made very accurate measures of the displacements of some of the iron lines in the Sun by the method of interference, the wave-lengths of the solar and arc spectra being determined absolutely as well as relatively. By a careful study of certain selected lines of iron in different spectral regions these observers concluded that pressures of 5 to 6 atmospheres must exist in the region of iron absorption *.

An extended research on the subject has recently been undertaken at the Kodaikanal Observatory with results that are entirely opposed to the accepted doctrine that the shifts are due to pressure. Taking into consideration probable differences of level represented by lines of different intensity, the Kodaikanal results lead to the conclusion that motion in the line of sight of the iron vapour (a descending motion on the Sun) affords an adequate explanation of the Sun—arc shifts.

This change of view is of such importance, in relation to the conditions prevailing in stellar photospheres generally, that some account of the work on which the results depend may not be out of place here.

At Kodaikanal the solar and arc spectra are photographed simultaneously and with very high dispersion, the spectra forming contiguous strips of small width on the plate. These are measured either in the ordinary way with a micrometer, or with a special form of spectro-comparator which has been specially designed for this kind of work. While the measures probably cannot claim quite the same order of accuracy as those of Fabry and Buisson, a much larger number of lines have been studied, including lines of great intensity in the Sun which were omitted by Fabry and Buisson on account of special difficulties in their measurement by the interference method.

The result of this wider range of measures has made it possible to compare the average shifts of the iron lines which are most affected by pressure with the average of those which are much less affected. In this way an estimate of the pressure may be made without reference to the absolute shifts of the solar lines, which may be influenced to some extent by motion in the line of sight.

Duffield has shown that the iron lines are shifted by very different amounts in the arc under pressure, certain groups of lines being displaced three or four times more than other groups.

* *Astrophysical Journal*, vol. xxxi. p. 114.

These same groups may be observed in the Sun and their relative displacements measured.

At Kodaikanal this has been done, with the rather unlooked-for result that on the average the lines most affected by pressure are decidedly *less* shifted towards the red than the lines least affected by pressure. Assuming that the solar iron lines are influenced by pressure in the same way as the iron lines in the arc, this can only mean that the pressure in the reversing layer is decidedly less than one atmosphere—in fact, a zero pressure would better fit the facts than a pressure of one atmosphere.

But Messrs. Fabry and Buisson consider that the lines which are most affected by pressure are also those which widen unsymmetrically towards the red in the arc, so that in measuring the centres of the emission lines in the arc under pressure a spurious displacement is obtained which would not be observed in the solar absorption lines. It is not at all certain, however, whether the solar lines would not also be affected by this unsymmetrical widening; but even if they are not, there can be no doubt that there are real differences of shift due to pressure alone between the different groups which Duffield has measured, and the relative shifts of these same groups in the Sun compared with the arc in air may, I think, be relied on to show whether the pressure in the reversing layer exceeds or falls short of one atmosphere.

The problem is further complicated by the circumstance that the different lines even of the same element in the solar spectrum do not necessarily represent the same level in the Sun, and the low-level lines would presumably be subject to larger pressure shifts than the high-level lines. Fortunately some light has been thrown on the problem of the different levels represented by different lines by the researches of St. John on radial motion in sun-spots. It has been shown that this movement is inwards towards a spot-centre in the higher chromosphere, but diminishes with the depth until a level is reached where the motion ceases. Below this inversion occurs, and the movement is outwards and necessarily increasing with the depth. This is the region of the reversing layer at the base of the chromosphere, and here St. John finds that it is possible to gauge the depth by the intensity of a line. As the strong lines give small motion in spots and the weak lines large motion, the latter must represent lower levels than the former. In this manner St. John has deduced a scale of levels corresponding in a remarkable way with the scale of intensities of the lines.

Applying this criterion of level to the Sun—arc shifts, most significant results are obtained. It is found that here the weak lines representing low levels give the smallest shifts towards the red, and the strong high-level lines the largest shifts. This is absolutely opposed to the pressure theory of the displacement, because one would expect the low-level gases to be subject to higher pressures than the high-level.

If we ascribe the shift to motion in the line of sight instead of pressure, no improbable assumptions have to be made to account for the different behaviour of the lines of different intensity; we merely have to suppose that there is a descending movement of the iron vapour all over the Sun, which is greatest in the higher levels and least in the low levels of the reversing layer. It is true we must assume a compensating upward movement or a circulation of the solar gases. Other considerations, however, favour this idea. In discussing the spectroscopic results of the solar eclipse of 1900, I have shown that an ascending movement of the hotter gases giving the enhanced lines, compensated by a descending movement of the cooler gases, explains in a satisfactory way the differences between the flash-spectrum observed at eclipses and the reversal of this spectrum—the ordinary dark-line spectrum of the Sun.

We may examine the Sun—arc shifts from another point of view to determine whether pressure or motion is the effective cause. The pressure shifts increase very largely as the wave-length is increased, being proportional to λ^2 or λ^3, whilst a motion shift is proportional to λ simply. But the Sun—arc shifts actually diminish as we go from the violet towards the red end of the spectrum, some of the largest shifts I have measured being in the ultra-violet region. This is quite inexplicable on the pressure theory, but is readily accounted for on the motion theory; for the lines in the less refrangible regions are, on the average, of much less intensity than those in the more refrangible regions, and therefore represent lower levels; and we have seen that the motion is retarded in the lower levels.

From the foregoing considerations it is concluded that the absolute shift of the solar lines towards the red is not due to pressure, but to a motion of descent of the iron vapour, which is greatest in the higher levels of the reversing layer and is retarded in the lower and denser regions. We find also that there is distinct evidence of a *minus* pressure effect in the relative displacements of groups of lines which are most and least affected by pressure, indicating a pressure in the region of iron absorption which is less than one atmosphere.

The conclusion reached that pressure in the reversing layer is of a very low order, perhaps less than $\frac{1}{4}$ atmosphere, opens up a new problem, for it leaves unexplained a remarkable phenomenon discovered by Halm when working at the solar rotation by the spectroscopic method. He found that certain lines at the Sun's limb are displaced towards the red when compared with the centre of the disk. This he explained as a result of pressure, the effective region of absorption for rays passing tangentially through the Sun's atmosphere being at a lower level, and therefore higher pressure than for rays passing normally through the atmosphere as they do when coming from the centre of the disk.

Later work by Adams at Mount Wilson, and the measures of a large number of lines made at Kodaikanal, have shown that the vast majority of the lines at the Sun's limb are shifted towards the red when compared with the lines at the centre of the disk.

These relative shifts appear to be related to intensity as in the Sun—arc shifts, but in the opposite sense, the weak lines being most shifted and the strong lines least. This relation is apparent only, for it is really due to the varying shifts of the lines at the centre of the disk; thus, when the limb shifts are added to the Sun—arc shifts, or, what comes to the same thing, when the limb shifts are determined absolutely by comparison with the arc lines, the relation to intensity vanishes, and the shifts are found to be remarkably uniform—at any rate, in the case of the iron lines.

The difference of pressure which would be indicated between the centre of disk and limb amounts to several atmospheres, or something of the same order as the pressures supposed to be indicated by the Sun—arc shifts. If, however, the Sun—arc shifts imply a pressure of $\frac{1}{4}$ atmosphere only, the large difference of pressure between limb and centre becomes very improbable, and we must seek a new explanation of the limb shifts.

Much work has already been accomplished at Kodaikanal on the limb shifts, and, without going into further details, I may simply state that the results seem clearly to indicate a motion shift rather than a pressure shift. The problem is a very puzzling one, for we cannot in this case assume motion without involving an apparent influence of the Earth on solar phenomena. The movement is directed away from the Earth at all points on the limb of the Sun, and is the same, so far as we know, at all times of the year. That it should be in any way controlled by the Earth appears almost unthinkable; yet the same relation is indicated by the prominences. The Kodaikanal observations show that movements in the line of sight in prominences at the limb are in general away from the Earth, and the line shifts in prominences can scarcely be attributed to pressure.

An apparent influence of the Earth is also shown in the distribution of sun-spots east and west of the Central Meridian, as has been shown by Mrs. Maunder; and the Kodaikanal records show a marked inequality in the distribution of the prominences on the eastern and western limbs, which is very difficult to explain, except by supposing the Earth to exert a sort of extinguishing influence on prominences.

It will be realized that the complete elucidation of the meaning of the limb shifts is a most interesting and pressing problem, involving, as it appears to do, such remarkable consequences.

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