# Kodaikanal Observatory.

## BULLETIN No. XVIII.

### PRESSURE IN THE REVERSING LAYER.

THE publication by Humphreys of measures of the displacements due to pressure of the principal lines of many of the elements * has made it possible to estimate pressures in the sun on the assumption that the spectra of the mixed metallic vapours in the reversing layer are subject to the same line displacements as occur in arc spectra when individual metallic elements are subjected to pressure in air.

The tables of line displacements published by Humphreys, and later by Duffield,† indicate a very wide range of variation in the amount of the displacements at a given pressure, both for different elements and for different lines of the same element. Thus the most affected lines of some elements are subject to a "pressure shift" over five times greater than that of the least affected lines.

The measurement of this relative shift of the different lines of an element affords by far the most promising method for estimating pressures in the sun, for the absolute shifts cannot with any certainty be assigned to pressure alone; there may be other causes of displacement such as motion of the source of light, or of the observer. But the relative displacements of the most and least affected lines will give a value of the pressure free from any uncertainties arising from possible Doppler shifts due to motion of the solar gases. Nor is it necessary to take account of the shifts due to the elliptic and diurnal motions of the earth. Even accidental shifts due to an instability of the apparatus during the exposure of a plate will have no effect on the result. In short any cause which gives an equal shift to all the lines can have no influence.

In the absence of very accurate wave-length tables for terrestrial spectra it is not at present possible to obtain an exact estimate of pressure in the general reversing layer of the sun, but a comparison of Kayser's values of the iron lines in the arc at normal pressure, and the corresponding values in Rowland's Preliminary Table of the solar spectrum is of interest as indicating the probability that the pressure is less than one atmosphere.

In the following table I have entered in the columns headed "Most Affected Lines" all the lines from Kayser's list which have a pressure shift exceeding 0·025 Å for 10 atmospheres, and Rowland's values of these lines in the sun. In the columns headed "Least affected Lines" similar entries are made of all lines occurring in the same regions which have a pressure shift less than 0·025 Å for 10 atmospheres. The pressure shifts given in the last columns headed H and D are from those given by Humphreys and by Duffield respectively, and are reduced to 10 atmospheres pressure. In deriving these values Humphreys' measures at 42 atmospheres and Duffield's at 40 atmospheres were used, and each reduced to 10 atmospheres. In Duffield's tables two sets of determinations are given and the values I have entered are from the mean of the two. All the values in the last three columns of each set of lines are in thousandths of angstroms.

* Astrophysical Journal XXVI., 18.

† Philosophical Transactions A 208, 111.

## IRON LINES IN SUN AND ARC.

| Most affected lines | | | | | Least affected lines | | | | |
|---|---|---|---|---|---|---|---|---|---|
| λ ⊙ Rowland | λ arc Kayser. | Difference ⊙ — arc. | Pressure shift, 10 At H | D | λ ⊙ Rowland. | λ arc Kayser | Difference ⊙ — arc | Pressure shift, 10 At H. | D. |
| | | | | | 3414 020 | ·025 | − 5 | 11 | ... |
| | | | | | 3450 469 | ·484 | − 15 | 13 | |
| 3458 442 | ·454 | − 12 | 26 | .. | 3471 404 | 413 | − 9 | 9 | . . |
| | | | | | 3475 594 | 600 | − 6 | 11 | . . |
| | | | | | 3476 849 | ·850 | − 1 | 14 | . |
| | | | | | 3618 919 | ·918 | + 1 | 19 | . |
| 3622·147 | ·158 | − 11 | 39 | | 3631 605 | ·617 | − 12 | 21 | . |
| | | | | | 3758 375 | ·381 | − 6 | 21 | |
| 3767 341 | ·339 | + 2 | 28 | | 3763 945 | ·940 | + 5 | 23 | . |
| | | | | | 3813·219 | ·202 | + 17 | 14 | |
| 3815 987 | 987 | 0 | 26 | .. | 3821·591 | ·591 | 0 | 10 | . |
| 3820·586 | 578 | + 13 | 30 | | 3826 027 | ·028 | − 1 | 21 | . |
| | | | | | 3827 980 | ·967 | + 13 | 24 | .. |
| 3834 364 | ·370 | − 6 | 26 | . | 3840 580 | ·586 | − 6 | 23 | |
| 4187 204 | ·221 | − 17 | | 120 | 4175·806 | ·799 | + 7 | ... | 21 |
| 4191·595 | 611 | − 16 | ... | 122 | 4181·919 | 918 | + 1 | 17 | 22 |
| 4210 494 | ·521 | − 27 | . | 50 | 4199 267 | ·256 | + 11 | 17 | 18 |
| 4222 382 | ·387 | − 5 | | 81 | 4202 198 | ·195 | + 3 | 17 | 21 |
| 4227 606 | ·606 | 0 | | 105 | 4219 516 | 523 | − 7 | 18 | 23 |
| 4233 772 | ·771 | + 1 | 57 | 133 | 4245 422 | 423 | − 1 | 14 | . |
| 4236·112 | ·118 | − 6 | 65 | 147 | 4250 945 | 948 | − 3 | 21 | 21 |
| 4250 287 | ·299 | − 12 | | 104 | 4271 934 | ·933 | + 1 | | 30 |
| 4260 640 | ·656 | − 16 | 59 | 64 | 4282 565 | ·567 | − 2 | 10 | 14 |
| 4271·325 | 333 | − 8 | | 87 | 4294 301 | ·290 | + 11 | 20 | 28 |
| 4299·410 | ·420 | − 10 | .. | 133 | 4369 941 | ·954 | − 13 | 13 | 16 |
| 4383 720 | ·724 | − 4 | 30 | 15 | 4376·107 | ·104 | + 3 | 9 | 15 |
| 4430·785 | 801 | − 16 | 45 | 68 | 4427·482 | ·490 | − 8 | 13 | 15 |
| 4442 510 | ·522 | − 12 | 45 | 63 | 4454 552 | ·572 | − 20 | 19 | 22 |
| 4447 892 | ·907 | − 15 | 43 | 64 | 4461 818 | ·838 | − 20 | 14 | 13 |
| 4494·738 | ·755 | − 17 | 48 | 62 | 4466·727 | ·737 | − 10 | 13 | 14 |
| ... | ... | | .. | | 4476·185 | ·207 | − 22 | 17 | 15 |
| | Means ... | − 8·8 | + 40 5 | + 85·4 | | Means ... | − 8·0 | +16·0 | +18·9 |

Mean relative shift of most affected lines in sun (8·8 − 3 0) = 0·0058 Å to Violet.
Mean relative shift of most affected lines for each atmosphere above normal pressure (Duffield) = 0·00665 Å to Red.
Deduced pressure in reversing layer = 0·13 Atmosphere.

An apparent displacement to the violet is shown in a large proportion of the solar lines, but it is to be observed that the average shift of the lines most affected by pressure is greater than that of the lines least affected, so that there appears a small relative shift to the violet of the most affected lines amounting to 0·0058 Å.

The pressure shifts determined by Duffield are in fairly good agreement with those of Humphreys' but the mean values are decidedly larger for the most affected lines, the relative shift of the most affected lines is therefore considerably greater in Duffield's determinations than in Humphreys'. If we take the former as a basis for the calculation, the pressure in the reversing layer corresponding to a relative shift of 0·0058 Å to the violet would be only 0·13 atmospheres, assuming that for pressures below 1 atmosphere the shift is proportional to pressure. If Humphreys' values are taken, the resulting pressure is a *minus* quantity.

It is well known that systematic errors of greater magnitude than the quantities here dealt with affect both the solar and arc wave-lengths. Rowland's solar wave-lengths were empirically connected with his arc standards, upon which Kayser's measures were based, and by this process systematic errors were introduced. The wave-lengths in sun and arc in the above table are therefore both subject to these errors, affecting the relative positions of lines in widely separated regions of the spectrum For this reason I have selected from the lines least affected by pressure only those which occur in the same spectral regions as the most affected lines, omitting all the rest in order that the distribution in the spectrum of the two sets of lines may be

nearly the same. Thus the systematic errors which are the same for the sun and arc wave-lengths will have no appreciable effect on the result.

The omitted lines, over a hundred in number, have a mean displacement, sun—arc, of—0·0019 Å and their inclusion would merely have the effect of slightly increasing the relative shift of the most affected lines to the violet.

Accidental errors of individual lines will of course have a much more serious effect. Almost all of the lines compared are single lines in the solar spectrum and for the most part well isolated from others, so that errors due to difficulties in measurement of the solar lines should not be great, however, in view of the uncertainties in the estimates of pressure shift and the wide divergencies in some of the lines in the table very little weight can be given to the numerical value of the pressure above deduced. What I wish especially to emphasise is the fact that, on the reasonable assumptions mentioned at the outset, it does not seem possible that the pressure in the reversing layer can exceed one atmosphere. If, for instance, a pressure of one atmosphere above normal pressure is assumed then instead of a relative shift of 0·0058 Å towards the violet, the most affected lines would be displaced towards the *red* with reference to the least affected 0·0066 Å if the means of Duffield's measures are relatively correct.

Nickel appears to be the only other element giving a sufficient number of widely differing pressure shifts to make a comparison with the sun desirable, unfortunately the arc wave-lengths are not nearly so well determined as those of iron, and the lines most affected by pressure occur in a limited region of spectrum where no lines of small shift have been measured. A comparison which will be free from the systematic errors of Rowland is not therefore possible.

The very low pressure thus deduced in the reversing layer conflicts with previous estimates based on the absolute differences of position of the lines in solar and terrestrial spectra. Messrs. Fabry and Buisson, in a recent paper,* deduce a pressure of 4 to 5 atmospheres above normal pressure, from the absolute displacements towards the red, observed by interference methods, in certain selected iron lines when passing from the arc to the sun. No mention is made, however, of corrections to the observed displacements depending on the elliptic and diurnal motions of the earth, the sum of which may equal or exceed the quantities measured. From this, and from the absence of information as to the exact part of the sun's disc observed, it is not possible to judge of the reliability of this result, even if it is assumed that no part of the observed shift was due to a motion of descent of the absorbing gases on the sun.

The same remarks apply also to a previous estimate by Jewell, Humphreys, and Mohler,† who deduced pressures ranging from 2 to 7 atmospheres, but appear to have made no corrections for movements of the earth.

Messrs. Fabry and Buisson distinguish between "normal" lines, *i.e.*, those which widen symmetrically on increasing the current in the arc, and abnormal lines, which widen unsymmetrically, either towards the red or violet, and their estimates of pressure are derived from the displacements of the normal lines only, which are not subject to so large a pressure shift as are the abnormal lines.

According to these observers, the lines most affected by pressure (Duffield's Group III.) are those which widen towards the red on increasing the current in the arc, and for these lines they find a small or negative displacement on passing from the arc in air to the sun, that is a relative displacement towards the violet compared with the normal lines. This is in agreement with the results of the above comparison of Kayser's and Rowland's wave-lengths; but Messrs. Fabry and Buisson do not interpret this fact as I have done. They consider that Humphreys' and Duffield's measures of pressure shifts for the abnormal lines may be subject to error "Mais leur déplacement par la pression peut comporter une erreur: aux pressions élevées, l'élargissement dissymétrique de ces raies devient très grand; la mesure du déplacement doit être très incertaine, et le déplacement apparent est accru par l'élargissement vers le rouge."‡

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* Comptes Rendus, 15th March 1909 † Astrophysical Journal III., 139. ‡ Comptes Rendus, 10th May 1909.

It appears to me that, if the large shifts observed under pressure are partly due to unsymmetrical widening, similar effects might be expected in the sun, so that these abnormal lines would still appear relatively shifted towards the red, compared with the normal lines, if the pressure in the reversing layer exceeds one atmosphere.

Messrs. Fabry and Buisson have also observed the arc in a partial vacuum. Under a pressure of a few millimeters the abnormal lines are reduced in width, and altered in position in such a manner that the general displacement towards the red in passing from the arc to the sun is the same for all the lines. In other words the width and relative positions of all the lines in the arc under reduced pressure approximate much more closely to the solar spectrum than is the case with the lines of the arc under normal pressure. But the obvious inference that the gases in the sun are subject to a correspondingly low pressure does not seem to have been considered by Fabry and Buisson, presumably because of the general shift towards the red of all the lines. It is not clear, however, how this can be distinguished from a motion shift.

KODAIKÁNAL,
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