THE RED SHIFT OF THE SOLAR LINES AND RELATIVITY

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The differences in wave-length between the centre of the sun's disk and the vacuum arc for 331 iron lines are used as the basis of a discussion, from the relativity point of view, of the displacements of the solar lines.

In favour of relativity is the general displacement to the red and against it is the discordance between the magnitudes of the observed displacements and the deductions from the theory. The accompanying table illustrates what has long been recognized, namely, that both the stronger lines and the weaker lines give displacements at the centre of the disk that differ systematically from the calculated values, columns 3 and 7, while for lines of medium intensity the displacements are in substantial agreement with the calculated values. The stronger lines show displacements about 50 per cent. greater and the weaker lines about 30 per cent. smaller than the displacements predicted by the theory of general relativity.

TABLE I

<table>
<thead>
<tr>
<th>Group</th>
<th>No. of Lines</th>
<th>Solar Intensity</th>
<th>Mean Wave-length</th>
<th>Calculated</th>
<th>Observed</th>
<th>Obs.-Cal.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>17</td>
<td>12</td>
<td>3825</td>
<td>0.008</td>
<td>0.012</td>
<td>+0.004 0.3 km. Down</td>
</tr>
<tr>
<td>2</td>
<td>24</td>
<td>14</td>
<td>3821</td>
<td>0.008</td>
<td>0.012</td>
<td>+0.0032 0.25 &quot; &quot;</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>10.4</td>
<td>4308</td>
<td>0.0091</td>
<td>0.013</td>
<td>+0.0022 0.16 &quot; &quot;</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>6.2</td>
<td>5443</td>
<td>0.0115</td>
<td>0.012</td>
<td>−0.0063 &quot; &quot;</td>
</tr>
<tr>
<td>5</td>
<td>131</td>
<td>4.8</td>
<td>4758</td>
<td>0.0100</td>
<td>0.0084</td>
<td>−0.0016 0.1 &quot; Up</td>
</tr>
<tr>
<td>6</td>
<td>106</td>
<td>4.5</td>
<td>4763</td>
<td>0.0100</td>
<td>0.0069</td>
<td>−0.0031 0.2 &quot; &quot;</td>
</tr>
<tr>
<td>7</td>
<td>33</td>
<td>3.3</td>
<td>4957</td>
<td>0.0105</td>
<td>0.0074</td>
<td>−0.0031 0.2 &quot; &quot;</td>
</tr>
</tbody>
</table>

This discrepancy between observed and calculated displacements has long stood in the way of an interpretation based upon general relativity. It is the purpose of the present discussion to suggest a harmonizing interpretation.

The key to the solution offered is that the deviations from theory shown by the strong and weak lines are to be correlated not with line-intensity but with the levels in the sun's atmosphere at which the lines are produced. This is clearly evident from the behaviour of lines of enhanced and normal titanium. Correlation with levels is shown in the accompanying tabulation where lines at heights in the flash spectra of 6000, 1300 and 435 km. show respectively absolute
displacements of +0.015, +0.0112 and 0.0054Å and deviations of +0.007,
+0.002 and −0.0034Å, from the displacements calculated from relativity
theory. That the deviations are not associated with line-intensity is shown by
comparing the displacements and deviations for enhanced and normal lines of
approximately equal intensities, which show respectively absolute displace­
ments of +0.0112 and +0.0054Å and deviations of +0.002 and −0.0054 from
the calculated values.

<table>
<thead>
<tr>
<th>Red Displacement and Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td>Enh. Ti . . . . . . . . . 2</td>
</tr>
<tr>
<td>Enh. Ti . . . . . . . . . 8</td>
</tr>
<tr>
<td>Normal Ti . . . . . . . . . 5</td>
</tr>
</tbody>
</table>

The low pressure in the reversing layer removes at one stroke consideration
of pressure shift and of ray-curving due to anomalous refraction. The Zeeman
effect of the general magnetic field tends only to produce a slight but sym­
metrical widening of the lines. The Stark effect has not been found in the sun
although looked for under conditions apparently favourable to its appearance.

There remain to be considered Doppler and general relativity, neither of
which alone is capable of producing red displacements of the solar lines in agree­
ment with the observations. These two in combination, however, offer the
simplest interpretation of the displacements at the centre of the disk. In
column 8 of Table I are shown, reading from top to bottom, the magnitudes and
the directions of the radial movements in the solar vapours that would account
for the deviations from the Einstein Theory for high and low-level lines.

These velocities, upward near the photosphere and downward at high
elevations, appear to result from spectrographic integrations over very extended
areas of the solar surface, millions of square miles. If currents are upward
over the bright hot granules and downward over the larger and cooler interspaces
the integrated Doppler effect would be a slight widening of the spectral line
greater on the violet than on the red edge. The decrease of upward velocity
with elevation brings about a balanced state at the level of lines of medium
intensity. Above the level of equilibrium the cooler downward drifting vapours
become of increasing influence and the integrated effect is an asymmetry on
the red edge increasing with increase of elevation.

The low pressure and the greater displacement to the red of high-level lines
in the sun are confirmed by the low pressure found in Sirius, Procyon and Arcturus
and by the larger red displacements of high-level in comparison with the dis­
placements of low-level lines in the stellar atmospheres. The velocities of the
solar vapours required to account for the deviations from the predictions of
relativity are of an order of magnitude consistent with the stellar observations.

At the sun’s limb where the radial components of velocity vanish, the red
displacements of all lines exceed the relativity displacements by small amounts.
This excess, the real limb effect from the relativity point of view, may be in­
terpreted as the effect of molecular scattering in accordance with the Rayleigh-
Schuster formulae. Professor Julius has called attention to the fact that in
general the refractive power is greater on the red than on the violet side of an
absorption line by twice the refractive power of the solar atmosphere. As the
coefficient of scattering increases as the square of the refractive power, the differen­
tial scattering tends to widen the lines on the red edge. The short paths
through layers of low density at the centre of the disk would account for the
absence of differential widening at the centre while the greatly lengthened paths
at the limb would furnish conditions favourable to the differential effect.

The conclusion is that three major causes are producing the regular differ­
ences between solar and terrestrial wave-lengths and that it is possible to dis­
entangle their effects. The causes appear to be the slowing up of the atomic
clock in the sun to an amount predicted by the theory of generalized relativity,
radial velocities of moderate cosmic magnitude and in probable directions, and
differential scattering in the longer paths traversed through the solar atmosphere
by light coming from the limb of the sun. The first obtains for all lines in all
parts of the sun, the second appears regularly and continuously, downward at
very high and upward at the very low levels, while the third manifests itself in
the so-called limb-effect.