THE PROBLEM OF THE RED SHIFT IN THE SOLAR SPECTRUM.

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We have heard a great deal recently about the red shift in the distant nebulæ. In the tiny spectra of these objects the great bands H and K, ordinarily situated near the limit of the visible spectrum, are found to take great leaps of hundreds of angstroms towards red, or rather we should say the whole spectrum shifts. Is this to be interpreted as an almost incredible motion of

* 'Archivio Universitario in Padova', Fitza 631, Carta 46.
† Bianchi-Giovini, 'Lettere di Paolo Sarpi', I. p. 250.

recession, up to about one-eighth of the velocity of light in the most distant nebulæ, or is something else affecting the wave-length of light ?

In the solar spectrum we have a similar problem, but on a microscopic scale. The minute shifts of the solar lines towards red in light coming from the centre of the Sun's disc, or in general sunlight, can be explained in terms of motion and of the gravitational effect of general relativity. But at all points of the Sun's limb, from the pole to the equator, there is an excess of shift for the iron and calcium lines, which has yet to receive a satisfactory explanation, since it cannot be ascribed to motion of recession without involving a repulsive action by the Earth.

It may be of interest to recall the earliest observations of the solar line shifts and of the successive stages in interpreting them.

In measuring spectra for Prof. Rowland's "New Table of Standard Wave Lengths", Jewell found that the lines in the spectra of the electric arc were invariably displaced to violet when compared with the same lines in the Sun. He also found that different lines on the same photograph gave different shifts, proving that the effect was not instrumental in origin, as Rowland had assumed.

No mention was made in Jewell's work of corrections applied for motions of the Earth in the direction of the Sun, which might account for a difference of ±0·010 A. in the violet region, according to whether the photographs were taken in the afternoon in the spring when we are receding from the Sun at an appreciable speed or in the morning in autumn when we are approaching. If these corrections are applied, and the spectra are taken at the centre of the Sun's disc, then the solar lines are invariably shifted by small amounts towards red with reference to terrestrial spectra. But the shift differs for lines of different intensity in the same element, and for iron may vary from 0·005 to 0·015 A. in the violet region, or if expressed as motion from about 1/3 km./sec. to 1 km./sec.

The discovery by Humphreys and Mohler in 1895 that pressure affects the wave-length of spectrum lines seemed to give the clue to this anomalous shift of the solar lines. In a joint paper, Jewell, Mohler, and Humphreys estimated from the measured amounts of the shift that the reversing layer in the Sun was subject to pressures of the order of 2 to 7 atmospheres (1). This apparently satisfactory explanation of the solar line-shifts held sway for 14 years thereafter, and was used also to explain the still larger shifts found all round the edge of the Sun.

In the year 1909 the question of pressure in sunspots and in the reversing layer was taken up at the Kodaikanal Observatory. The spectra of sunspots gave somewhat inconclusive results as regards pressure, but at once revealed the more obvious line-shifts due to the outflow of gases from the umbra (radial motion). It was, however, shown from studies of the relative shifts of lines more or less affected by pressure, and of lines representing high or low levels, both at the Sun's centre and at the limb, that the pressure close to the photosphere could not exceed 3/4 of an atmosphere, the air pressure at Kodaikanal (2). In the *Observatory*, vol. **32**, the low pressure which my earlier observations indicated was challenged by E. T. Whittaker on the ground that it is unsafe for various reasons to apply laboratory pressure shifts to solar conditions, where, owing to the great depth of the gases in the chromosphere, and the enormous force of gravity at the surface of the Sun, a pressure of the order of thousands of atmospheres might be expected.

In 1923, the late Dr. St. John at Mt. Wilson made similar differential measures of line-shifts when much more material had become available. He deduced a pressure at low levels in the reversing layer of $0{\cdot}13 \pm 0{\cdot}06$ atmosphere (3); thus confirming the Kodaikanal result that pressure shifts in the reversing layer might be ruled out of consideration, even for the iron lines. Saha's estimates of ionization in the Sun also led to extremely low pressures.

Having simplified the problem by eliminating pressure, there remained only two possible causes of shift, namely motion in the line of sight in a direction away from the Earth, and Einstein's prediction for general relativity of a small redward shift, or possibly a combination of both. If motion alone were the cause of the shift, it would appear that in general sunlight reflected by the planet Venus from the unseen hemisphere of the Sun the shift would have the opposite sign. And if the light came from a region on the Sun directed 90° from the Earth, the shift would be zero. To discover whether this happened or not, a long series of grating spectra of Venus was photographed and measured at Kodaikanal, and a comparison of these spectra with sky spectra taken with the same apparatus appeared to show a zero shift when the angle Venus–Sun–Earth was about 90°, and a change of sign when the angle was considerably greater. It appeared later, however (1922/23), that this was an illusion and the difference between the Venus and sky spectra may have been due to unequal illumination of a rather wide slit in the case of the Venus spectra. After building a more efficient spectrograph, in which a larger image of Venus was projected on a narrower slit, a series of spectra obtained when the angle V–S–E was very large clearly showed that the shifts of the lines from light coming from the back of the Sun were the same as in the check plates of the sky spectra.

This result, and innumerable measures of the shifts of the iron lines at the Sun's centre and limb, told heavily in favour of the Einstein effect being mainly responsible for the general redward shift.

Going back to the year 1917, St. John measured the shifts of 40 band lines of cyanogen in the Sun and carbon arc, hoping in this way to eliminate completely effects of pressure and pole-effect, since these lines are unaffected by either. The result was no shift at the Sun's centre, and a very small positive shift at the limb, a result clearly opposed to Einstein's prediction (4). But at Kodaikanal in 1920, confining attention to the stronger *CN* bands or lines having the same relative intensities in Sun and arc, the shifts at the Sun's centre averaged +0·004 and at the polar limbs +0·007 A., the latter in close agreement with the predicted shift of +0·008 A. (5). The discrepancy with Mt. Wilson illustrates the difficulties encountered in measuring faint lines in the ultra-violet, especially those selected by St. John.

In 1927 St. John made a further set of measures of 515 lines in the cyanogen band, and these later results for limb and centre are in very close agreement with the Kodaikanal measures. He refers to his earlier selected lines as " the forty thieves ".

In his final paper on the " Gravitational Displacement of Lines in the Solar Spectrum ", St. John summarizes the results of very numerous measures, including the lines of iron, titanium, manganese, silicon and the bands of cyanogen. From a total of 1537 spectral lines at the centre and 133 iron lines at the edge of the Sun, compared with their wave-lengths in the vacuum arc, he concludes that Einstein's prediction is well confirmed, although a small excess over prediction was found in the 133 iron lines at the limb (6). This excess proves, however, to have been greatly under-estimated. Actually for iron and calcium the total shift at the limb varies from 1·5 to 1·9 times the Einstein effect, according to innumerable measures made at Kodaikanal and at Ewhurst (7). These measures, made in ordinary sunlight, have been confirmed in a small group of lines by some measures by Royds of limb spectra at the eclipse of 1936. The excess in some iron lines in the red region nearly equals the Einstein effect, so that a factor of 2 appears to be required to bring prediction into line with observation in this region.

In the ' Proceedings of the National Academy of Sciences of India ' (vol. **6**, 1936) and in the Indian Physico-Mathematical Journal ' (vol. **8**, 1937), Dr. Sir S. M. Suleiman has propounded a new theory of light, according to which a light corpuscle consists of a binary system with components of equal mass and opposite charges, rotating round each other and travelling with the velocity of light. One consequence of this theory is that the spectral shift at the edge of the Sun should be twice the Einstein value. Another makes the deflection of light of stars past the Sun to be between 1·3 and 1·5 times the Einstein value. These predictions might be thought to be confirmed by my measures of the iron lines in the red, and by Freundlich's observed value of the deflection of stars near the edge of the Sun. But it does not seem probable that all the lines of iron are subject to a shift which is twice the Einstein value, and we have to consider also the lines of other elements than iron. I have found from recent measures of the sodium D lines that the displacement at the limb of the Sun and at the centre, and presumably over the entire disc, has precisely the Einstein value of +0·0145 A. These lines represent a high level in the reversing layer, and are therefore not subject to the outward movement of the lower gases, but there is no excess at the limb.

The excess shift of the calcium and iron lines at the limb cannot easily be explained by Compton's scattering, due to the very long path of the rays through the chromosphere, for one would expect a diffusive widening on the red side of the lines instead of the perfect symmetry shown when a positive image is reversed on the negative. Moreover, innumerable measures of the calcium lines in prominence spectra at considerable altitudes above the limb give exactly the same shift.

There can be little doubt that the Einstein effect accounts for most of the shift in the solar spectrum. Were we situated on the planet Pluto, instead of on the Earth where we can observe the Sun in detail, we should certainly be satisfied about general relativity, for although we should get a medley of shifts in the spectrum of the star-like Sun, as we do here in general sunlight, the mean of all would be close to the predicted shift, and the differences could be readily explained by radial movements of the solar gases, as shown by St. John.

The limb effect remains, however, an unsolved problem. If we suppose the nebular shifts to be due to some cause other than a motion of recession, as Hubble suggests is probable, might we not apply this to the solar limb effect? Probably not, for if the nebular shift is strictly proportional to distance, as it appears to be, then the solar shift should be at least ten billion times smaller than the shift in the more distant nebulæ, whereas it is actually only some 80,000 times smaller.

References.

(1) *Astrophysical Journal*, **3**, 139, 1895.
(2) *Kodaikanal Observatory Bulletins* 18, 36, and 39.
(3) *Astrophysical Journal*, **60**, 32, 1923.
(4) *Astrophysical Journal*, **46**, 265.
(5) *Kodaikanal Observatory Bulletin* 44.
(6) *Astrophysical Journal*, **67**, 44.
(7) *Monthly Notices of the Royal Astronomical Society*, **96**, 152–159.