Displacement of the Lines in the Solar Spectrum and Einstein's Prediction.

A SMALL displacement towards the red of the solar spectrum lines when compared with terrestrial spectra has been known since Rowland first applied high dispersion to the spectra, but the cause of this discrepancy in wave-length has yet to be determined.

At Kodaikanal the problem has received a large share of attention since the year 1913, and the results have been published from time to time in the Observatory 'Bulletins.'

It may be well, however, to re-state the main conclusions reached, and to give a brief account of the present position with regard to Einstein's predicted line-displacement. The problem has gained additional interest because of the brilliant confirmation at the recent eclipse of the predicted deflection of light near the Sun.

The early suggestion that the displacement was due to pressure in the reversing layer of the order of six or seven atmospheres was generally considered to be the correct explanation. It was shown, however, in Kodaikanal Observatory Bulletin No. 36 that the only true pressure-effect traceable indicates a lower pressure in the Sun than exists in the electric arc in air, and the evidence favoured the view that the displacement was due to a motion of descent of the gases in the higher levels of the solar atmosphere which was retarded in the lower levels.

As a general movement of the solar gases in a direction radial to the Sun would affect the wave-length of the solar lines near the centre of the disc but not at the limb, it became of interest to measure the shifts, Sun–arc, both at the limb and at numerous intermediate points between centre and limb, to determine the law of change of wave-length across the disc.

The results of the measures of limb shifts are given in K.O. Bulletin No. 39, and of relative shifts at intermediate positions in Bulletin No. 49. It was found, as was already known, that the wave-length increases near the limb—that is, the Sun–arc displacement becomes greater. But here, again, we were able to show that there was little or no indication of a pressure-effect. Also it was shown that the large variations of shift depending on line-intensity observed at the centre of the disc tend to disappear at the limb where the shifts limb–arc are more nearly uniform; they have no relation to intensity, and do not increase with wave-length even when rather widely separated regions of the spectrum are compared. The rate of change of wave-length in passing from the centre of the disc to the limb was also found to be quite incompatible with Halm's theory of a relative pressure-effect at the limb*

* In a study of the limb–arc shifts of lines sensitive to pressure and density, or "pole-effect," Mr. Narayana Aiyar finds additional evidence against any relative pressure-effect at the limb.—K.O. Bulletin No. 44.

This absence of pressure-effects in the reversing layer is perhaps surprising, considering that the depth of the layer is roughly 2000 km. and the force of gravity nearly 28 times greater than at the surface of the Earth. But even supposing that the gases are subject to gravity only, and are not influenced by the opposing force which causes prominences to leave the Sun with accelerating motion, it appears that the line-spectrum itself is evidence of extreme tenuity of all the gases above the photospheric level. In the case of hydrogen a ray of photospheric light coming from near the limb traverses 90,000 km. before emerging from the upper surface of the chromosphere, yet this prodigious depth of gas appears perfectly transparent to all wave-lengths between the Balmer lines; and even the lines themselves are partially transparent, only the stronger members of the series, Hα, β, γ, giving evidence of approximately complete absorption.

The appearance of the line α in a radial section of the Sun's limb, spreading at the base like the outline of the Eiffel tower, was formerly supposed to indicate a great increase of pressure near the photosphere; but the widths of the successive lines prove that this is not so, the width being approximately proportional to λ, whilst a pressure widening is roughly proportional to λ^{-3}*. The widening is probably a Doppler effect depending on the increase of temperature near the photosphere.

As regards the density of the iron vapour and other metallic constituents of the reversing layer, it is not necessary to suppose that a ray of light in its passage through the so-called "atmosphere" of the Sun encounters more atoms of iron than are present in a few centimetres' thickness of luminous vapour in the iron arc! And, of course, the total pressure of all the 34 elements tabulated by Rowland would on this basis be negligible. It is of significance also with regard to pressure in the Sun that in the spectrum of the iron arc in vacuum the relative positions of the lines are in much better agreement with the solar lines than are the lines of the arc in air.

I lay stress on the evidence for a low pressure at the base of the reversing layer because, if my conclusion is correct that the pressure is less than one atmosphere, we may disregard pressure-shifts in our study of the Sun–arc displacements.

So far, then, we have shown that over the entire face of the Sun the iron lines are displaced towards red by amounts that increase from the centre towards the limb, where they reach the maximum value. Eliminating pressure-shifts from consideration, we have to account for the phenomenon either by motion in the line of sight or by the gravitational effect of Einstein, or by both causes combined.

The average displacements of 42 iron lines not subject to pole

* Rossi, *Astrophysical Journal*, xxxiv. p. 312.

effect in the arc, and measured at the centre of the disc and at the limb, are given in K.O. Bulletin No. 36 as follows:—

	In angstroms.	In km./sec.
At centre of disc	+0·0094	+0·643
Near limb	+0·0148	+1·000

To eliminate possible motion of the solar gases in a direction radial to the Sun we consider the limb-shifts only, since at the limb such motion would have no component in the line of sight.

Had it been practicable to measure the displacements at the limb instead of slightly within the disc, the result for the limb-shift would probably be about 20 per cent. greater; thus in velocity it becomes 1·20 km./sec., or almost twice the amount (0·634 km./sec.) predicted by Einstein. The pressure-shifts of all the lines measured are known, and it would be necessary to assume a pressure of three atmospheres above the air-pressure at Kodaikanal to account for this excess of displacement above Einstein's prediction. In view of what has been stated above, this seems to me quite inadmissible.

At the centre of the disc the displacement is almost in agreement with prediction, but this is an accidental coincidence because, as already mentioned, the shift at the centre varies greatly from line to line, depending on intensity, and the mean values obtained in any series of measures will depend very largely on the mean intensity of the particular group of lines chosen.

Discussing the results with reference to level in the reversing layer, it appears that the ultra-violet strong lines representing high levels show the largest Sun–arc shifts at the centre of the disc; but the increase of wave-length at the limb is least for these lines. The low-level lines in the red part of the spectrum, on the other hand, show the largest increase of wave-length at the limb, but only a very small Sun–arc shift at the centre. Interpreting these results on the motion hypothesis, it would mean that over the entire face of the Sun there is a motion of recession from the Earth, affecting only the higher levels at the centre, but involving the entire depth of the reversing layer at the limb, where the movement exceeds 1 km./sec.

It was with a view to verifying or otherwise this extraordinary movement, implying repulsion by the Earth, that the observations of Venus were instituted; and it must be admitted that, contrary to expectation, the Venus spectra have, so far, given almost unqualified support to this hypothesis.

Four series of Venus spectra have been obtained since January 1917, with the planet atternately a morning and an evening star. All of them indicate smaller wave-lengths in the light reflected by the planet when compared with control plates of ordinary daylight. The most complete and apparently trustworthy series

was obtained between April and September 1918. The mean displacements in angstroms from this series are given below :—

		9 more affected lines.	7 less affected lines.
17 control plates of daylight.....		+0·010	+0·003
8 Venus plates in April and May.			
Mean angle ♀ ☉ ⊕	45°	+0·008	+0·002
4 plates June " "	75°	+0·002	−0·002
7 " July " "	95°	−0·001	−0·004
4 " September " "	135°	−0·006	−0·010

This shows a progressive diminution of wave-length as the angle Venus–Sun–Earth increases and the planet approaches superior conjunction. Corrections for the relative motion of planet and Earth and the Earth's diurnal movement have, of course, been applied, and there can be no error in the solar parallax large enough to account for the result ; moreover, any such error would have its greatest effect in the April plates, which give the smallest deviation from the control plates.

If we can believe these measurements, we have to conclude that when sunlight is derived from a hemisphere of the Sun turned 90° or more from the Earth, the Sun-arc displacement does not exist ; and if we could observe the hemisphere turned opposite the Earth the displacement would be towards violet instead of towards red.

It is evident from this defiance of Einstein's theory and the favouring of a very incredible hypothesis that the most careful confirmation is needed—preferably by independent investigators.

Assuming for the moment that the Venus measures are affected by some undiscovered source of error, we will see how far it may be possible to bring the direct measures of the displacements into line with Einstein's prediction.

In order to eliminate the pressure-shifts from the problem, measures have been made by St. John at Mt. Wilson of a group of band-lines in the carbon arc spectrum known to be unaffected by pressure. With "limited observational material" St. John finds a very small displacement towards red of the stronger lines in the bands, and a practically zero shift for the fainter lines, which he considers to be of especially high weight. At Kodaikanal measures have been made by Mr. Narayana Aiyar of a series of 15 plates of the limb and carbon arc spectra and 10 of the centre of disc and arc, all obtained during the months of March and April 1918 in exceptionally clear sky. The results unfortunately do not bear out St. John's conclusion. We find that by selecting 10 of the most characteristic triplet-bands in the first head near 3883 the mean shift towards red, limb–arc, closely approximates to Einstein's prediction. The different plates of the same limb are in good agreement, but there is a systematic difference between north and south polar limbs, the north giving smaller shifts than

the south. The individual triplet-bands give nearly the same limb-shifts, and there seems no reason to suspect them to be affected by blends with other lines. But we agree that the fainter lines in the series give shifts at the limb which are, at any rate, much less than the equivalent of 0·634 km./sec.

Our results for the bands referred to are :—

	In angstroms.	In km./sec.
North polar limb	+0·0061	+0·47
South polar limb	+0·0088	+0·68
Centre of disc	+0·0043	+0·35

It is quite probable from this result and from a recent series of measures of the iron lines, which also confirm the difference between north and south, that we have to deal with a somewhat variable quantity.

The general result of our measures of band-lines and of metallic lines, including measures by Dr. Royds of the lines of nickel, titanium, and several other elements*, shows that there is a general displacement of the lines at the Sun's limb, which, if not in exact agreement with Einstein's prediction, is of the right sign and the right order of magnitude. This displacement cannot be explained by pressure, nor by motion, unless we admit an Earth effect. But the shifts differ for different substances, and for the different lines in the same substance, so that if Einstein's hypothesis be true there is some unknown modifying influence at work. In the case of the iron lines the absence of any increase of shift with wave-length also requires explanation. The smaller shifts at the centre of the disc present no serious difficulty, since a general ascending movement of the gases would readily account for it.

On the motion hypothesis all of these anomalies are easily explained, and no unknown modifying influence is necessary; but we have to believe in the Earth influence.

This being the present position of the problem, it is evident that the most pressing need is to obtain further confirmation of the Venus measures, because it is these which offer the most stubborn opposition to Einstein's theory. J. EVERSHED.

Kodaikanal, 1920, January 12.