Kodaikanal Observatory.

BULLETIN No. XXXVI.

A NEW INTERPRETATION OF THE GENERAL DISPLACEMENT OF THE LINES OF THE SOLAR SPECTRUM TOWARDS THE RED.

In Bulletin No. XVIII a rough estimate was attempted of the pressure in the reversing layer of the sun, based on the assumption that those lines which are most and least affected by pressure in the laboratory would also be similarly affected in the sun, so that a comparison of relative positions of the solar lines and the lines in the spectrum of the electric arc at atmospheric pressure should give a value of the pressure in the sun which would be independent of the absolute displacements of the solar lines which might be affected also by motion in the line of sight.

The result of a comparison of the iron arc wave-lengths measured by Kayser and the solar wave-lengths of Rowland, the only material then available, seemed to show clearly that if the above assumption is correct the pressure in the reversing layer could not exceed one atmosphere, the evidence tending to show indeed that the lines most affected by pressure are in the sun slightly displaced towards the violet relatively to those least affected by pressure, indicating a less pressure in the sun than in the iron arc in air.

This conclusion conflicts with estimates of the pressure based on the absolute shift of the solar lines to the red compared with the normal positions of those lines in terrestrial sources, such estimates indicating pressures up to five or six atmospheres.

I propose to show in this paper that taking into consideration probable differences of level the absolute and relative shifts can be quite easily explained as due to motion in the line of sight, and have very little relation to pressure shifts.

The relative shifts to the red of the lines in the spectrum of the sun's limb compared with the centre of the disc can also be much more readily explained as a motion shift, than as a pressure shift, although this interpretation involves an apparent influence of the earth on solar phenomena analogous to that which affects the distribution of sunspots and prominences. I shall give in a subsequent paper the results of our measures of the limb shifts and the conclusions to be drawn from them.

Since the introduction of the electric installation at Kodaikanal Observatory it has been possible to get direct measures of the absolute and relative shifts of the solar lines compared with those in the spectrum of the electric arc. It is evident that by directly confronting the arc and sun on the same plate, and measuring the absolute displacements, much more reliable results can be obtained than by comparing wave-length determinations of sun and arc by different observers

Although the quantities measured are exceedingly small and subject to considerable errors, the results of the investigation so far as it has gone are so strongly opposed to the view that pressure is the main factor in producing the solar line-shifts that I consider it proper to publish these results, notwithstanding the fact that a very large amount of measuring work needs yet to be accomplished before the exact values of the shifts of each line can be considered as definitely established.

The spectrograph employed for the work is designed to give the highest photographic resolution that can be obtained in the third order spectrum of either a Rowland or a Michelson grating. The former has 15,028 lines per inch over a ruled surface 3¼ in. long, and the latter has about 14,500 lines per inch and an effective ruling of 5 inches. The slit, collimator, and grating are mounted on a solid mass of masonry, the slit-mounting being firmly attached to a heavy iron rail which is embedded in cement. The camera-tube is inclined to the collimator at an angle of 60 degrees, and the plate-holder is attached to a heavy mounting fixed on a separate masonry pier. The collimator lens is a visual achromatic of 7 ft. 6 in. focal length, and the camera lens is a single plano-convex of about 14 ft focus for D. About bisecting the angle between camera and collimator is placed a 3-inch observing telescope, which receives light from the first or second order spectrum of the grating.

The slit is provided with various devices for simultaneous exposures on different light-sources and for alternate exposures. For the simultaneous exposures great attention is paid to the adjustment for securing a perfectly equal illumination of the grating from the different light sources to be compared. For the sun and arc comparisons photographs were obtained with a reflecting device placed in front of the slit, by means of which simultaneous exposures were obtained at the exact centre of the sun's disc and the arc spectrum of iron or other metal. The solar spectrum forms a central strip, 2 mm. in width, with the arc lines contiguous to it on each side. The illumination of the grating is adjusted with a wide slit, so that an image of the object glass or projecting lens may be seen on the grating by observing through the telescope with the eye-piece removed, and adjusted to coincidence for each source. The slit is then closed to its working width of 03 to ·04 mm., the beam of light from each source is then spread laterally by diffraction and covers much more than the entire ruled surface of the grating. With this adjustment properly effected there can be no possibility of spurious shifts of the lines, due to unequal illumination of the grating from the two sources.

The arc was obtained with a direct current and with iron poles burning in air at a pressure of 580 mm., the normal pressure of the air at the elevation of the observatory. The current strength was between 5 and 10 amperes, and the length of the arc varied from about 5 to 10 mm. The poles were usually reversed during the middle of the exposure so as to equalise the intensity of the iron lines above and below the solar spectrum. Owing to the unequal relative intensities in different spectral regions of the sun and arc spectra, it was found necessary in photographing some of the less refrangible lines to give considerably longer exposures to the arc than to the sun, in order to get good measurable lines in both spectra, but in the more refrangible regions the exposures were usually synchronous, although in the H and K region where the arc lines are very intense the reverse procedure might be adopted with advantage.

The plates were measured in the direct and reversed position on the micrometer, and the mean of the observed shifts taken. Owing to a systematic bias in measuring the lines of bright and dark line contiguous spectra the shifts appear considerably larger in one position than in the other but this error is eliminated in the means. In a few cases the measures were made by the positive on negative method described in Kodaikanal Bulletin No. 32 A large number of the plates were measured in duplicate by different measurers and the mean results taken. In this work I have been greatly assisted by Miss Feline and Mr. Narayana Ayyar, B.A., third Assistant at this observatory.

The scale of the plates varies; it is about 1·2 mm. to the angstrom near K, and 1·8 mm. to the angstrom near D. A few fourth order plates have been measured in which the scale was 2·6 mm. to the angstrom.

The measures are difficult, and in some cases rather unsatisfactory. As the largest shifts found do not exceed 0·03 mm. in linear measure, and the limits of perception in the micrometer microscope for ordinary observers may be put at about 1/10 of this, it is obvious that the tabulated results must be subject to considerable errors, even when the mean is taken of several determinations. Nevertheless it is claimed that the order of magnitude of the different shifts is very fairly reliable, and cannot, I believe, be subject to changes which would modify the conclusions which I have based on them. Specially difficult lines such as those which are close doubles in the sun, or unsymmetrically widened, as well as lines which are very weak in the arc, are probably greatly affected by the personal habit of the measurer.

Some of the lines show a decided instability of position, giving sometimes a + and sometimes a — shift. This is not due to difficulty of measurement, since the lines are well defined in both sun and arc. I cannot say whether this instability is in the solar or arc lines, but in most cases where it occurs the plates have been re-measured and the results confirmed.

Another difficulty encountered is the systematic variation of the shifts from plate to plate. Although individual lines generally give the same relative shift on different plates, the absolute shift varies somewhat from plate to plate, so that measures from a single plate can only be trusted to give relative shifts.

As relative shifts however are of great importance in determining the relation to pressure shifts, I include in this discussion a number of lines for which only single plates have been available.

The actual measured shifts between solar and arc lines are of course affected by the earth's movements relative to the sun and in the reductions the component of the diurnal movement has been computed from the usual formula V=·464 sin t. cos δ. cos φ, t being the hour angle of the sun, δ its declination and φ the latitude of Kodaikanal. The velocity at the earth's equator, 464 Km/sec. is derived from Clarke's value of the equatorial semi-diameter. The orbital movement is taken out directly from the Nautical Almanac values of the radius-vector of the earth, no computation being required for the lunar perturbation since this is included in the velocities so obtained.

In table 1, I give the residual shifts of the solar iron lines after eliminating the shifts due to the earth's movements. These are given in the fourth column. The fifth column gives the pressure shifts at nine atmospheres, taken from the tables of Gale and Adams * and supplemented by the measures of Humphreys and Duffield reduced to the same pressure. The unit in each of these columns is 0·001A. A sixth column is added for remarks. In the first two columns the wave-lengths and intensities are from Rowland, and the third column gives the number of plates measured from which the average shifts have been determined.

TABLE I.

λ Rowland.	Intensity	Number of Plates.	Residual shift ⊙ − arc.	Pressure shift, 9 atmospheres.	Remarks.	λ Rowland	Intensity.	Number of Plates	Residual shift ⊙ − arc.	Pressure shift, 9 atmospheres	Remarks
3895 803	7	1	+ 11	+ 11		4308 081	6	2	+ 7	+ 21	
3899 850	7	4	+ 19	+ 12		4315 262	4	2	+ 5?	+ 19	The plates give very inconsistent values
3903 090	10	4	+ 17	+ 22							
3906 628	10	4	+ 11	+ 11							
3920·410	10	4	+ 15	+ 10		4325 439	8	2	+ 11	+ 20	
3923·054	12	4	+ 14	+ 11		4337·216	5	1	+ 6	+ 27	
3928 075	8	4	+ 18	+ 12		4352 908	4	1	+ 5	+ 17	
3930 450	8	4	+ 14	+ 13		4369 941	4	1	+ 11	+ 23	
3931·269	1	1	+ 8	...		4376·107	6	1	+ 14	+ 18	
3935 965	2	1	+ 13	...		4383 720	15	2	+ 11	+ 27	
3948 925	4	1	+ 6	+ 11		4404 927	16	2	+ 9	+ 21	
3956 819	6	4	+ 4	+ 14		4415·293	8	2	+ 12	+ 18	
3964·413	10	4	+ 14	+ 22		4427 482	5	1	+ 3	+ 17	
3977 891	6	3	+ 6	+ 17		4430·785	3	1	+ 2	+ 48	
3986·321	3	1	+ 5	+ 13		4442·510	6	1	+ 9	+ 53	
3998·205	4	1	± 0	+ 14		4443 365	3	1	+ 5	+ 19	
4005 408	7	3	+ 8	+ 19		4447 892	6	1	+ 14	+ 51	
4009 864	3	1	− 5	+ 8		4454 552	3	1	+ 8	+ 23	
4014 677	5	1	− 7	+ 11		4461 818	4	1	+ 8	+ 15	
4022·018	5	1	± 0	+ 8		4466 727	5	2	+ 17	+ 18	
4045 975	30	1	+ 4	+ 22		4494·738	6	2	+ 12	+ 53	
4063·759	20	1	+ 2	+ 22		4528 798	8	2	+ 11	+ 61	
4071·908	15	1	+ 5	+ 21		4531·327	5	1	+ 4	+ 29	
4132 235	10	2	+ 20	+ 22		4548 024	3	2	+ 6	+ 21	
4144 038	15	2	+ 14	+ 20		4592·840	4	2	+ 8	+ 24	
4181 919	5	2	+ 3	+ 22		4603·126	6	2	+ 8	+ 20	
4187 204	6	2	+ 7	+ 111		4607·831	4	1	+ 2	..	
4187 943	5	2	+ 8	+ 108		4619·468	3	1	+ 5	..	
4191 595	6	1	− 1	+ 110		4625·227	5	1	− 1	...	
4199 267	5	2	+ 10	+ 32		4637·685	5	1	+ 1		
4202·198	8	2	+ 17	+ 15		4638·193	4	1	+ 1	..	
4219·516	7	2	+ 15	+ 26	Appears to be a single line in ⊙ and arc of intensity 7.	4647·617	4	2	+ 10	+ 15	
						4654 672	4	1	+ 3	...	
						4654 800	5	1	+ 1	...	
						4667·626	4	1	− 1		
4227·606	4	2	− 1	+ 95		4679·027	6	1	+ 2	.	
4233·772	6	2	− 6	+ 90		4707·457	5	1	+ 5	.	
4236 112	8	2	+ 4	+ 90		4710·471	3	1	+ 4	+ 13	
4250·287	8	1	+ 3	+ 70		4707 457	5	1	± 0	...	
4260·640	10	1	+ 7	+ 51		4710 471	3	1	± 0		
4271 325	6	1	+ 4	+ 123		4733 779	4	1	+ 1	..	
4271·931	15	1	+ 9	+ 22		4736·963	6	1	+ 1	+ 18	
4282 565	5	1	+ 1	+ 21		4787·003	2	1	+ 4	+ 16	

* Astrophysical Journal XXXV, 17.

TABLE I—*continued*.

λ Rowland.	Intensity.	Number of Plates.	Residual shift ⊙ – arc.	Pressure shift, 9 atmospheres.	Remarks.
4789·849	3	1	+ 6	+ 17	
4859·928	4	3	+ 2?	+ 100	The plates do not give consistent values.
4871·512	5	3	+ 4?	+ 80	
4872·332	4	3	+ 3	+ 94	
4878·407	4	3	+ 4	+ 87	
4890·948	6	3	+ 8	+ 70	
4891·683	8	3	+ 10	+ 53	
4903·502	5	3	± 0	...	
4919·174	6	2	± 0	+ 72	
4920·685	10	2	+ 4?	+ 82	One plate gives + and the other a – shift
4938·997	4	1	– 2	...	
4957·480	5	1	+ 5	+ 83	
4957·785	8	1	+ 11	+ 86	
4966·270	4	1	– 1		
5002·044	5	1	– 2	.	
5005·896	4	1	– 1		
5006·306	5	1	+ 3		
5050·008	6	3	+ 6	.	
5051·825	4	3	+ 10	...	
5068·944	5	2	– 3		
5083·518	4	2	+ 7		
5098·885	3	1	+ 8		
5107·619	4	2	+ 4	.	
5107·823	4	2	+ 4	.	
5139·427	4	6	– 3	..	One plate gives a + and the rest – shifts.
5139·644	4	6	± 0	..	
5167·678	5	4	+ 16	...	
5169·069	3	1	+ 11		
5171·778	6	4	+ 15	+ 16	
5191·629	4	4	– 1		
5192·523	5	4	+ 2		
5195·113	4	4	+ 6	+ 17	
5216·437	3	3	+ 6		
5227·362	5	3	+ 3?	+ 31	The plates are inconsistent
5233·122	7	3	+ 7	+ 110	
5266·738	6	2	– 4	+ 130	
5269·723	8	2	+ 9	+ 27	
5281·971	5	2	– 3?		The plates do not agree well
5283·802	6	2	– 1?		
5302·480	5	2	– 3		
5324·373	7	2	– 8?	+ 120	The plates are inconsistent.
5328·236	8	2	+ 15	+ 29	
5328·696	4	2	+ 8	+ 26	The line is single in ⊙ and are not two lines as given in Rowland.
5340·121	6	2	– 6	+ 140	
5371·734	7	2	+ 13	+ 29	
5397·344	7	4	+ 12	+ 29	
5405·989	6	3	+ 9	+ 27	
5424·290	6	1	+ 30	.	Very hazy line in arc (not included in discussion).
5429·911	6	4	+ 6	+ 29	
5434·740	5	4	+ 8	+ 27	
5447·130	6	4	+ 5	+ 31	
5455·834	4	4	+ 10	+ 29	
5569·848	6	1	+ 5	+ 140	
5573·075	6	1	+ 7	+ 140	
5586·991	7	2	+ 4	+ 120	
5615·877	6	2	+ 9	+ 130	

TABLE II.

λ Rowland.	Sun – Arc $\frac{A}{1000}$. Evershed.	Sun – Arc $\frac{A}{1000}$. Fabry and Buisson.	Remarks.
4181·919	+ 3	+ 2	
4187·204	+ 7	– 3	
4202·198	+ 17	+ 18	
4227·606	– 1	– 29	
4233·772	– 6	– 8	
4236·112	+ 4	– 19	
4250·287	+ 3	– 14	
4271·325	+ 4	– 18	
4282·565	+ 1	+ 7	
4337·216	+ 6	+ 7	
4352·908	+ 5	+ 4	
4369·941	+ 11	+ 6	
4376·107	+ 14	+ 12	
4427·482	+ 3	+ 4	
4430·785	+ 2	+ 6	
4442·510	+ 9	+ 12	
4443·365	+ 5	+ 7	
4447·892	+ 14	+ 7	
4461·818	+ 8	+ 9	
4466·727	+ 17	+ 14	
4531·327	+ 4	+ 5	
4787·003	+ 4	+ 6	
4789·849	+ 6	+ 8	
4859·928	+ 2?	– 7	In some plates the shift is + and in others –
4871·512	+ 4?	– 15	
4919·174	± 0	– 8	
5171·778	+ 15	+ 25	
5266·738	– 4	± 0	
5269·723	+ 9	+ 8	
5281·971	– 3	– 8	
5283·802	– 1?	+ 5	Measures not accordant.
5302·480	– 3	– 6	
5324·373	+ 8?	± 0	Measures not accordant.
5340·121	– 6	– 11	
5397·344	+ 12	+ 13	
5405·989	+ 9	+ 15	
5424·290	+ 30	+ 30	Arc line hazy.
5434·740	+ 8	+ 7	
5586·991	+ 4	+ 3	

In table II, I give a comparison of my results with the measures of MM. Fabry and Buisson,* who used the interference method in determining the displacements sun—arc. The two series are in fairly good agreement for most of the lines, but my measures differ from those of Fabry and Buisson chiefly in the case of the lines to which they assign large negative shifts. In six of these lines I get much smaller negative shifts, and in the remaining six small positive shifts. I do not think this difference can be due to errors of measurement, but is more probably the result of differences in the condition of the arc itself. MM. Fabry and Buisson refer to these lines as those which enlarge unsymmetrically towards the red in passing from the arc in vacuum to the arc in air, or on increasing the strength of the current in the arc. But in all my high dispersion plates taken with the arc at 110 volts and a current strength of about 6 amperes, the arc lines are very narrow and sharply bounded on both sides with no trace of any unsymmetrical widening, either towards the red or towards the violet; the only exceptions being lines which are reversed, and in these the settings were made on the exceedingly narrow reversal, which is sometimes unsymmetrically placed on the emission line.

In most cases the arc lines or their reversals are narrower than the solar lines, and it is difficult to believe that they do not represent the true centres of the lines, unaffected by unsymmetrical widening. This unsymmetrical widening appears to have caused a shift towards the red of the lines which in MM. Fabry and Buisson's measures give large negative sun—arc shifts. Possibly the sharp definition of the lines in my spectra may be due in part to the low atmospheric pressure of Kodaikanal, and in part to the fact that I used only the central portion of a comparatively long arc.

A glance at the fourth and fifth columns in table I is sufficient to show that no general relation exists between the solar and pressure shifts. The largest sun—arc shifts occur mostly in the ultra-violet region, whilst the pressure shifts increase enormously towards the red end of the spectrum.

If the shifts of the individual lines in the same spectral region are compared no marked relation can be made out, but differences of effective level may mask the relationship, those lines which are produced at greater depths in the reversing layer giving larger shifts owing to the greater pressure, and not necessarily because they are lines greatly affected by pressure.

But in order to justify the assumption that pressure is the cause of the solar shifts, an independent criterion of level must be sought, so that it may be determined whether an approximate agreement results between pressure shifts and solar shifts after making allowance for differences of level.

Although an exact correspondence between the relative shifts of individual lines is not to be expected, an approximate relation should be shown in the average shifts of groups of lines which are more and less affected by pressure; and low level lines should in general give larger shifts than high level. A general agreement in the law of increase of shifts with wave-length should also be found when groups of lines in different spectral regions are averaged. Thus, according to Duffield, the pressure shift is proportional to λ^2 or λ^3, and the solar shifts if due to pressure should increase similarly if the effects of differences of level can be eliminated.

In his research on radial motion in sunspots Dr. St. John has discovered a criterion of level in the intensity of the solar lines. It is clear, from my own observations and those of St. John, that the radial movement of the highest levels in the chromosphere is inward towards a spot centre, but the velocity of inrush decreases downwards to zero in a neutral zone at about the upper limits of the reversing layer. Below this, inversion occurs, the motion being outwards and necessarily increasing with the depth. In this region therefore the lines giving highest velocities in sunspots are due to absorption at the lowest levels, and St. John has deduced a scale of levels corresponding in a remarkable way with the scale of intensities of the lines, the weak lines indicating low levels, and the strong lines high levels. This result may be applied to the sun—arc shifts.

Owing to the comparatively small number of lines available it will be sufficient for the purpose of this inquiry to divide the lines in table I into three groups representing different spectral regions, each group containing the same number of lines with known pressure shifts. Group I contains a total of 35 lines

* Astrophysical Journal XXXI, 109.

between the limits λ 3895 and λ 4236 ; group II includes 46 lines between λ 4250 and λ 4787 ; and group III, 55 lines between λ 4789 and λ 5615.

If we subdivide these groups into high level and low level lines, according to intensity, we get the following interesting results :—

		Mean shift, sun—arc. A
Group I (Mean λ 4040) ...	Eighteen high level lines, Mean intensity, 11·2 ...	+ ·0125
	Seventeen low level lines, Mean intensity, 4·5 ..	+ ·0029
Group II (Mean λ 4500) ...	Seventeen high level lines, Mean intensity, 8 0 ...	+ ·0085
	Twenty-nine low level lines, Mean intensity, 4·0 ...	+ ·0043
Group III (Mean λ 5170)...	Twenty-three high level lines, Mean intensity, 6 8 .	+ ·0066
	Thirty-two low level lines, Mean intensity, 4·2 ...	+ ·0039

There is here shown to be a very marked relation between the shifts and the intensities of the solar lines, the strong or high level lines giving in each group a much larger shift than the weak or low level lines, and the greater the difference of intensity (or level) the greater the difference of shift.

This is, of course, contrary to what would be expected if the solar shifts are due to pressure, for the low level lines represent higher pressures and therefore should show a larger shift than the high level lines.

If next we consider only the lines with known pressure shifts in the same three groups and separate them into those more and less affected by pressure, we get the following mean shifts sun—arc :—

	More affected	Less affected.
Group I	+ 0077A	+ ·0082A
Group II	+ ·0073A	+ ·0076A
Group III	+ ·0045A	+ ·0096A

In all the groups the less affected lines are slightly more shifted than the more affected. The grouping of the lines into those more or less affected by pressure is to some extent arbitrary, but owing to the very large differences of shift for different lines with no intermediate values, little or no ambiguity is involved. In the more affected lines I include those of Duffield's groups II and III, and in the less affected lines those of his group I.* Many more lines outside the range for his measures are however included, the pressure shifts being taken from the tables of Gale and Adams and of Humphreys.

The average pressure shift for the more and less affected lines in the three groups is as follows :—

	Mean λ.	More affected.	Less affected
Group I	4050	·0076A per atmosphere.	0017A per atmosphere.
Group II	4440	·0067A "	·0022A "
Group III	5170	·0102A "	0026A "

Had the arc been under the normal pressure of 760 mm. in my experiments instead of about three-fourths of this value, or 580 mm., we may assume that all the arc lines would have been proportionately displaced towards the red, and the sun—arc shifts would have been reduced by about $\frac{1}{4}$ of the values given above. But since the more affected lines are shifted by amounts three to four times greater than the less affected, there will be a relative shift at the two pressures of approximately ·0015 A for groups I and II, and ·002 A for group III.

* Phil. Trans. A 208, 160.

A correction should therefore be applied to the sun—arc shifts to reduce them to normal pressure, and the mean shifts already given would be modified as follows:—

	More affected.		Less affected.	
Group I	+ ·0077 − ·0019	= + ·0058	+ ·0082 − ·0004	= + ·0078
Group II . .	+ ·0073 − ·0017	= + ·0056	+ ·0076 − ·0005	= + ·0071
Group III	+ ·0045 − ·0025	= + ·0020	+ ·0096 − ·0007	= + ·0089

This corrected result shows that in all the three groups the lines less affected by pressure give quite appreciably larger displacements to the red than do the lines more affected by pressure; in other words, the most affected lines are relatively slightly displaced towards the violet in the sun, a result which confirms the conclusion I had previously arrived at in Bulletin No. XVIII, namely, that the pressure in the reversing layer is less than that in the arc at normal pressure.

MM. Fabry and Buisson however, in discussing the results of their measures, consider that the lines more affected by pressure, such as those of Duffield's group III, are unsuitable for estimating pressure in the sun, because they are the lines which widen unsymmetrically towards the red. In measuring the emission lines of the arc under pressure, a spurious displacement would be obtained, due to the unsymmetrical widening, and not to pressure. No indication is therefore given of the shifts of the absorption lines or reversals which alone would be applicable to the sun.

This appears to be partly true, for Duffield finds that when under pressure the emission line is unsymmetrically reversed, the absorption line is less shifted towards the red than the centre of the emission line, so that lines of his group III would then show only half the shift, and fall into group II. It is not at all clear, however, why the unsymmetrical widening which seems to cause excessive shifts to some of the emission lines in the arc under pressure should not also affect in a similar manner the solar absorption lines; for these do not represent a superficial layer of relatively low density, as do the reversals of the arc lines, but probably the entire mass of luminous gas above the photosphere. To make the arc under pressure strictly comparable with the sun, it would need to be observed with a background of continuous spectrum due to matter at a higher temperature than the luminous gas, and under these conditions the absorption lines would be the exact counterpart of the emission, and would show the combined shifts due to pressure and unsymmetrical widening.

However this may be, a comparison of the mean values of the shifts of Duffield's groups I and III, when reversals only are measured, shows a large difference of shift between the two groups. Granting therefore that the determinations of pressure shift of these more affected lines are to subject to considerable uncertainty, there can be no doubt as to their being much more shifted even as absorption lines than the less affected lines; and we may compare them in the sun with the less affected lines in order to discover whether the pressure in the reversing layer exceeds or falls short of one atmosphere.

MM. Fabry and Buisson proceed to estimate the pressure in the sun from the absolute shifts of the lines least affected by pressure. They get accordant values (5·5 atmospheres total pressure) from two sets of lines, namely, twenty lines between λλ 4000 and 4500 and ten lines between λλ 5100 and 5500. For the former the average shift sun—arc is + ·0062A and the latter + ·0105A.

Apart from the fact that the more affected lines are here ignored, for as I believe, a quite insufficient reason, no account is taken of differences of level in the effective regions of absorption of the different lines.

MM. Fabry and Buisson in measuring lines of only moderate intensity in the sun missed what appears to me to be a most significant fact, namely, the relation between shift and intensity. This was however recognized by Jewell,* who remarks that "the stronger reversed lines are those whose displacement is greatest (with reference to the solar lines), and there is gradual decrease in the amount of displacement as the lines are weaker and more difficult to reverse."

As regards the actual pressure indicated by the relative shifts of the more and less affected lines, the results of the three groups are not very consistent, except in so far as they indicate a pressure lower

* Astrophysical Journal III, 94.

than one atmosphere. The shifts of groups I and II would indicate a pressure only slightly less than that of the atmosphere at Kodaikanal, whilst group III would show an almost zero pressure.

If we suppose the solar gases to be under a pressure of five or six atmospheres, as MM. Fabry and Buisson's results appear to indicate, there can scarcely be a doubt that the lines most affected by pressure would in the sun show larger shifts than those less affected, even allowing that the pressure shifts of the more affected lines have been over-estimated.

The mean pressure shifts of the particular lines I have compared with the sun increase very greatly towards the longer wave-lengths, as is seen in the table of pressure shifts per atmosphere. For the more affected lines the shift is much larger for group III at mean λ 5200 than for group I at mean λ 4050. But for these same lines the sun—arc shifts actually diminish from +·0058A in group I to +·0020A in group III. Pressure therefore cannot be concerned with the shift to the red of these lines, and the smaller shifts of the less refrangible lines is only another instance of the relative displacement towards the violet of the lines most affected by pressure.

My conclusion therefore is that while pressure is not the cause of the shift of the solar lines to the red, there is in fact a small pressure effect traceable in the relative positions of the solar and arc lines, which is a *minus* effect, that is, indicating a decidedly smaller pressure in the sun than in the arc in air.

Assuming the pressure effect to be very small when comparing the arc at 580 mm. with the sun, we have now to account for the absolute shifts of the solar lines, most of which show a comparatively large displacement towards the red. I have already shown that these shifts are closely related to the intensities, the strong lines showing larger shifts than the weak. If we consider the shift to be due to motion in the line of sight, and also accept St. John's conclusions from movements in spots that the stronger lines represent in general higher levels and the weaker lines lower levels, we arrive at the interesting result that in the higher levels there is a movement of descent which is retarded in the lower levels.

For a comparison of the velocities deduced we are not limited to lines with known pressure shifts. Taking therefore all the lines I have measured, and separating them into strong and weak lines as before the following velocities are obtained:—

		Strong Lines (Intensity 6 and over.)		*Weak Lines.* (Intensity 3 to 5.)	
Group.	Mean λ	Mean shift.	Km/sec.	Mean shift	Km/sec.
I	4040	0125A	·93	·0029A	·22
II	4500	·0085A	·57	·0043A	·29
III	5170	·0066A	·38	·0030A	23

The movement is one of recession from the earth or descent on the sun in all cases, and the smaller velocity for the weaker lines is here clearly shown. The reduction of velocity for the strong lines in passing from group I to group III is readily explained, since the mean intensities decrease from 11·2 for group I to 8·0 for group II, and 6 8 for group III. For the weak lines the mean intensities are 4·5, 4·0, and 4·2, respectively.

The retardation of velocity in the lower region of the reversing layer satisfactorily explains the otherwise anomalous result that the shift, considered as a motion shift, does not increase towards the longer wave-lengths proportionately to λ but on the other hand tends to diminish. Considered as a pressure shift, this fact is quite inexplicable, for not only should the shift increase in proportion to λ^2 or λ^3 but it should, as already stated, be greater for the low-level lines than for the high level.

St. John has found that in general the lines at the red end of the spectrum represent lower levels than those at the violet end. This again tells against the pressure theory for it implies that the shifts if due to pressure should increase towards the red at an even greater rate than the pressure shifts.

Considering the pressure in the reversing layer to be less than one atmosphere, and the only possible explanation of the shifts of the solar lines to be motion in the line of sight, we leave unexplained the remarkable fact discovered by Halm of the relative shift to the red of the lines at the sun's limb compared with the centre of the disk. I propose to deal with this in a subsequent paper and will not say more here than that the usual interpretation of this shift based on differences of pressure of several atmospheres in the reversing layer appears from my results to be almost certainly erroneous.

The movement of descent of the iron vapour as observed at the centre of the disk seems to confirm the hypothesis I advanced in discussing the eclipse spectra photographed in 1900 namely that the cooler absorbing gases of the reversing layer are descending on the sun * In this paper however I assumed a continuous *circulation* of the solar gases to account for the differences of intensity between the flash spectrum lines as observed at eclipses and the Fraunhofer lines; the hotter gases giving the enhanced lines rising, and the cooler gases falling. It seems probable that the descending motion of the iron vapour may turn out to be part of this circulating movement, but evidence of the ascending motion is still to be sought. It would be of much interest to compare the strongly enhanced spark lines of iron with the solar lines such as those at λλ 4924, 5018, 5169, and 5317 which might be expected to show an ascending movement, or a shift towards violet compared with the iron spark spectrum.

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