Kodaikanal Observatory.

BULLETIN No. LIII.

THE DISPLACEMENTS OF NICKEL AND TITANIUM LINES IN THE SUN AND ARC.

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The displacements of the iron lines in the solar spectrum have been given in previous bulletins [1], and from the sun-minus-arc displacements Mr. Evershed deduced a vertical current at the centre of the sun's disc decreasing with depth, and a low pressure in the sun. It was shown, however, that lines which are unsymmetrical in the arc have abnormal displacements in the sun, and these lines had to be left out of consideration. In extending the investigation to nickel and titanium it has to be remarked that these abnormal displacements are much more frequent than with iron. In the case of nickel it is doubtful whether there are any really symmetrical lines in its spectrum. So rare are symmetrical lines in nickel and titanium that it has not been possible to confirm, except to a limited extent, the conclusions arrived at from the iron lines, but one can only sav that the results from nickel and titanium are not inconsistent with those indicated by iron.

Five separate investigations of displacements were carried out, namely :—

(i) Centre of sun's disc minus centre of nickel arc,
(ii) Centre of sun's disc minus centre of titanium arc,
(iii) Limb of sun minus centre of sun's disc,
(iv) Negative pole of nickel arc minus centre of nickel arc,
(v) Negative pole of titanium arc minus centre of titanium arc.

The displacements measured are given in Tables IX and X at the end of this bulletin. The limb-minus-arc displacements were obtained by addition of the displacements in (i) and (iii), and in (ii) and (iii) for nickel and titanium respectively.

Experimental Details.

The spectrograph has been described previously[2], but has now an Anderson grating with 9·7 × 12·8 cm. ruled space and 75,085 lines. The third order spectrum was used and the dispersion varied from 0·85 angstroms per mm. at λ 3560 to 0·64 angstroms per mm. at λ 5170. The optical arrangement for photographing sun and arc simultaneously was the same as that employed previously[2] and the device used for photographing the two limbs and the centre of the disc simultaneously was the same as that described in Kodaikanal Observatory Bulletin No. XXXIX. Care was taken that the grating was uniformly illuminated from each of the different light sources whose spectra were required in juxtaposition for measurement of the displacement of the lines. For the adjustment of the limb and centre plates in the micrometer, lines of the iron arc were impressed on the plates but were not used for measuring displacements.

The electric arc was supplied from a battery of 110 volts and burned in air at 580 mm. pressure (the normal atmospheric pressure at the altitude of the observatory). The arc was placed vertical, parallel to the slit, with a length of 10 mm., enlarged to 32 mm. on the slit plate by a condensing lens. The arc length

[1] Kodaikanal Observatory Bulletins Nos. XXXVI, XXXVIII, XXXIX, XLIV, XLVI.
[2] Kodaikanal Observatory Bulletin No. XXXVI.

and current were kept as constant as possible throughout the series of experiments but it will be readily understood that the displacement at the negative pole depends to such a large extent on the instantaneous condition of the arc that the photographs do not form one homogeneous series even though the regions photographed were made to overlap. This does not apply however to the sun-minus-arc determinations, for the wavelength at the centre of a long arc is sufficiently stable for the whole set of photographs of about 100A each to form a homogeneous series.

The arc had generally to be exposed longer than the sun to give easily measurable arc lines, so that the exposures were not always strictly simultaneous, but the exposure in the sun was always made in the middle of the arc exposure without interrupting the latter.

In each region of the spectrum it was found necessary (as also previously with the iron spectrum) to have some photographs with a short exposure on the arc and some with a longer exposure. The stronger arc lines are measured in the short exposure plates and the fainter lines in the long exposure with a sufficient number of lines measured in both to prevent systematic differences being unnoticed. This procedure is necessary in order to avoid making measures on overexposed arc lines, for in my experience it is not possible to set accurately on them and in the case of unsymmetrical lines the measures may not be true owing to the difficulty of distinguishing the position of maximum intensity.

Measurements of each plate were made with the red on the right hand side and again with the red on the left, and were made in duplicate by two measurers.

Many lines are included in Table IX which were not identified by Rowland, but there is little reason to doubt their identity. Rowland missed them perhaps because he did not recognise that lines nebulous and faint in the arc are generally strengthened in the sun (being high temperature lines) and had no reason to expect such large differences of wavelength between sun and arc which we now know to be due to the unsymmetrical character of spectrum lines.

I.—Nickel Lines.

1. The displacement at the negative pole of the nickel arc.

These displacements, given in Table IX, column 6, each the mean of three determinations, have been measured in the same way as those of iron and other elements described in Kodaikanal Observatory Bulletin No. XL. As there was no supply of pure nickel available, "nickel" coins (value one anna) of the Indian coinage were taken for the arc. The coins are an alloy consisting of 80 per cent of nickel with 20 per cent of copper. A coin was made the lower, negative, electrode and the upper electrode was commercial iron. With this arrangement the arc burned very steadily, more steadily than the arc between two iron electrodes; the iron lines were produced simultaneously and gave a check on the consistency of the results with previous measures of the sun and iron arc. The arc length was 10 mm. throughout, enlarged to 32 mm. on the slit plate, and the current strength $5\frac{1}{2}$ ampères. In order to avoid iron globules adhering to the anna coin when the arc was struck, the electrodes were never brought into contact but the arc was started by inserting a piece of arc carbon between the electrodes.

Except in the region above λ 3900, most nickel lines undergo a large displacement either to the red or to the violet. As in the cases of other elements the lines are displaced in the direction to which they widen unsymmetrically in the arc and those lines which appear symmetrical have zero or small displacements. It is not claimed that the negative pole displacements less than about 0·004A recorded in Tables IX and X are real, but the means of the measures have been given without modification. In some cases where the lines are too faint or diffuse for measurement the direction of the displacement at the negative pole was evident under low magnification and has been noted in the table.

There is a parallelism between the pressure displacements given by Duffield[1] and the displacements at the negative pole but it is very doubtful whether there is any physical relation between the true pressure effect and the negative pole displacement. It seems more than probable that pressure displacements as determined

[1] Duffield, Phil. Trans. Roy. Soc., 215, 205, 1915.

from increasing the pressure of the atmosphere surrounding the electric arc are, to a greater or less degree depending on the condition of the experiments, not free from the displacements observed at the poles of the arc. Consider, for example, the values given by different experimenters for the pressure shift of the Mount Wilson group *e* of the iron lines which are displaced to the violet at the negative pole. The lines of this group were originally defined as those which shift, and widen unsymmetrically, towards the violet under pressure,[1] and Gale and Adams give the pressure shift of the group in the region λ 5400 to be − 0·014A per atmosphere (i.e., to the violet) in comparing the arc *in vacuo* with the arc at pressures up to 1 or 2 atmospheres.[2] St. John and Babcock, however, comparing the arc *in vacuo* with that at pressures up to 1 atmosphere obtain a value of + 0·0017A per atmosphere (i.e., to the red), at mean wavelength λ 5392 and − 0·0035A per atmosphere (i.e., to the violet) for the lines at mean wavelength λ 3755[3]. St. John and Babcock do not state why their experience differs from that of Gale and Adams working between the same pressures, but one may assume it is because they have had a longer arc, or have avoided the polar regions, or both. It is probable that the values of St. John and Babcock are more free from the pole displacement but it is open to question whether they represent the true pressure shift even now.

It is to be noted that the lines showing decided displacement at the negative pole are generally high temperature lines belonging to those groups which are faint or absent in the furnace spectrum according to the experiments of King,[4] but are not enhanced in the spark.

2. The sun-minus-arc displacements of nickel lines.

These are given in column 7 of Table IX. Only the central portion of a long arc was used for comparison with the centre of the sun's disc.

(*a*) *Relation to negative pole displacements.*—The intimate relation between the displacements in the sun and at the negative pole of the arc is at once evident from Table IX. The lines with a decided shift to the violet at the negative pole are displaced in the sun more to the red than lines with zero or slight shift at the negative pole, and those with a shift to the red at the negative pole are displaced to the violet in the sun or, in a few cases, only slightly to the red. This indicates that the condition of the vapour (probably vapour density[5]) at the centre of a long arc is intermediate between that in the sun and that at the negative pole of the arc. In the following table, the average sun-minus-arc displacements are given for lines classified according to the amount of the shift at the negative pole of the arc. The result of the table is embodied in the accompanying diagram.

TABLE I.—*Relation between sun-minus-arc displacements and negative pole displacements for nickel lines.*

Displacement at negative pole.	Over − ·014A.	− ·014A to − ·004A.	− ·003A to + ·003A.	+ ·004A to + ·014A.	Over + ·014A.
Mean displacement at negative pole ..	− ·0226A.	− ·0090A.	+ ·0005A.	+ ·0108A.	+ ·0225A.
Mean centre-minus-arc displacement	+ ·0106A.	+ ·0073A.	+ ·0034A.	− ·0043A.	− ·0063A.
Number of lines	7	6	32	23	28

On account of the non-homogeneity in the series of the negative pole shifts referred to previously, it is of no service to attempt to formulate algebraically the law connecting solar displacements and negative pole displacements, but it would seem from the diagram that a displacement to the red at the negative pole results in greater abnormality in the solar displacement than an equal one to the violet would, and that small displacements at the negative pole are proportionately more effective than large displacements.

[1] St. John and Miss Ware, Astrophysical Journal, 36, 14, 1912.
[2] Gale and Adams, Astrophysical Journal, 37, 391, 1913.
[3] St. John and Babcock, Astrophysical Journal, 42, 231, 1915.
[4] King, Astrophysical Journal, 42, 344, 1915.
[5] Royds, Kodaikanal Observatory Bulletins Nos. XXXVIII and XL.

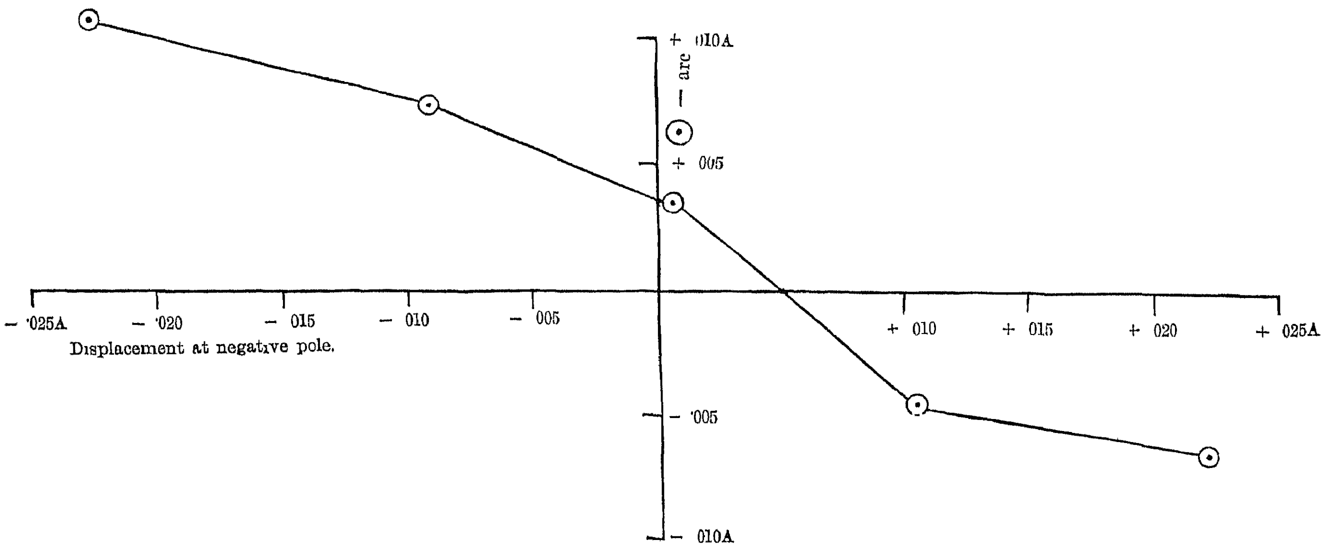

FIG. 1.—RELATION OF SOLAR DISPLACEMENT TO THE DISPLACEMENT AT THE NEGATIVE POLE OF THE ARC.

To the relation expressed in Table I and the diagram there are only 13 exceptions (not included in the table) out of 124 lines with negative pole displacements noted. Perhaps they are due to their being unsuspected blends in the solar spectrum. These 13 exceptions are given below :—

Exceptions to Table I.

λ	Shift at negative pole	⊙ − arc.
3772 673	+ ·001 A	+ ·019A
3793 745	0	− 7
3913 123	− 2	− 1
4164 804	0	− 2
3670·536	+ 5	+ 5
4006 304	+ 13	+ 15
4284 838	+ 13	+ 4
4325 777	+ 13	+ 6
4401 709	+ 19	+ 4
4459 199	+ 24	+ 4
4925 746	+ 13	+ 6
5099 497	+ 15	+ 4
3724 970	− 17	+ 3

(*b*) *Relation of sun-minus-arc displacement to intensity.*—Mr. Evershed has shown that the stronger iron lines (i.e., high level lines) have larger displacements to the red than the weaker lines, and these displacements were interpreted as Doppler effects due to a descending current at the centre of the sun's disc decreasing with depth. The nickel lines, however, taking account only of those with zero and slight pole displacements, do not show any variation with intensity as the summary in Table II shows.

TABLE II.—*Relation of sun-minus-arc displacements to intensity for nickel lines with zero or slight pole displacements (between* ± 0·003*A) excluding* λλ 3772·673, 3793·745.

Intensity ...	0	1	2	3	4	5	6	7	8	10
Mean ⊙ − arc ..	+ 0020	+ 0023	+ 0032	+ 0022	+ 0028	+ 0037	+ ·0023	+ ·0040	+ 0035	+ ·0030
Number of lines .	2	3	5	6	4	3	6	2	2	1

	Intensities 0–3	Intensities 4–10
Mean intensity ...	1 9	6 0
Mean ⊙ − arc ...	+ 0·0025A	+ 0·0030A
Number of lines ...	16	18

Thus the lines of mean intensity 6·0 have a mean displacement larger than that of lines of mean intensity 1·9 by the doubtful amount of 0·0005 A. According to St. John[1] lines of nickel and iron of equal intensity originate at the same level in the sun, and consequently we must expect equal displacements if due to Doppler effects. The absolute displacements of the nickel lines, + 0·0028A for mean intensity 4·1 are in good agreement with those of the iron lines[2] between intensities 2 and 7, namely + 0·0031A, mean intensity 3·9.

The variation of the displacement between lines of mean intensity 1·9 and 6·0 is small, in agreement with the results for iron lines of like intensity but the strongest nickel lines in the above table would have been expected to give larger displacements. Perhaps the reason for this discrepancy is to be found in the fact that the nickel lines although almost or quite symmetrical in the arc at atmospheric pressure are really unsymmetrically widened towards the red, only becoming obviously so under pressure as shown for almost every line in column 5, Table IX, from the data of Duffield[3] and Bilham.[4] It should be remembered, however, that the nickel lines on the whole originate at lower levels than the iron lines which have been studied, and there is some evidence with the iron lines that the variation with intensity becomes less at the lower levels.

(*c*) *Pressure in the sun.*—A relationship could also be traced between the sun-minus-arc displacements and the pressure shift, giving indications of nearly zero pressure in the sun if all lines are considered, but this apparent relation is principally due to the dependence of the pressure shifts of unsymmetrical lines on the shift at the negative pole. At present we can only make use of the lines which undergo zero and slight shifts at the negative pole, although even these lines seem, from what has been said in (*b*), to be under suspicion. The range of the pressure shifts for these lines is small but they can be divided into two groups of more and less affected lines and the mean displacements for the two groups are given in Table III.

TABLE III.—*Solar pressure deduced from lines with negative pole shifts between* ± 0·003*A*, *excluding* λλ 3772·673, 3793·745, 4855·600.

——	Less affected lines	More affected lines
Pressure shift per atmosphere	+ 0 0011A	+ ·0024A
⊙ − arc displacement ...	+ 0·0032A	+ ·0032A
Number of lines	15	16

There is no difference in the solar displacement for the two groups of symmetrical lines with a relative difference of pressure shift of 0·0013A per atmosphere. The solar pressure is therefore equal to the pressure of the atmosphere at the altitude of the observatory. This result is in agreement with the pressure deduced from the symmetrical iron lines.

3. *Displacement of nickel lines at the sun's limb.*

It is seen from column 9 of Table IX that the limb-minus-centre displacements are more regular than the centre-minus-arc displacements; Mr. A. A. Narayana Ayyar has shown[5] that lines with very large centre-minus-arc displacements have normal values for the limb-minus-centre displacement and the values for nickel confirm this There seems to be no connection whatever between limb-minus-centre displacements and the unsymmetrical character of the lines as evidenced by the shift at the negative pole.

(*a*) *Relation to intensity.*—Only 21 lines with slight shift at the negative pole are available and their mean limb displacement is given in Table IV. As, however, there seems to be no abnormality depending on pole displacements the means of all lines irrespective of the value of their pole shifts have been given in Table V.

[1] St John, Astrophysical Journal, 38, 341, 1913
[2] Kodaikanal Observatory Bulletin No. XXXVIII.
[3] Duffield, Phil Trans Roy. Soc., 205, 215, 1915.
[4] Bilham, Phil. Trans. Roy Soc., 214, 359, 1914.
[5] Narayana Ayyar, Kodaikanal Observatory Bulletin No. XLIV.

TABLE IV.—*Relation of limb-minus-centre and limb-minus-arc displacements to intensity for lines with negative pole shift between* ± 0·003*A*.

Intensity	0	1	2	3	4	5	6	7
Limb − centre	·0000	+ ·0045	+ ·0026	+ ·0050	+ ·0085	+ ·0065	+ ·0045	+ ·0035
Centre − arc[1]	+ ·0020	+ ·0023	+ ·0032	+ ·0022	+ ·0028	+ ·0037	+ ·0023	+ ·0040
Limb − arc	+ ·0020	+ ·0068	+ ·0058	+ ·0072	+ ·0113	+ ·0102	+ ·0068	+ ·0075

TABLE V.—*Relation of limb-minus-centre displacements to intensity for all lines*

Intensity	0	1	2	3	4	5	6	7
Limb − centre	+ ·0014	+ ·0034	+ ·0034	+ ·0044	+ ·0048	+ ·0056	+ ·0043	+ ·0035
Centre − arc[2]	+ ·0020	+ ·0023	+ ·0032	+ ·0022	+ ·0028	+ ·0037	+ ·0023	+ ·0040
Limb − arc	+ ·0034	+ ·0057	+ ·0066	+ ·0066	+ ·0076	+ ·0093	+ ·0066	+ ·0075

From these two tables there is slight evidence of the variation of the limb-minus-centre displacement with intensity which was found with the iron lines. Except for the lines of intensity 0, the variation is so small as to be of doubtful reality, however. The absolute values of the displacements are slightly smaller than those of the iron lines at the same level.

(*b*) *Relation to wavelength.*—There is a slight variation of the limb-minus-centre displacement with wavelength, the mean for lines from λλ 3662 to 4490 being + ·0025A and that from λλ 4513 to 5160 being + ·0036Å.

(*c*) *Limb-minus-arc displacements.*—If the limb-minus-arc displacements are obtained by adding the limb-minus-centre shifts to the centre-minus-arc shifts the results are seen to be mainly dependent on the influence of the negative pole displacement on the last mentioned. Taking, therefore, the centre-minus-arc displacements of only those lines which have zero or slight displacements at the negative pole, the relationship of the limb-minus-arc displacements with intensity is shown in Tables IV and V. As was to be expected from the approximate uniformity in both limb-minus-centre and centre-minus-arc displacements, the resultant limb-minus-arc displacement is also nearly constant.

The absolute values of the limb-minus-arc displacements of nickel lines are smaller than those of iron lines due to smaller values for both limb-minus-centre and centre-minus-arc.

III.—TITANIUM LINES.

1. *The displacement at the negative pole of the titanium arc.*

The arc spectrum of titanium was obtained by feeding small quantities of titanium metal on to the lower, negative, electrode of a carbon arc. The determination of the displacement at the negative pole was confined to a few regions containing strong lines as the supply of titanium was insufficient for the complete spectrum. On account of the surprising brilliancy of the luminous spot near the negative pole the lines are usually overexposed in the few photographs obtained, and the measurements are consequently not so accurate as is desirable. The arc length was 10 mms., and the current strength 6 ampères.

The displacements at the negative pole of the titanium arc are given in Table X, column 4. It is seen that the majority of the lines investigated give appreciable displacements at the negative pole, mostly to the red, and the displacements seem to have no relation to the pressure shifts.

2. *The sun-minus-arc displacements of titanium lines.*

These are given in column 5 of Table X.

(*a*) *Relation of sun-minus-arc displacements to negative pole displacements.*—As in the case of nickel, the shifts at the negative pole are seen to account for most of the deviations from normal displacement. Grouping the lines according to the direction and amount of their pole shift a relation similar to that for the nickel lines is obtained in Table VI.

[1] The centre-minus-arc displacements are derived from a larger number of lines in some cases.
[2] The centre-minus-arc displacements are derived from lines with slight pole displacement only.

TABLE VI.—*Relation between sun-minus-arc displacements and negative pole displacements for titanium lines.*

Displacement at negative pole	− ·008A to − ·004A	− ·003A to + ·003A	+ ·004A to + ·010A	Over + ·010A
Mean displacement at negative pole ..	− ·0063A	+ ·0005A	+ ·0063A	+ ·0188A
Mean sun-minus-arc displacement ..	+ ·0030A	+ ·0030A	+ ·0021A	− ·0024A
Number of lines	3	13	22	9

(*b*) *Relation of sun-minus-arc displacements to intensity.*—The range of intensities of titanium lines is less than that of either nickel or iron. All lines were taken into consideration as the pole shifts are not known throughout the spectrum and the means are given in Table VII.

TABLE VII.—*Relation of sun-minus-arc displacements to intensity for all titanium lines except* λ 5025·749.

Intensity	00	0	1	2	3	4	5
Centre − arc	− ·0015	+ ·0017	+ ·0002	+ ·0024	+ ·0031	+ ·0021	+ ·0040
Number of lines ..	2	12	16	26	20	10	1
Mean intensity . ..	0·4			2·4		4·1	
Centre − arc	+ ·0007			+ ·0027		+ ·0024	
Number of lines	30			46		11	

According to St. John the lines of titanium originate at the same level as iron lines of intensity higher by one unit. Above intensity 2, the absolute value of the mean displacement is in satisfactory agreement with that for nickel and iron, but below intensity 2, the shifts are smaller than expected. Perhaps the exclusion of all lines exhibiting pole shift would rectify this.

(*c*) *Pressure in the sun.*—On account of the dependence of the solar displacements on the pole displacements and also on account of the paucity of lines with small displacements at the pole it is of little service to attempt to deduce the pressure in the sun from the relative shift of the more and less affected lines of titanium. The result however, as in the case of nickel, taking all lines into account is in the neighbourhood of absolute zero pressure in the sun, but this is not believed to represent the true solar pressure, because lines exhibiting pole displacements have not been excluded.

3. Displacement of the titanium lines at the sun's limb.

The limb-minus-centre displacements are fairly regular for the titanium lines also. For lines above intensity 2, the displacements are practically independent of intensity, as shown in Table VIII.

All lines have been taken into consideration on account of the incompleteness of the determination of the negative pole displacements.

TABLE VIII.—*Relation between limb displacements and intensity for all titanium lines.*

Intensity	00	0	1	2	3	4	5
Limb − centre	·0000	+ ·0030	+ ·0008	+ ·0036	+ ·0029	+ ·0037	+ ·0040
Centre − arc	− ·0015	+ ·0017	+ ·0002	+ ·0024	+ ·0031	+ ·0021	+ ·0040
Limb − arc	− ·0015	+ ·0047	+ ·0010	+ ·0060	+ ·0060	+ ·0058	+ ·0080
Number of lines	2	12	17	26	20	10	1

The absolute values of both limb-minus-centre and limb-minus-arc displacements are smaller than those for the iron lines at the same level in the sun. The smallness of the latter displacement is probably principally due, as in the case of nickel, to the abnormality of the centre-minus-arc displacements on account of the unsymmetrical character of the lines in the arc.

My best thanks are due to Mr. A. A. Narayana Ayyar, B.A., Third Assistant, who has done the bulk of the measurement of the plates, and to Mr. G. Nagaraja Ayyar, Second Assistant; also to Mr. S. Sitarama Ayyar, B.A., First Assistant, who was able to make some measures before he went to Kashmir.

I would also express my indebtedness to Mr. J. Evershed, F.R.S., the Director, for his interest and valuable criticisms.

SUMMARY.

1. The majority of nickel lines show abnormal displacements in the spectrum of the centre of the sun's disc owing to their unsymmetrical character in the arc as evidenced by the displacement at the negative pole of the arc. The deviation of the solar displacements from normal is in the opposite direction to the displacement at the negative pole, showing that the condition (vapour density, probably) at the centre of the arc is intermediate between that in the sun and that at the negative pole of the arc. Conclusions can consequently only be drawn, at present, from those lines which have zero or slight displacement at the negative pole. Since even these lines, or at any rate most of them, become obviously unsymmetrically widened in the arc under pressure there is possibly still some abnormality in their solar displacement, and this fact may account for the slight discrepancies when compared with the symmetrical iron lines. Consequently, it can only be said that the conclusions from the displacements of the nickel lines (and of the titanium lines, for similar considerations apply to titanium also) are not inconsistent with those drawn for the iron lines.

2. Taking only those nickel lines with zero or slight displacement at the negative pole of the electric arc, the mean centre-minus-arc displacement is practically identical with that of the symmetrical iron lines originating at the same level in the sun, but shows no variation with intensity (i.e., with depth in the reversing layer) as would have been expected from the results for iron. On the whole, however, the nickel lines originate at lower levels than the iron lines which have been studied and with the latter there is evidence that the variation with intensity is less at the lower levels

3. Again taking nickel lines with zero or slight displacement at the negative pole, the solar pressure, estimated from the relative shift of the lines more and less affected by pressure, is about three-quarters of an atmosphere, in agreement with that deduced from the symmetrical iron lines.

4. The relation between the negative pole displacement of the nickel lines and the centre-minus-arc displacement has been roughly formulated and is shown in fig. 1.

5. The limb-minus-centre and the limb-minus-arc displacements also vary but slightly with intensity. The absolute values are smaller than those of the iron lines.

6. The displacements of the titanium lines are similar to those of the nickel lines. The displacement at the negative pole of the arc is again a disturbing factor.

7. The conclusions drawn from the investigation of the iron lines, namely, that the displacements at the centre of the sun's disc and at the sun's limb are Doppler effects due to descending motion in the line of sight and that the solar pressure is of the order of three-quarters of an atmosphere, are not modified by the investigation of the nickel and titanium lines.

THE OBSERVATORY, KODAIKANAL,
2nd December, 1916.

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TABLE IX.—*Nickel lines.*

Serial number	λ	Intensity	Character. Atmospheric arc	Character. Under pressure.	Shift at negative pole.	Centre − arc.	Limb − centre	Limb − arc.	Pressure shift per atmosphere.	Remarks	Number of plates. Centre − arc.	Number of plates. Limb − centre	Serial number
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
					A/1000	A/1000	A/1000	A/1000	A/10000				
1	3561·898	3	...	..	+ 2	+ 1	..		7		3	.	1
2	66·522	10	(ur), R		− 1	+ 3	..	..	21		3		2
3	72 014	6	(ur), R	ur (B)	+ 1	+ 3	..	...	19		3	..	3
4	88·084	6		ur (B)	+ 1	+ 5	..	. .	11		3	..	4
5	97 854	8	(ur), R	ur	0	+ 3	...	...	21		3	. .	5
6	3602 559	4	.	ur	0	0		...	18		3	. .	6
7	09 467	5d?		...	+ 1	+ 3		...	10		3	...	7
8	10 647	5	(ur), R	ur (B)	− 1	+ 5	...	...	22		3	...	8
9	12 882	6d?	..	ur	+ 1	+ 1		...	14		3	...	9
10	19 539	8	(ur), R	ur	− 2	+ 4	..	...	26		3	...	10
11	24 873	4	...	ur	+ 1	+ 3		..	8		3	. .	11
12	30 045	1	n	uv	−43	+ 9	..	...	...		3	...	12
13	41 784	1	...	.	+ 3	+ 2	...	. .	...		4	. .	13
14	62 096	3		ur	0	+ 6	+ 4	+10	11		3	3	14
15	64·234	5d?	...	ur	+ 3	+ 4	+ 7 ?	+11 ?	17		3	3	15
16	69 381	4		ur	− 1	+ 7	+ 6 ?	+13 ?	13		3	2	16
17	70 566	5	. .	ur	+ 5	+ 5	+ 6	+11	21		3	3	17
18	74 287	4		ur	+ 3	+ 1 ?	..	..	17		3	.	18
19	3724 970	1	n	uv	−17	+ 3	+ 1	+ 4	I		2	3	19
20	36·958	3	.	ur (B)	+ 2	+ 3	...	...	16		3	..	20
21	39 370	3	...	...	0	+ 2	+ 6	+ 8	12		3	3	21
22	62·758	...1	n	..	large +	−21	+ 2	−19	...		3	3	22
23	72·673	2	...	...	+ 1	+19	− 1	+18	11		3	3	23
24	75·717	7	...	ur (B)	− 1	+ 4	+ 4	+ 8	15		2	3	24
25	78·203	2	.	..	0	+ 1	+ 2	+ 3	9		3	2	25
26	83 674	6	.	..	0	+ 1	+ 6	+ 7	13		3	3	26
27	92·482	1	...	...	+ 2	+ 3	+ 5	+ 8	10		3	3	27
28	93·745	4	.	ur	0	− 7	+11	+ 4	19		3	3	28
29	3807·293	6	(ur), R	ur (B)	0	+ 1	+ 3	+ 4	15		3	3	29
30	31·837	6	...	ur	+ 2	+ 3	+ 4	+ 7	47		3	3	30
31	44·378	C 4d?	. .	..	large +	−30	+ 2	−28	22		3	3	31
32	58·442	7	(ur), R	ur	− 2	+ 4	+ 3	+ 7	21		5	3	32
33	63 201	...1	n, (ur)	ur	+ 8	− 1	+ 4	+ 3	I		6	3	33
34	89·810	2	n, (ur)	ur	+ 6	− 1	+ 4	+ 3	25	p Ni.	3	3	34
35	3909·064	...1	nn	.	...	−16	+ 7	− 9	I		2	3	35
36	12 445	Ni ? 2	nn	...		−29	+ 3	−26	I		2	3	36
37	13 123	2	. .	...	− 2	− 1	+ 6	+ 5	I		2	3	37
38	70 631	1	nn	.	+24	− 8	+ 6	− 2	I		4	3	38
39	72·313	2	...	..	0	+ 7	+ 4	+11	8		4	3	39
40	73 702	Ni,Zr3	...	ur	0	+ 4	+ 5	+ 9	19		5	3	40
41	74 774	2	nn	..	+14	−28	+ 3	−25	I		4	3	41
42	4006·304	1	n, (ur)	.	+13	+15	+ 5	+20	...		4	3	42
43	17·724	Ni ? 1	(uv)	.	large − ?	+35	+ 1 ?	+36 ?	...		4	1	43
44	64 515	1	nn, (ur)	ur	+14 ?	−15	+ 2	−13	II		3	1	44
45	86·283	...0	nn	.	−27	+15	− 1	+14	..		3	1	45
46	4116·138	.. 0	n	...	+ 6	− 7	+ 1 ?	− 6 ?	15		3	2	46
47	42 465	...2	n, (ur)	ur	+36	−19	+ 1	−18	II ?		3	3	47
48	64 804	. 0	...	...	0	− 2	0 ?	− 2 ?	I		3	3	48
49	84 641	...0	.	ur	+11	0	+ 2	+ 2	II		3	3	49
50	95·684	.. 1	ur	ur	+10	−19	+ 4 ?	−15 ?	78		3	3	50
51	4200 611	1	n, (ur)	ur	+ 9	− 1	− 2	− 3	82		3	3	51
52	31 183	4 N	n, ur	ur	+36	−21	+ 4	−17	II		3	3	52
53	84·838	1	(n)	ur	+13	+ 4	0	+ 4	95		3	3	53
54	88·149	1	(n), (ur)	ur	+24	− 9	+ 4	− 5	109		3	3	54
55	96 044	1	n, ur	ur	+27	− 4	+ 6	+ 2	150		3	3	55
56	4325 777	1	(n)		+13	+ 6	− 2 ?	+ 4 ?	..		3	3	56
57	31·811	2	...	..	0	+ 5	+ 2	+ 7	30 ?		3	3	57
58	56·163	0	n, ur	ur	+44	−15	+ 1 ?	−14 ?	II	Appears also under pressure group I.	2	2	58
59	68·462	0	(n), ur	ur	+15	− 6	+ 5	− 1	II		1	1	59
60	84·698	0	(n)	ur	+15	− 4	− 1	− 5	II		3	2	60
61	99 776	0	(n), ur	.	+10	− 6	+ 5	− 1			1	3	61
62	4401 020	0	n	ur	+28	−15	0	−15	...		3	3	62
63	01·709	2	...	...	+19	+ 4	+ 4	+ 8	120		2	3	63

TABLE IX.—*Nickel lines*—cont.

Serial number	λ	Intensity.	Character.		Shift at negative pole	Centre — arc.	Limb — centre	Limb — arc	Pressure shift per atmosphere.	Remarks	Number of plates		Serial number
			Atmospheric arc.	Under pressure.							Centre — arc	Limb —centre	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
					A/1000	A/1000	A/1000	A/1000	A/10000				
64	4410 683	2	n, uv	...	−13	+17	+ 1	+18	. .		3	3	64
65	37·729	.	n, u	. .	+37	−17	0	−17	117		2	3	65
66	59 199	2	...	ur	+24	+ 4	+ 3	+ 7	109		2	2	66
67	62·621	1	...	ur	+24	− 4	+ 3	− 2	95		3	2	67
68	66·548	0	n	..	large +	− 25	+ 2	−23	...		1	1	68
69	70 648	Ni-Zr2		ur	+26	− 3	+ 2	− 1	110		2	3	69
70	73 095	Ni ? 0	...	..	small	+ 4	+ 4	+ 8			1	3	70
71	90·701	0	n	uv	large −	+24	+ 2	+26	I	broad in ⊙	2	3	71
72	4513 164	0	...	ur	...	− 4	+ 2	− 2	II	Appears also under pressure group I.	3	2	72
73	20 157	0	..	...	+ 2	+ 6	0	+ 6	17		3	2	73
74	47 101	1	n, ur	...	+27	− 9	+ 4	− 5	. .		5	3	74
75	47·401	0	...	..	+14	− 2	− 5	− 7	.		4	3	75
76	51·399	0	n	ur	+23	− 9	+ 6 ?	− 3 ?	II		4	3	76
77	53 346	0		..	..	..	+ 3	.	...		.	3	77
78	92 707	2	ur	ur	+16	− 4	+ 2	− 2	103		5	3	78
79	4600 541	2	...	ur	+16	− 4	+ 3	− 1	93		4	3	79
80	05 171	3	ur	ur	+16	+ 1	+ 3	+ 4	95		3	3	80
81	48·835	4	ur	ur	+10	− 2	+ 5	+ 3	114		4	2	81
82	67 159	1	.	..	+ 8	− 6	+ 2	− 4	89		3	2	82
83	67 941	1	...	...	+ 7	− 1	+ 5	+ 4	92		4	1	83
84	86 395	3	...	ur	+15	− 1	+ 6	+ 5	117		4	2	84
85	4701·714	1	...	ur	+26	− 7	+ 5	− 2	135		4	2	85
86	03·994	3	n	uv	− 6	+ 6	+ 3	+ 9	I		3	2	86
87	15 946	4	...	ur	+15	− 5	+ 2	− 3	111		4	2	87
88	31 984	1	...	ur	+ 6	+ 2	+ 3	+ 5	89		3	2	88
89	32 640	1	n	ur	+21	− 5	+ 2	− 4	II		3	2	89
90	52 289	2	n	...	...	−14	+ 4	−10	...		3	2	90
91	52·613	3	n	uv	−17	+11	+ 4	+15	I		3	3	91
92	54·949	1	..	ur	+16	− 1	+ 3	+ 2	96		3	2	92
93	56 705	3	ur	ur	+15	− 1	+ 4	+ 3	113		3	2	93
94	62 820	1	...	...	+ 1	+ 2	+ 4	+ 6	47		3	3	94
95	86·472	0	. .	ur	...	+ 3	+ 2	+ 5	106		3	3	95
96	86 727	3	ur		+14	+ 1	+ 4	+ 5			3	3	96
97	4807·179	2	...	ur	+18	0	+ 4	+ 4	117		3	1	97
98	29·214	3	n, ur	ur	+14	− 8	+ 4	− 4	62		3	1	98
99	31 365	3	ur	ur	+18	+ 2	+ 3	+ 5	121		3	1	99
100	55 600	3	n		+ 2	0	+ 5	+ 5	62		2	1	100
101	66 465	2	...	ur	+13	+ 1	+ 4	+ 5	122		2	1	101
102	73·630	2	...	ur	+16	− 1	+ 2	+ 1	128		2	2	102
103	4904 597	...3	n, uv	uv	−10	+ 5	+ 6	+11	I		2	1	103
104	18·543	2	...	ur	+13	0	+ 7	+ 7	136		2	1	104
105	25·746	1	...	ur	+13	+ 6	+ 7	+13	II		3	1	105
106	36 015	2	. .	ur	+10	− 1	+ 5	+ 4	157		3	1	106
107	37·524	Ni ? 3	n, uv	...	large −	+18	+ 6	+24	I		3	1	107
108	45·622	1	n	.	large + ?	− 8	+ 6	− 2	I		3	1	108
109	53·392	2	...	ur	+14	− 1	+ 6	+ 5	II		3	1	109
110	71 531	Ni- 1	uv	uv	−16	+13	+ 2	+16	I		3	1	110
111	80 352	Ni- 4	n, uv	uv	−14	+ 9	+ 4	+13	I		3	4	111
112	84·297	2	n	uv	− 4	+ 2	+ 4	+ 6	I		3	4	112
113	98 408	1	.	ur	+10	− 1	+ 5	+ 4	II		3	3	113
114	5000·526	Ni- 2	n, uv	uv	−19	+10	+ 4	+14	I		3	3	114
115	12 625	1	...	ur	+14	− 3	+ 4	+ 1	II		3	3	115
116	17 762	3	ur	ur	+14	0	+ 4	+ 4	149		3	3	116
117	18 463	1	n	..	...	−11	+ 6	− 5	.		3	3	117
118	35 542	5	n, uv	uv	−17	+ 7	+ 4	+11	I		3	3	118
119	38 774	Ni ? 2	...	..	large − ?	+11	+ 4	+15	. .		1	3	119
120	42 367	1	...	...	large −	+ 6	+ 3	+ 9	I		1	3	120
121	49 035	Ni- 2	...	...	large −	+10	+ 4	+14	I		1	3	121
122	80 714	4	n, uv	uv	−19	+ 9	+ 4	+13	I		3	2	122
123	81 286	2	n	...	− 7	+ 5	+ 2	+ 7	I		3	2	123
124	84·279	3	n, uv	...	large −	+18	+ 4	+22	...		3	2	124
125	99 497	1	...	...	+15	+ 4	+ 2	+ 6	.		1	2	125
126	5100·108	...	n, ur	...	+24	−10	+ 2	− 8	.		1	2	126

TABLE IX.—*Nickel lines*—cont.

Serial number (1)	λ (2)	Intensity. (3)	Character. Atmospheric arc (4)	Character. Under pressure. (5)	Shift at negative pole (6)	Centre − arc. (7)	Limb − centre (8)	Limb − arc. (9)	Pressure shift per atmosphere. (10)	Remarks. (11)	Number of plates. Centre − arc. (12)	Number of plates. Limb − centre. (13)	Serial number. (14)
					A/1000	A/1000	A/1000	A/1000	A/10000				
127	5115 566	2	(ur)	...	+17	+ 2	+ 5	+ 7	...		1	2	127
128	29 546	2		...	.	− 4	+ 4	0	...		2	2	128
129	37 250	3	...	.	− 1	+ 1	+ 4	+ 5	...		3	2	129
130	42 958	2	...	. .	large − ?	+10	+ 4	+14	...		2	2	130
131	46·659	Ni-3	n	...	large −	+13	+ 5	+18	...		3	2	131
132	55 935	2	. .	..	large −	+13	+ 5	+18	...		1	2	132
133	68·832	1	...	.	. .	− 6	+ 4	− 2	...		2	3	133

Column 3—Intensity.—The intensities are taken from Rowland's Table of solar wavelengths and unless otherwise noted in this column the line was identified by him as due to nickel only. The dots before the intensity indicate that the line was not identified by Rowland.

Column 4—Character in the arc at atmospheric pressure—The character in this column was derived from the appearance of the spectrum lines, more particularly at the negative pole. The letters have the following interpretation:—

ur denotes unsymmetrically widened towards the red
uv denotes unsymmetrically widened towards the violet
n denotes hazy or diffuse.
nn denotes very hazy or diffuse.
R denotes that the line is reversed at the negative pole.
If the letters are enclosed in brackets the character is only slightly evident.

Column 5—Character in the arc under pressure.—These are taken mostly from Duffield; the few from Bilham are marked (B).

Column 6—The displacements at the negative pole are derived mostly from three plates.

Column 10—Pressure shift per atmosphere.—The shifts are taken from Duffield's paper. It should be remarked that Duffield has included lines displaced to the violet in the same class as those displaced to the red.

TABLE X.—*Titanium lines.*

Serial number (1)	λ (2)	Intensity. (3)	Shift at negative pole (4)	Centre—arc. (5)	Limb—centre (6)	Limb—arc. (7)	Pressure-shift at 8 atmospheres. (8)	Remarks (9)	Number of plates: Centre—arc (10)	Number of plates: Limb—centre. (11)	Serial number. (12)
			A/1000	A/1000	A/1000	A/1000	A/1000				
1	3904 926	3	.	+ 1	+ 3	+ 4	19		3	3	1
2	24 673	4	..	+ 2	+ 4	+ 6	10		2	3	2
3	47·918	2	...	+ 8	+ 9	+17	4		2	3	3
4	48 818	4	...	+ 3	+ 3	+ 6	13		3	3	4
5	62 995	3	...	+ 6	+ 2	+ 8	10		2	3	5
6	64·416	2		+ 5	+ 4	+ 9	10		2	3	6
7	81·917	4	...	+ 8	+ 4	+12	16	Probably blend with Fe or impurity in Fe.	2	3	7
8	89·912	4		0	+ 2	+ 2	16		2	3	8
9	98·790	4	...	+ 1	+ 6	+ 7	16		5	3	9
10	4024·726	3	...	− 1	+ 3	+ 2	8		3	1	10
11	60·415	1	.	− 4	+ 1	− 3	15		1	1	11
12	64·362	1	...	− 1	− 3	− 4	.		2	1	12
13	78·631	3	.	− 1	0	− 1	5		2	3	13
14	4112 869	1	...	+ 3	− 1	+ 2	14		1	3	14
15	86 280	1	...	+ 1	0	+ 1	16		2	3	15
16	4274·746	2	...	0	+ 3	+ 3	.		2	3	16
17	81·530	0	...	+ 1	+ 3	+ 4	14		2	3	17
18	87·566	1	..	0	+ 2	+ 2	24		4	3	18
19	89 237	2	...	+ 8	+ 6	+14	25		4	2	19
20	98·828	2	..	0	+ 3	+ 3	25		4	3	20
21	99·803	2	...	+ 4	+ 4	+ 8	23		4	3	21
22	4314·964	1	...	+ 2	− 1?	+ 1?	32	? Blend	2	3	22
23	26·520	0	.	0	+ 3	+ 3	29		2	3	23
24	95 201	3	− 1	+ 3	+ 6	+ 9	25	p Ti.	3	3	24
25	4404 433	1 N	+ 5	− 4	− 4	− 8			5	3	25
26	17·450	0	+ 6	+ 6	+ 6	+12	27		3	3	26
27	21·928	00	+12	− 1	0?	− 1?	38	p Ti. Broad in sun	3	3	27
28	22 985	0	+ 5	0	+ 2	+ 2	28		3	3	28
29	27·266	2	+ 6	+ 3	+ 2	+ 5	17		3	3	29
30	40 515	00	+ 6	− 2	0	− 2	29		3	3	30
31	43·976	5	− 2	+ 4	+ 4	+ 8	21	p Ti.	2	3	31
32	49 313	2	+12	0	+ 1	+ 1	29		3	3	32
33	51 087	1	+14	0	+ 5	+ 5	29		3	3	33
34	53·486	2	+24	− 2	+ 2	0	40		3	3	34
35	53·876	1	− 7	+ 1	+ 1	+ 2	26		3	3	35
36	65·975	1	+ 4	+ 1	+ 2	+ 3	25		3	2	36
37	71·408	0	+ 5	0	+ 1	+ 1	24		7	4	37
38	89 262	0	+ 5	− 1	+ 2	+ 1	29		7	4	38
39	96 318	1	0	+ 5	+ 5?	+10?		? Blend	7	3	39
40	4512·906	3	+ 4	0	+ 2	+ 2	29		7	4	40
41	18·198	3	+ 8	+ 2	+ 2	+ 4	29		4	2	41
42	22·974	2	+ 6	+ 2	+ 5	+ 7	31		4	3	42
43	27·490	3	+ 7	+ 9	− 1	+ 8	29		4	3	43
44	33 419	4	+ 9	+ 2	+ 3	+ 5	44		4	3	44
45	34·953	4	+12	+ 2	+ 4	+ 6	34		4	3	45
46	35 741	3	+10	0	+ 3	+ 3	29		4	3	46
47	36·094	2	+ 3	+ 2	+ 2	+ 4	23		4	4	47
48	36·222	2	+12	+ 1	+ 5	+ 6	31		4	3	48
49	44·864	3	+ 7	+ 2	+ 6	+ 8	31		3	3	49
50	48·938	2	+ 8	+ 2	+ 4	+ 6	31		3	3	50
51	52 632	2	+ 9	+ 1	+ 8	+ 9	29		4	3	51
52	55 662	3	+ 7	+ 2	+ 2	+ 4	29		4	3	52
53	63 939	4	+ 3	+ 2	+ 4	+ 6	34	p Ti	4	3	53
54	4617·452	3	.	+ 6	+ 1	+ 7	29		2	2	54
55	23 279	2	...	+ 2	+ 4	+ 6	27		2	2	55
56	39 538	2	..	+ 3	0	+ 3	...		2	2	56
57	39·846	2	.	+ 2	+ 3	+ 5	.		2	2	57
58	40 119	1	...	+ 1	0	+ 1	...		2	2	58
59	45 368	0	.	0	+ 3	+ 3	39		2	2	59
60	50 193	0	...	+ 3	+ 3	+ 6	37		2	2	60
61	56·644	3	...	+ 3	+ 4	+ 7	17		2	2	61
62	67 768	3	...	+10	+ 4	+14	20		2	2	62
63	75 294	1	...	− 8	+ 2	− 6	30		2	2	63

TABLE X.—*Titanium lines*—cont.

Serial number (1)	λ (2)	Intensity. (3)	Shift at negative pole. (4)	Centre—arc. (5)	Limb—centre (6)	Limb—arc (7)	Pressure-shift at 8 atmospheres. (8)	Remarks. (9)	Number of plates. Centre—arc. (10)	Number of plates. Limb—centre (11)	Serial number (12)
			A/1000	A/1000	A/1000	A/1000	A/1000				
·64	4682·088	3	...	+ 4	+ 4	+ 8	18		2	2	64
·65	98 946	1	.	+ 7	+ 4	+ 11	37		2	2	65
66	4722·797	0	...	+ 1?	+ 1	+ 2?	36		2	2	66
67	42 979	1	..	+ 2	− 2	0	37		2	2	67
·68	58 308	1		− 3	+ 2	− 1	27		2	2	68
·69	59 463	2	...	+ 2	+ 4	+ 6	31		2	2	69
70	4981 912	4		+ 2	+ 3	+ 5	25		4	3	70
71	91 247	3	− 1	+ 4	+ 4	+ 8	29		4	3	71
·72	5014 369	2	− 8	+ 10 ?	.	. .	21		4		72
73	16 340	2	0	+ 2	+ 2	+ 4	27		3	3	73
·74	20 208	2	− 4	− 2	+ 3	+ 1	29		4	3	74
75	23 052	2	0	+ 3	+ 1	+ 4	28		3	2	75
76	25 027	3	0	0	+ 3	+ 3	27		3	3	76
77	25·749	1	+ 56	− 16	0	− 16			3	3	77
78	36 645	2	+ 12	− 3	+ 4	+ 1	42		3	3	78
79	38 579	2	+ 15	− 3	0	− 3	48		3	3	79
80	40 138	3	− 1	+ 4	+ 3	+ 7	5		4	3	80
81	64·836	3	0	+ 4	+ 2	+ 6	12		4	3	81
82	5145·636	0	+ 5	+ 2	+ 4	+ 6	29		2	2	82
83	47 652	0	+ 7	+ 8	+ 4	+ 12	17		2	2	83
84	52·361	0	+ 3	0	+ 4	+ 4	18		2	3	84
85	73 917	2	+ 4	+ 7	+ 6	+ 13	23		4	3	85
86	88 863	2		. .	+ 4		.	p Ti.	...	3	86
87	93 139	2	+ 3	+ 6	+ 4	+ 10	19		4	3	87
88	5210·555	3	+ 5	+ 4	+ 5	+ 9	16		4	3	88

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