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PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

The Effect of Pressure upon Arc Spectra. No. 5. Nickel, λ 3450 to λ 5500, Including an Account of the Rate of Displacement with Wave-Length, of the Relation between the Pressure and the Displacement, of the Influence of the Density of Material and of the Intensity of the Spectrum Lines upon the Displacement, and of the Resolution of the Nickel Spectrum into Groups of Lines

W. Geoffrey Duffield

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VIII. *The Effect of Pressure upon Arc Spectra.*

No. 5.—Nickel, λ 3450 to λ 5500, including an Account of the Rate of Displacement with Wave-length, of the Relation between the Pressure and the Displacement, of the Influence of the Density of the Material and of the Intensity of the Spectrum Lines upon the Displacement, and of the Resolution of the Nickel Spectrum into Groups of Lines.

By W. GEOFFREY DUFFIELD, *D.Sc., Professor of Physics, and Dean of the Faculty of Science in University College, Reading.*

Communicated by Prof. A. SCHUSTER, *Sec. R.S.*

[PLATES 1–5.]

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1. *Preliminary.*—The apparatus and method of taking photographs of the spectra of metallic arcs under pressure have been described in previous papers.* The arc was formed between two poles of the metal (not quite pure) $\frac{5}{8}$-inch diameter and about 6 inches long, which were enclosed in a steel cylinder, the design of Prof. PETAVEL, F.R.S., capable of resisting a high internal pressure. The light from the arc passed through a window in the side of the cylinder, and was reflected by a system of mirrors upon the slit of the $21\frac{1}{2}$-foot Rowland grating spectrograph in the Physical Laboratory of the University of Manchester.

As in previous experiments, the spectrum of the second order was used, the dispersion being 1·3 Ångström Unit per 1 mm.

An increase in pressure was obtained by the admission of air into the cylinder from a gasholder, suitable valves and gauges being interposed.

The arc was fed by continuous current from the Corporation mains, which supplied 100 volts; this was reduced to about 50 volts at the terminals of the arc.

2. *Behaviour of the Nickel Arc under Pressure.*—As in the case of the gold arc the ease with which the arc burned depended both upon the coolness of the poles and the freshness of the air supply. The arc was maintained for short intervals without difficulty.

Of electrodes previously used the nickel arc behaved more like that between copper poles. The intensity increased very markedly with the pressure, but photometric measurements were again out of the question, owing to the unsteadiness of the arc.

At low pressures the nickel arc was distinctly mauve in tint, but it became whiter as the pressure of the surrounding air was increased.

3. *The Photographs:* (1) *Region Investigated.*—The investigation of the spectrum extended from $\lambda = 3450$ to $\lambda = 5500$: as this range of wave-lengths extends over about 162 cms., it was necessary to move the 50-cm. camera into four different positions. This involved a large amount of labour, as it practically quadrupled the amount of work which would have been necessary had it been possible to photograph the whole of the spectrum at once.

The photographs were taken partly during October, 1908, and the remainder during April, May, and June of 1910, the series being interrupted by the writer's absence in Australia.

The following table shows the pressures at which photographs have been taken in different regions of the spectrum:—

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* W. G. DUFFIELD, 'Phil. Trans.,' A, vol. 208, p. 111, 1908 (Iron Arc); vol. 209, p. 206, 1908 (Copper Arc); vol. 211, p. 33, 1910 (Silver Arc); vol. 211, p. 51, 1910 (Gold Arc).

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TABLE I.

$\lambda = 3450$ to $\lambda = 4050$.		
10 atmospheres	40 atmospheres	80 atmospheres
20 ,,	60 ,,	100 ,,
$\lambda = 4050$ to $\lambda = 4600$.		
10 atmospheres	70 atmospheres	110 atmospheres
20 ,,	80 ,,	155 ,,
40 ,, (2)	93 ,,	200 ,,
60 ,, (2)		
$\lambda = 4600$ to $\lambda = 5120$.		
10 atmospheres	40 atmospheres	80 atmospheres
20 ,,	60 ,,	100 ,,
$\lambda = 5120$ to $\lambda = 5500$.		
10 atmospheres	20 atmospheres	75 atmospheres

The plates used were Imperial Flashlight and the developer Imperial Pyro-Metol Standard. The exposure varied from five minutes to one hour according to the region examined, and the difficulty with which the arc burned. It should be noted that one hour is the total time expended upon the exposure, and includes the time when the arc was being re-struck. The total time during which the arc burned is a small fraction of this as a rule. The effect upon the photographic plate is that of the sum of a very large number of short-lived arcs.

(2) *Description of the Plates.*—Plates 1 to 5 illustrate the behaviour of the Nickel Arc under different pressures. Plate 1 includes the region $\lambda = 3450$ to $\lambda = 3740$, Plate 2 the region $\lambda = 3740$ to $\lambda = 4050$, Plate 3 the region $\lambda = 4030$ to $\lambda = 4350$, Plate 4 the region $\lambda = 4350$ to $\lambda = 4610$, and Plate 5 the region $\lambda = 4600$ to $\lambda = 4900$. The photographs are full-size positive reproductions of the originals, and are arranged in order of increasing pressure from the top at one atmosphere to the bottom at +100 or +200 atmospheres. The arbitrary numbers enumerated in Table III. have been affixed to facilitate reference to them.

The central strip in each photograph is the spectrum at atmospheric pressure, and corresponds to the spectrum at the head of each Plate. Above and below this strip are the lines as they appear when the arc is subjected to pressure. The central strip was taken partly before and partly after the pressure exposure, and this provides a check upon the value of each photographic plate. The shutter which made this

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possible is a modification of that originally used by HUMPHREYS,* and it has already been described.†

4. *The Broadening of the Lines:* (1) *General Features.*—The general phenomenon of the broadening of lines under pressure has been described elsewhere. In the Nickel Spectrum :—

(*a*) Some lines broaden nearly symmetrically; but
(*b*) Most lines broaden unsymmetrically.

Of the latter class by far the larger number are more extended towards the red end of the spectrum, but a few are unmistakably broadened more on the violet side.

It is usually possible to distinguish between two classes of lines at atmospheric pressure: namely those that are sharp and those that are soft or nebulous.

Under pressure some few of the former retain some of their characteristic hardness of outline at moderate pressures (10 to 20 atmospheres), while others lose their sharp appearance altogether and quickly become nebulous. Many that start by being nebulous become more so and disappear.

Measurements of the broadening of the lines have not been made, but some indication of their relative behaviour in this respect is given in the first row of the eighth column of Table IX., which classifies them in the following order of increasing width: slight, s; moderate, m; considerable, c; great, g; very great, vg; very very great, G.

The other columns give some account of the nature of the broadened line, whether sharp or nebulous, symmetrical or unsymmetrical. The abbreviation b_s indicates that the broadening is nearly symmetrical (very few are quite symmetrical, there is usually a slightly larger wing on the red side), b_r indicates that the broadening is greater towards the red, and b_v that it is greater on the violet side. It is impossible to examine the broadening of lines in any detail without being impressed by the inadequacy of the nomenclature of the spectroscopist. Under pressure a "line" is but a courtesy title for the extended patch of luminosity into which its original sleek proportions have degenerated, and it is valueless as a description. Nor is the term band quite appropriate, since a banded spectrum is by common usage something rather different in appearance from that of a spectrum ordinarily produced by pressure. With reluctance I have retained the word line.

The terms sharp and nebulous are usually employed to distinguish between the two well-known types of spectrum lines, but the former does not seem quite satisfactory when applied to a line whose energy has been diffused over several Ångström Units. Nevertheless a distinction is to be discerned even under pressure in the appearance of the lines, which it is valuable to make, and I have adopted the usual terms. The origin of the difference seems to lie in the shape of the intensity curves—these are gradual at the boundaries of those lines which are usually called

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* HUMPHREYS, 'Astrophysical Journal,' vol. VI., p. 169, 1897.

† DUFFIELD, 'Phil. Trans.,' A, vol. 208, p. 117, 1908.

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nebulous, and steeper in the case of those which are called sharp. The nebulous lines are not so clean-cut as those described as sharp, indeed the former frequently stand out against what looks very much like a fogged background.

Many of the strong unsymmetrically broadened lines from 159 onwards are accompanied by a haziness towards the red. It is doubtful whether it is continuous with the intensity curve of the chief part of the line or whether the luminous patches are superposed. It is possible that the different portions are due to light emitted by different parts of the arc.

A critical comparison between the broadening of the lines of various metals will be given in a subsequent paper.

(2) *Continuous Spectrum.*—It has been shown that under great pressure the silver arc spectrum becomes continuous, and that it is due, at any rate in the region of the spectrum investigated, to the broadening of the lines of the first subordinate series.* This phenomenon has been looked for in the nickel spectrum, but though there is a certain amount of continuous spectrum upon certain photographs (*e.g.* Plates 3 and 4 at 155 atmospheres), it is generally caused by the hot metallic poles rather than by the spreading of a line; as evidence of this we note that the continuous background is less pronounced at the higher pressure of 200 atmospheres.

There is, however, a very great broadening of some of the lines upon Plate 1, the spreading of lines 19 ($\lambda = 3566 \cdot 50$) and 31 ($\lambda = 3619 \cdot 52$) being particularly noticeable (Plate 1). Under 100 atmospheres the wings of 31 extend beyond line 36 on one side and 26 on the other, and may be responsible for some of the continuous spectrum which extends towards the region of longer wave-lengths. It is thus in some ways analogous to the silver lines which belong to the 1st sub-series, and it may be a member of this sub-series in the nickel spectrum.

5. *The Reversal of Lines.*—With increase of pressure there is at first a greater tendency for lines to reverse, and these reversals are indicated in Table III., those in italic (thus *3619·52*, *47*, *36*, *148*, &c.) representing a strong reversal, and those in clarendon type (thus **3670·57**, **39, 41, 102,** &c.) a weak one. It will be observed that more reversed lines are found in the region of small wave-length than in other parts of the spectrum.

In addition to the information conveyed in Table III., further details concerning the reversal of lines are given in Table IX., where the width of the absorption line is indicated, and also the symmetry or dissymmetry of the position of the fine line upon the broadened emission line.

As in the case of broadening, the widths of the reversals are classified by s = slight, m = moderate, c = considerable, g = great, vg = very great, G = very very great. The term r_s indicates that the absorption line is nearly symmetrically disposed upon the emission line; r_v indicates that the absorption line is on the violet side of the centre of the emission line.

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* W. G. Duffield, 'Phil. Trans.,' A, vol. 211, p. 33, 1910.

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Where it is stated that a line is nearly symmetrical, but that the absorption line is slightly to the violet of the centre of the broadened line, it is to be understood that it is the geometric centre that is indicated; it is possible that the positions of maximum emission and maximum absorption are coincident, though this is not necessarily the case, as was demonstrated for certain iron lines.

We note from the photographs that when a line which is self-reversed is encroached upon by the wing of an adjacent line, it gives rise to an absorption line upon the bright wing. (*Cf.* 32 on 31.)

But that when a line which is not self-reversed at a lower pressure is similarly encroached upon it does not reverse. (*Cf.* 35 and 36 in the wings of 31.)

It seems probable that this is due to differences in the distribution of the vibrating centres responsible for the different lines in the arc itself, which give rise to self-reversed lines having a different density or temperature gradient from those which do not produce absorption so readily.

6. *Changes in the Relative Intensities of Nickel Lines.*—With increase of pressure the spectrum undergoes a change which involve some lines becoming relatively more prominent than they were before. It has previously been pointed out that it is very difficult to assign a value to the intensity of a broadened line, because though the area it covers is greatly increased by pressure the intensity per unit area is reduced. The energy due to each line is the important quantity, but unfortunately it could only be determined by an integration which it would be extremely difficult to carry out.

In the sixth and seventh columns of Table IX. is given an account of the changes which have been observed in the intensities of nickel lines.

The following are the enhanced lines of nickel given by LOCKYER[*]:—

3849·70	4067·30	4245·0	4609·4
3889·80	4187·8	4279·4	4665·7
4015·76	4192·4	4362·3	4679·4

Only one of these lines has been observed to show a marked change in intensity under pressure, namely, 3889·80 (line 87 upon Plate 2), which is classified as weakened with increase of pressure; this is the result of its great broadening, and does not necessarily denote any reduction in the total energy emitted by the vibrating centre responsible for it. One other enhanced line, 4067·30, appears upon the photograph at 10 atmospheres pressure, which has had a prolonged exposure, and it is there strengthened relatively to some of the faint lines near it; it does not persist at higher pressures; as none of the other enhanced lines have been observed under pressure, it is the only exception to the general conclusion that pressure does not favour the appearance of enhanced lines[†]. This is in agreement with previous work upon other spectra.

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[*] LOCKYER, 'Report,' Solar Physics Committee.

[†] REECE, in a less conservative list of enhanced lines includes 4368·45, here classified as strengthened under pressure, 'Astrophysical Journal,' vol. XIX., p. 334, 1904; also 4231·23, here weakened.

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MITCHELL* attributes the occurrence of enhanced lines in the chromospheric spectrum partly to the reduction of pressure consequent upon the greater altitude and partly to the presence of hydrogen there. This will be further discussed in a subsequent paper.

7. *The Displacement of the Lines:* (1) *The Measurement of the Plates.*—The bulk of the measurements were made by Mr. F. E. PEARSE, for whose assistance I am indebted to the Government Grant Committee. The photographs were placed in the fixed carrier of a modified Hilger photo-measuring machine in which the movable part was the microscope which was controlled by a screw whose drumhead reading could be estimated to the thousandth part of a millimetre. In order that lines of various breadths could be measured the microscope could be converted into a telescope and a considerable range of magnification achieved. There were two pairs of parallel wires of different intervals in the eye-piece, either of which could be set perpendicular to the direction of travel of the slide and parallel to the spectrum lines. This latter operation had been found difficult in previous work, so the later photographs had been taken with a shutter, in which short slits had been cut to allow the top and bottom of the comparison lines to affect the photographic plate above and below the central strip. In each 50 cm. there were three such extra pairs of slits, each about 2 cm. long, *e.g.*, lines 15, 16, 17, 18, Plate 1. It was always possible to find one at least of these in the range of spectrum upon the measuring machine, and the parallelism of the cross wires was consequently attained with ease and considerable accuracy. Two readings were taken with the plate placed with the red on the right-hand side, the setting being first on the upper and then on the lower half of the line under pressure; the plate was then reversed and the readings repeated. Four readings were thus invariably taken. In many instances others were made. The readings were checked by the writer, who made a point of measuring each line at some one pressure. As a rule these readings were not included in the mean results, because there was some personal equation in the measurements, and it seemed best to have a homogeneous set of readings made by one individual because these are then more strictly comparable with one another. It is interesting to note that even though different observers may obtain different absolute values for the displacements upon a single photographic plate, there is usually agreement between the relative values of their measurements of the displacements of different lines. For instance, the groupings are usually the same and also the ratios of the mean displacements of the groups.

The order of accuracy obtained is shown by the following, Table II., in which a few readings taken at random are reproduced. They illustrate the agreement of Mr. PEARSE's readings amongst themselves and with those of the writer.

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* MITCHELL, 'Astrophysical Journal, vol. XXXVIII., p. 407, 1913.

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TABLE II.

Plate 5.—Nickel, 20 Atmospheres.

Line.	Readings in thousandths of a millimetre.	Means.	Check readings. (G.D.).
193	194, 204, 151, 151, 199, 176, 162	176	200, 205
195	129, 123, 154, 153, 128	137	160, 142
196	133, 147, 122, 135, 140, 171, 153, 150	143	160, 200
197	243, 242, 224, 223	233	205, 200
201	196, 214, 222, 219, 183, 193, 194, 205	203	195, 210
202	147, 137, 116, 156, 140, 162	143	130, 200
203	125, 131, 147, 134, 152	137	130, 150

Plate 2.—Nickel, 10 Atmospheres.

Line.	Mean readings in thousandths of an Å.U.		Line.	Mean readings in thousandths of an Å.U.		Line.	Mean readings in thousandths of an Å.U.	
	PEARSE.	DUFFIELD.		PEARSE.	DUFFIELD.		PEARSE.	DUFFIELD.
53	37	23	*62*	25	29	*70*	40	46
54	23	26	*63*	10	8	*71*	22	43
55	21	29	*64*	13	18	*72*	61	55
56	30	29	*65*	13	20	*73*	32	35
57	35	29	*66*	27	22	*74*	35	29
59	40	42	*67*	52	39	*78*	32	27
60	27	26	*68*	30	18	*79*	39	31
61	40	18	*69*	53	46	*83*	26	34

Plate D.—Nickel, 10 Atmospheres. The lines are those of short wave-length and are in 3rd Order.

Line.	Mean readings in thousandths of an Å.U.		Line.	Mean readings in thousandths of an Å.U.		Line.	Mean readings in thousandths of an Å.U.	
	PEARSE.	DUFFIELD.		PEARSE.	DUFFIELD.		PEARSE.	DUFFIELD.
26	*49*	*43*	*32*	*34*	*17*	*40*	*31*	*29*
27	*31*	*41*	*35*	68	30	*41*	*39*	*17*
28	*29*	*43*	*36*	65	47	*42*	*42*	*48*
29	*64*	*17*	*38*	37	27	*43*	*37*	*44*
30	*44*	*26*	*39*	*32*	*48*	*44*	26	v. small
31	47	—						

Lines whose displacements are given in italics are reversed at the corresponding pressure.

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Except in a few instances the agreement is good. When there were differences Mr. PEARSE made additional readings; from these and from the measurements of the displacements at other pressures it was usually possible to decide upon the more probable value.

Experience in the measurement of displacements under pressure clearly shows that the personal equation of a computor is not a fixed quantity; there is a tendency for a novice to record values that are too high, and it is found by experience that an interval may make a considerable difference in one's judgment of a set of displacements. For instance, the writer measured some lines before and after a voyage of some months' duration, and found marked differences in the readings, the second set being only about 70 per cent. of the first. There was, however, excellent agreement between the rate of displacement with wave-length for lines with the same type of intensity curves. It is on this account that the writer does not wish to lay too great a stress upon the absolute values of the displacements for any one metal. The accuracy of the relative values for different metals depends also upon the shapes of the intensity curves of the lines; if these are similar they are more likely to be reliable.

In measuring displacements it is very important that the photographs shall be illuminated by a source of constant brilliance, and for this purpose measurements made in artificial light are more constant than those made in daylight of variable intensity.

(2) *Description of Table of Displacements* (1 *to* 110 *Atmospheres*).—Table III. gives in thousandths of an Ångström Unit the value of the displacement of each line at the pressure stated at the top of each column. The first column contains a list of the arbitrary numbers assigned to the lines, the second the wave-lengths of the lines according to HASSELBERG. The displacements measured for various pressures follow in successive columns.

Reversed lines are indicated in the manner stated in Section 5, p. 209.

That the displacement increases with the pressure is at once evident.

The second half of the table contains the displacements per atmosphere in thousandths of an Ångström Unit, the readings being obtained by dividing those in the first part of the table by the excess pressure above that of one atmosphere.

A column is devoted to the Mean Displacement per atmosphere in thousandths of an Ångström Unit, to which reference will be made later; and the final columns which contain the quotient obtained by dividing the Mean Displacement per atmosphere respectively by the first power, square and cube of the wave-length of the line, will also be the subject of subsequent discussion.

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TABLE III.—Nickel.

Line.	Wave-length (HASSELBERG).	Mean displacements in thousandths of an Ångström Unit.									Displacements per atmosphere in thousandths of an Ångström Unit.									Mean displacements per atmosphere in $\frac{1}{1000}$ Å.U., excluding displacements at 10 atmospheres.	d/λ.	d/λ^2.	d/λ^3.
		Atmospheres.									Atmospheres.												
		10.	20.	40.	60.	70.	80.	93.	100.	110.	10.	20.	40.	60.	70.	80.	93.	100.	110.				
1	3453·04 (7)		r																				
2	53·64 (5)		r																				
3	*58·59 (8nr)*		r																				
4	*61·78 (8nr)*		r																				
5	*72·68 (7nr)*		r																				
7	*93·10 (9nr)*		*(114)*									(5·7)											
8	3501·00 (6)		*70*	*35*	*(44)*				*(98)*			3·5	0·9	(0·7)				(1·0)		(1·5)			
9	02·76 (4)		*(62)*																				
10	*10·47 (8nr)*		75	*106*	*(94)*							3·7	2·6	(1·6)						(2·6)	(74)		
11	*15·17 (9nr)*		*(60)*	*(197)*	*(229)*		r		r			(3·0)	(4·9)	(3·8)						(3·9)			
12	18·80 (4)		*(62)*																				
13	19·90 (6)		*35*	*49*	*80*				*(140)*			1·7	1·2	1·3				(1·4)		1·4	40	113	321
14	*24·65 (10nr)*		*(78)*	*(215)*	*(242)*		r		r			(3·9)	(5·4)	(4·0)						(4·4)			
15	48·34 (5)		*32*	*43*	*70*		*61*		*133*			1·6	1·1	1·2		0·8		1·3		1·2	34	95	268
16	51·66 (5)		(**52**)	50	111							2·6	1·3	1·8						1·9	53	150	424
17	53·63 (4)		44	76								2·2	1·9							2·0	56	158	446
18	61·91 (4s)		*22*	21	30		66		80			1·1	0·5	0·5		0·8		0·8		0·7	20	55	155
19	*66·50 (9nr)*		*50*	*96*	*128*		*150*		*(138)*			2·5	2·4	2·1		1·9		(1·4)		(2·1)	59	165	463
21	*71·99 (7nr)*		*36*	*76*	*118*		*151*		*171*			1·8	1·9	2·0		1·9		1·7		1·9	53	149	417
25	88·08 (5s)		*32*	*41*	*76*		*67*		*119*			1·6	1·0	1·3		0·8		1·2		1·1	31	85	238
26	**97·84 (7n)**	*49*	*40*	*79*	*132*		*186*		*(206)*		4·9	2·0	2·0	2·2		2·3		(2·0)		2·1	58	162	451
27	3602·41 (5)	*31*	*58*	*47*	*164*		*(120)*		*80*		3·1	2·9	1·2	2·7		(1·5)		0·8		1·8	50	139	385
28	09·44 (5)	*29*	*19*	*45*	*69*		*83*		*98*		2·9	1·0	1·1	1·1		1·0		1·0		1·0	28	77	213
29	*10·60 (4r)*	*64*	*44*	*71*	*150*		*211*		*221*		6·4	2·2	1·8	2·5		2·6		2·2		2·2	61	169	467
30	12·86 (7)	*44*	*30*	*45*	*98*		*113*		*160*		4·4	1·5	1·1	1·6		1·4		1·6		1·4	39	107	297
31	*19·52 (10nr)*	*47*	*36*	*148*	*192*		*186*		*(220)*		4·7	1·8	3·7	3·2		2·3		(2·2)		(2·6)	72	198	548
32	24·87 (6s)	*34*	*17*	*30*	*59*		*45*		*66*		3·4	0·8	0·7	1·0		0·6		0·7		0·8	22	61	168
34	3630·04 (3)																						
36	35·10 (4s)	47	34	54	109		113		(127)		(4·7)	1·7	1·4	1·8		1·4		(1·3)		1·5	41	113	312
38	62·10 (4s)	37	21	50	91		66		(94)		(3·7)	1·0	1·3	1·5		0·8		(0·9)		1·1	30	82	224
39	64·24 (6s)	48	*34*	*74*	*109*		*(100)*		*208*		(4·8)	1·7	1·8	1·8		(1·2)		2·1		1·7	47	126	345
40	69·38 (4s)	**31**	**22**	**54**	**83**		129		(98)		3·1	1·1	1·4	1·4		1·6		(1·0)		1·3	36	97	263
41	70·57 (5s)	**39**	**41**	**102**	**127**		**136**		**207**		3·9	2·1	2·5	2·1		1·7		2·1		2·1	57	156	425
42	74·28 (7s)	*42*	*31*	*83*	*119*		*109*		*172*		4·2	1·5	2·1	2·0		1·3		1·7		1·7	46	126	343
43	88·58 (5s)	**37**	**36**	**70**	**123**		123		214		3·7	1·8	1·7	2·0		1·5		2·1		1·8	48	132	358
44	94·10 (4)	26	25	35	88		75		94		2·6	1·2	0·9	1·5		0·9		0·9		1·0	27	73	198
46	3722·63 (6)	r	**31**	**83**	**184**		**171**		**255**			1·5	2·1	3·1		2·1		2·5		2·2	60	159	426

Lines whose displacements are given in italics thus (*3619·52, 47, 36*, &c.) have well-marked reversals. The reversal of lines represented thus (3670·57, **39**, **41**, &c.) are less obvious, but can be seen under a magnifying glass.

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Line.	Wave-length.	10.	20.	40.	60.	70.	80.	93.	100.	110.	10.	20.	40.	60.	70.	80.	93.	100.	110.	Mean.	*d*/λ.	*d*/λ^2.	*d*/λ^3.
47	3724 ·95 (3)																						
48	30 ·88 (3)		19	54	70		57		71			1 ·0	1 ·4	1 ·2		0 ·7		0 ·7		1 ·0	27	72	192
50	36 ·94 (7s)	r	*72*	*48*	*80*		**74**		**133**			3 ·6	1 ·2	1 ·3		0 ·9		1 ·3		1 ·6	43	114	306
51	39 ·36 (5)		18	35	89		97		188			0 ·9	0 ·9	1 ·5		1 ·2		1 ·9		1 ·2	32	86	229
52	44 ·68 (5s)																						
55	49 ·15 (4s)	21	23	40	57		119				2 ·1	1 ·2	1 ·0	0 ·9		1 ·5				1 ·1	29	78	209
58	62 ·76 (4)																						
61	69 ·58 (2)	40	30	56	80						4 ·0	1 ·5	1 ·4	1 ·3						1 ·4	37	99	261
62	72 ·70 (5s)	25	26	48	63		91		109		2 ·5	1 ·3	1 ·2	1 ·0		1 ·1		1 ·1		1 ·1	29	77	204
63	75 ·71 (9)	*10*	*31*	*58*	*98*		*120*		*157*		1 ·0	1 ·5	1 ·4	1 ·6		1 ·5		1 ·6		1 ·5	40	105	278
64	78 ·22 (3)	13	25	37	56		43				1 ·3	1 ·2	0 ·9	0 ·9		0 ·5				0 ·9	24	63	167
65	83 ·67 (8)	*13*	*30*	*35*	*67*		*118*		*128*		1 ·3	1 ·5	0 ·9	1 ·1		1 ·5		1 ·3		1 ·3	34	91	240
66	92 ·48 (5s)	27	21	48	61		72		115		2 ·7	1 ·0	1 ·2	1 ·0		0 ·9		1 ·1		1 ·0	26	69	183
67	93 ·75 (6s)	52	40	76	116		131		206		5 ·2	2 ·0	1 ·9	1 ·9		1 ·6		2 ·0		1 ·9	50	132	348
68	3807 ·30 (8)	*30*	*23*	*59*	*94*		*120*		*155*		3 ·0	1 ·2	1 ·5	1 ·6		1 ·5		1 ·5		1 ·5	40	103	273
73	31 ·82 (6)	*32*	30	91	**115**		122		189		3 ·2	1 ·5	2 ·3	1 ·9		1 ·5		1 ·9		1 ·8	47	122	320
74	32 ·44 (5)	35	25	47	57		54				3 ·5	1 ·2	1 ·2	0 ·9		0 ·7				1 ·0	26	68	177
77	38 { 44 ·40 (3n) 44 ·71 (3)		44									2 ·2								(2 ·2)	57	149	387
81	*58 ·40 (9r)*	*39*	*39*	*84*	*133*		*168*		*215*		3 ·9	1 ·9	2 ·1	2 ·2		2 ·1		2 ·1		2 ·1	55	140	364
82	63 ·21 (5)	50									5 ·0												
87	89 ·80 (5s)	59	81	61	(158)		(148)				5 ·9	4 ·1	1 ·5	(2 ·6)		(1 ·8)				2 ·5	65	165	425
89	3909 ·10 (3n)																						
90	12 ·44 (3n)																						
91	13 ·12 (4)	31	35	52	78		(97)				3 ·1	1 ·7	1 ·3	1 ·3		(1 ·2)				1 ·4	36	92	234
96	44 ·25 (7n)																						
98	54 ·61 (3n)																						
99	62 ·00 (n)																						
100	70 ·65 (4n)																						
101	72 ·31 (5)	12	12	32	62		53		100		1 ·2	0 ·6	0 ·8	1 ·0		0 ·7		1 ·0		0 ·8	20	51	128
102	73 ·70 (8)	44	48	69	107		132		182		4 ·4	2 ·4	1 ·7	1 ·8		1 ·6		1 ·8		1 ·9	48	120	304
103	74 ·83 (4n)																						
104	84 ·18 (4n)																						
105	94 ·13 (4n)																						
106	95 ·45 (7)	43	53	72	123		146		184		4 ·3	2 ·6	1 ·8	2 ·0		1 ·8		1 ·8		2 ·0	50	125	313
109	4006 ·30 (4)																						
110	17 ·65 (4n)																						
112	19 ·20 (3)	26	6	27	52						2 ·6	0 ·3	0 ·7	0 ·9						0 ·6	15	37	92
113	25 ·26 (3)																						
126	64 ·55 (4)	(119)									(11 ·9)												
133	4104 ·37 (2)																						
135	16 ·14 (4)	(41)			(88)						4 ·1			(1 ·5)						(1 ·5)			
137	21 ·48 (6s)	39	57	76	85	114	114	116		157	3 ·9	2 ·8	1 ·9	1 ·4	1 ·6	1 ·4	1 ·2		1 ·4	1 ·7	41	100	243
138	23 ·96 (2)																						
140	38 ·67 (2)	(74)									(7 ·4)												
141	41 { 42 ·34 (2) 42 ·47 (4)	105									10 ·5												
143	50 ·55 (3)	53									5 ·3												
144	64 ·82 (20)	17									1 ·7												
145	67 ·16 (3n)	31									3 ·1												
146	84 ·65 (3)	85									8 ·5												
147	95 ·71 (5)	67	(170)	(286)							6 ·7	(8 ·5)	(7 ·1)							(7 ·8)		(443)	(1060)
148	4200 ·61 (4s)	87	179	303							8 ·7	8 ·9	7 ·6							8 ·2	195	465	1103

Lines whose displacements are given in italics thus (*3619 ·52*, *47*, *36*, &c.) have well-marked reversals. The reversal of lines represented thus (3670 ·57, **39**, **41**, &c.) are less obvious, but can be seen under a magnifying glass.

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TABLE III.—Nickel (continued).

Line.	Wave-length (HASSELBERG).	Mean displacements in thousandths of an Ångström Unit. Atmospheres.									Displacements per atmosphere in thousandths of an Ångström Unit. Atmospheres.									Mean displacements per atmosphere in $\frac{1}{1000}$ Å.U., excluding displacements at 10 atmospheres.	d/λ.	d/λ^2.	d/λ^3.
		10.	20.	40.	60.	70.	80.	93.	100.	110.	10.	20.	40.	60.	70.	80.	93.	100.	110.				
149	4201 ·88 (5s)	(186)	215	241							(18 ·6)	10 ·7	6 ·0							8 ·3	197	471	1120
151	21 ·87 (2)	93									9 ·3												
153	31 ·23 (4)	189									18 ·9												
155	36 ·55 (3)	69									6 ·9												
159	84 ·83 (5)	100	224	356	(496)						10 ·0	11 ·2	8 ·9	(8 ·3)						9 ·5	222	518	1200
160	88 ·16 (7)	162	300	377	(629)		(693)				16 ·2	15 ·0	9 ·4	(10 ·5)		(8 ·6)				10 ·9	255	592	1380
161	96 ·06 (6)	158	(397)	404							15 ·8	(19 ·9)	10 ·1							(15 ·0)	(350)	(813)	(1890)
162	98 ·68 (3)																						
163	4307 ·40 (3)	39	79	88	127		182				3 ·9	3 ·9	2 ·2	2 ·1		2 ·3				2 ·6	60	140	325
164	25 ·75 (50) 25 ·49 (3n)																						
165	30 ·85 (5) 31 ·78 (6)	63		129	170		232				6 ·3		3 ·2	2 ·8		2 ·9				3 ·0	70	159	370
166	56 ·07 (4n)	116									11 ·6												
167	59 ·73 (6s)	115	273	531	520		828				11 ·5	13 ·6	13 ·3	8 ·7		10 ·3				12 ·2	285	630	1440
168	68 ·45 (4)	96									9 ·6												
170	84 ·68 (5)	103									10 ·3												
171	90 ·00 (4)	98									9 ·8												
172	4401 ·70 (9)	116	265	525	651	846	986	1052		(1234)	11 ·6	13 ·3	13 ·1	10 ·8	12 ·1	12 ·3	11 ·3		(11 ·2)	12 ·0	276	619	1400
174	37 ·17 (5)	115	234								11 ·5	11 ·7								11 ·7	264	589	1324
176	59 ·21 (9)	102	225	483	690	682	815	(997)		(1188)	10 ·2	11 ·3	12 ·1	11 ·5	9 ·7	10 ·2	10 ·7		(10 ·8)	10 ·9	244	549	1222
177	62 ·59 (8)	123	160	445	566						12 ·3	8 ·0	11 ·1	9 ·4						9 ·5	213	480	1068
178	70 ·61 (8)	124	280	484	593	613	916			(1060)	12 ·4	14 ·0	12 ·1	9 ·9	8 ·8	11 ·4			(9 ·6)	11 ·0	247	550	1238
179	81 ·30 (2n)																						
180	90 ·71 (4n)																						
181	4513 ·20 (4)	106									10 ·6												
182	20 ·20 (5s)	31		83			114				3 ·1		2 ·1			1 ·4				1 ·7	38	83	184
185	47 ·14 (4) 47 ·44 (5)																						
186	51 ·45 (4)	146									14 ·6												
187	60 ·10 (4)	128									12 ·8												
188	92 ·69 (7)	141	221	488	560	541	874				14 ·1	11 ·5	12 ·2	9 ·4	7 ·7	10 ·9				10 ·3	228	492	1068
189	4600 ·51 (6)	138	176	390	560						13 ·8	8 ·8	9 ·8	9 ·4						9 ·3	203	438	948
190	05 ·15 (8)	120	202	340	560	658	828				12 ·0	10 ·1	8 ·4	9 ·4	9 ·4	10 ·3				9 ·5	207	450	970
191	06 ·37 (5)																						
192	47 ·47 (3)	171									17 ·1												
193	48 ·82 (6)	140	228	518	773		844		910		14 ·0	11 ·4	12 ·9	12 ·9		10 ·5		9 ·1		11 ·4	248	528	1132

Lines whose displacements are given in italics thus (*3619 ·52, 47, 36*, &c.) have well-marked reversals. The reversal of lines represented thus (3670 ·57, **39, 41,** &c.) are less obvious, but can be seen under a magnifying glass.

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Line.	Wave-length.	10.	20.	40.	60.	70.	80.	93.	100.	110.	10.	20.	40.	60.	70.	80.	93.	100.	110.	Mean.	d/λ.	d/λ^2.	d/λ^3.
194	4655 ·85 (2)	126									12 ·6												
195	67 ·16 (3)	133	177								13 ·3	8 ·9								8 ·9	190	407	875
196	67 ·96 (4)	140	185								14 ·0	9 ·2								9 ·2	197	423	905
197	86 ·39 (5s)	184	302	432	(641)		827				18 ·4	15 ·1	10 ·8	(10 ·7)		10 ·3				11 ·7	250	532	1139
199	4701 ·72 (4)	212	270								21 ·2	13 ·5								13 ·5	288	611	1300
200	03 ·96 (5n)	58									5 ·8												
201	14 ·59 (9)	171	263		(675)		(714)				17 ·1	13 ·1		(11 ·2)	1	(8 ·9)				11 ·1	235	500	1060
202	15 ·93 (6)	170	185		(721)		(894)				17 ·0	9 ·2		(12 ·0)		(11 ·2)				10 ·8	230	485	1030
203	32 ·00 (4)	131	177								13 ·1	8 ·9								8 ·9	188	396	839
204	32 ·66 (4)	208									20 ·8												
205	52 ·58 (4)	63									6 ·3												
206	54 ·95 (3)	158	193								15 ·8	9 ·6								9 ·6	200	425	888
207	56 ·70 (6)	157	239	519	(647)		819				15 ·7	11 ·4	13 ·0	(10 ·8)		10 ·2				11 ·3	234	500	1050
208	62 ·78 (3)	62	102	245	276		250				6 ·2	5 ·1	6 ·1	4 ·6		3 ·1				4 ·7	99	207	435
209	64 ·07 (4)	140	206								14 ·0	10 ·3								10 ·3	216	454	951
211	86 ·{ 42 (2) 46 (6)	168	261	498	(531)		660				16 ·8	13 ·1	12 ·4	(8 ·8)		8 ·2				10 ·6	217	462	967
212	4807 ·17 (4)	131	223	493							13 ·1	11 ·1	12 ·3							11 ·7	245	506	1055
213	29 ·18 (6)	94	125								9 ·4	6 ·2								6 ·2	128	266	550
214	31 ·30 (5)	163	261	541			(782)				16 ·3	13 ·1	13 ·5			(9 ·8)				12 ·1	252	520	1075
215	32 ·86 (3)	116	176								11 ·6	8 ·8								8 ·8	183	376	780
216	38 ·80 (4)	247									24 ·7												
217	55 ·57 (6)	65	124								6 ·5	6 ·2								6 ·2	128	263	541
218	57 ·57 (3)	160									16 ·0												
219	66 ·42 (7)	151	289	533			(702)				15 ·1	14 ·4	13 ·3			(8 ·8)				12 ·2	252	516	1060
220	70 ·97 (4)	(76)									(7 ·6)												
221	73 ·60 (4)	168	314	502			(817)				16 ·8	15 ·7	12 ·5			(10 ·2)				12 ·8	264	540	1104
222	87 ·16 (3)	(132)									(13 ·2)												
223	4904 ·56 (7)	45									4 ·5												
224	12 ·22 (3n)	149									14 ·9												
225	14 ·15 (4n)	(81)									(8 ·1)												
226	18 ·53 (5s)	145	272								14 ·5	13 ·6								13 ·6	276	562	1142
227	25 ·74 (3)	158									15 ·8												
228	36 ·02 (4s)	154	314								15 ·4	15 ·7								15 ·7	320	643	1350
229	37 ·51 (4n)	−80									−8 ·0												
230	45 ·63 (3n)																						
231	53 ·34 (3)	176									17 ·6												
232	71 ·54 (3)	−65									−6 ·5												
233	80 ·36 (7)	−48									−4 ·8												
234	84 ·30 (7)	(14)									(1 ·4)												
235	98 ·42 (4)	157									15 ·7												
236	5000 ·48 (5n)	−47									−4 ·7												
237	12 ·62 (4s)	184									18 ·4												
238	17 ·75 (7)	185	298								18 ·5	14 ·9								14 ·9	298	592	1180
239	35 ·55 (10)	−56									−5 ·6												
240	38 ·80 (4)																						
241	42 ·35 (5n)																						
242	49 ·01 (5n)																						
243	80 ·70 (10)	(65)									(6 ·5)												
244	81 ·30 (10n)	(25)									(2 ·5)												
244*a*	99 ·50 (5s)	(160)									16 ·0												
244*b*	5135 ·55 (8s)	(140)									14 ·0												
244*c*	37 ·23 (8s)	(100)									10 ·0												
245	5424 ·85 (4)	79									7 ·9												
246	36 ·10 (5s)	89									8 ·9												
247	77 ·13 (10)	*77*	*153*								7 ·7	7 ·6								7 ·6	139	253	462

Lines whose displacements are given in italics thus (*3619 ·52*, *47*, *36*, &c.) have well-marked reversals. The reversal of lines represented thus (3670·57, **39**, **41**, &c.) are less obvious, but can be seen under a magnifying glass.

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(3) *The Spectrum of the Nickel Arc under Pressures of* +155 *and* +200 *Atmospheres.*—The range of spectrum which has been explored at higher pressures of +155 and +200 atmospheres extends from λ = 4050 to λ = 4600. The investigation, which involved a certain amount of risk, showed that there is no discontinuity in the nature of the pressure-effect between 1 and +200 atmospheres. As special interest attaches to the effect of such high pressures, and as measurements of the lines are extremely difficult, a qualitative account of the behaviour of the nickel lines at these pressures is given in the following table; when readings have been attempted they are included, but they cannot be regarded as more than approximate:—

TABLE IV.

Line.	Wave-length.	155 atmospheres.	200 atmospheres.
126	4064·55	Vanished.	Vanished.
133	4104·37	Faint indication only.	Invisible.
135	4116·14	Vanished.	Vanished.
137	4121·48	Considerably broadened, fairly symmetrical. Remains fairly compact throughout. Resembles 136, which is due to iron. Displacement 0·170 Å.U. to red. Displacement per atmosphere = 0·0011 Å.U.	Considerably broadened, as at 155 atmospheres. Displacement 0·250 Å.U. Displacement per atmosphere = 0·0013 Å.U.
141	4142·4	No sign of line, but background is of increased intensity here.	Invisible.
146	4184·65	Faint indication of very broad line.	Invisible.
147	4195·76	Vanished.	Vanished, though strong at 1 atmosphere.
148 }	4200·61	Merged.	Merged into very faint hazy band.
149 }	4201·88		
153	4231·23	Vanished.	Vanished.
(Mn)154	4235·3	Broadened, but not unduly, remains fairly compact.	Very faint.
(Fe) 158	4271·3	” ” ”	” ”
159	4284·83	Greatly broadened and displacement. Merged into 160.	Greatly broadened and displaced. Merged into 160.
160	4288·16	Same as 200 atmospheres.	Immense broadening and displacement. Unsymmetrical to red, but curve too flat topped for accurate measurement.
161	4296·06	Immense broadening and displacement. Unsymmetrically broadened to red.	Very faint.
163	4307·40	Considerably broadened.	Broadening rather greater, but now very faint.
165	4331·0	Vanished.	Vanished.
167	4359·73	Greatly broadened and displaced to red. Broadening unsymmetrical. Displacement between 0·57 to 0·83 Å.U.	Very broad and diffuse.

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TABLE IV. (continued).

Line.	Wave-length.	155 atmospheres.	200 atmospheres.
172	4401·70	Immensely broadened. Unsymmetrical to red. Displacement approximately 0·6 Å.U. Mean displacement per atmosphere = 0·0039 Å.U.	Immensely broadened. Unsymmetrical to red. Displacement between 0·71 and 0·91 Å.U. Mean displacement per atmosphere between 3·5 and 4·5 thousandths of an Å.U.
174	4437·17	Doubtful whether the hazy band is due to this line or a close neighbour.	Faint hazy patch of luminosity. Flat-topped intensity curve.
176	4459·21	Immense unsymmetrical broadening. Displacement approximately 0·69 Å.U. Mean displacement per atmosphere = approximately 4·5 thousandths of an Å.U.	Immensely broadened. Displacement between 0·9 and 1·6 Å.U. Mean displacement per atmosphere = approximately 6 thousandths of an Å.U.
177	4462·59	Immense unsymmetrical broadening. Displacement approximately 1·1 Å.U. Mean per atmosphere = 0·007 Å.U.	Immense unsymmetrical broadening.
178	4470·61	Immense unsymmetrical broadening. Displacement approximately 0·97 Å.U. Mean per atmosphere = 0·0063 Å.U.	Immense unsymmetrical broadening. Displacement approximately 1·7 Å.U. Mean per atmosphere = 0·0085 Å.U.
182	4520·20	Considerably broadened. Fairly compact.	Not quite merged in background.
185	4547·30	Immense unsymmetrical broadening.	Faint hazy patch of luminosity.
188	4592·69	Immense unsymmetrical broadening. Displacement 0·83 Å.U. Mean per atmosphere = 0·0054 Å.U.	Immense unsymmetrical broadening. Displacement (1·9) Å.U. Mean per atmosphere = (0·0095) Å.U.
189	4600·51	Immense unsymmetrical broadening.	Faint patch of luminosity.
190	4605·15	Immense unsymmetrical broadening. Displacement 0·91 Å.U. Mean per atmosphere = 0·006 Å.U.	Immense unsymmetrical broadening. Displacement 0·97 to 1·9 Å.U. Mean per atmosphere = 0·005 to 0·009 Å.U.
191	4606·37	Merged into 190 or else vanished.	Merged or vanished.

(4) *Displacement towards the Violet*:—The writer has on previous occasions chronicled the displacement of a few lines towards the more refrangible part of the spectrum and so have other observers. In the nickel spectrum similar displacements have been recorded, and it will be seen from the following table that there is good agreement between the readings made by my assistant and myself upon these lines. In accordance with precedent Mr. PEARSE's determinations are those which are included in Diagram 5, where the negative displacements are distinguished by a horizontal line passing through the dot. It would be of great interest to observe if the displacement towards the violet increases or decreases with increase of pressure, but unfortunately reliable measurements of the displacements of these lines were not feasible above a pressure of 10 atmospheres. The reality of displacements towards the violet

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has been questioned, but in the writer's opinion they are real and not due merely to unsymmetrical broadening; it is true that the negatively displaced nickel lines are more broadened towards the violet than the red, but the broadening takes place about a negatively displaced position. Several theories can explain qualitatively how displacements and unsymmetrical broadening towards the red may be accounted for; the displacement of a line towards the violet should not be more difficult to explain than an unsymmetrical broadening in that direction; the latter phenomenon is unquestionably true.

The following are the displacements of lines towards the violet measured by Mr. Pearse and by myself. The photographs were taken when the pressure of the air was 10 atmospheres:—

TABLE V.

Line.	λ.	Pearse.	G.D.
229	4937·51		−50
232	71·54	−65	−30
233	80·36	−48	−30
236	5000·48	−47	−30
239	35·55	−56	−40
244	81·30	−25	0

Line 243 λ = 5080·70 is apparently reversed and displaced towards the violet, but this is found to be due to the strengthening under pressure of a faint line on its violet edge.

(5) *Displacement Diagrams.*—In Diagram 1 lines are drawn connecting the different readings of the displacements at different pressures of a few of the spectrum lines dealt with, and each line represents the behaviour of one spectrum line. The proportionality between the displacement and the pressure is apparent from the diagram, and is approximately linear. In Section 7, p. 224, this point is further examined. The diagram further illustrates the fact that the lines are capable of resolution into two groups according to their rates of displacement, a feature which is more fully treated later.

The diagram includes both reversed and bright lines, but does not distinguish between them. Without exception the former fall into the group with the smaller displacement. Lines displaced towards the violet are not included in this diagram.

(6) *Comparison with Previous Observations.*—The displacements of certain nickel lines have been observed by Humphreys and Mohler* at pressures of $9\frac{3}{4}$, $12\frac{1}{2}$, and $14\frac{1}{2}$

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* Humphreys and Mohler, 'Astrophysical Journal,' vol. III., p. 114, 1896.

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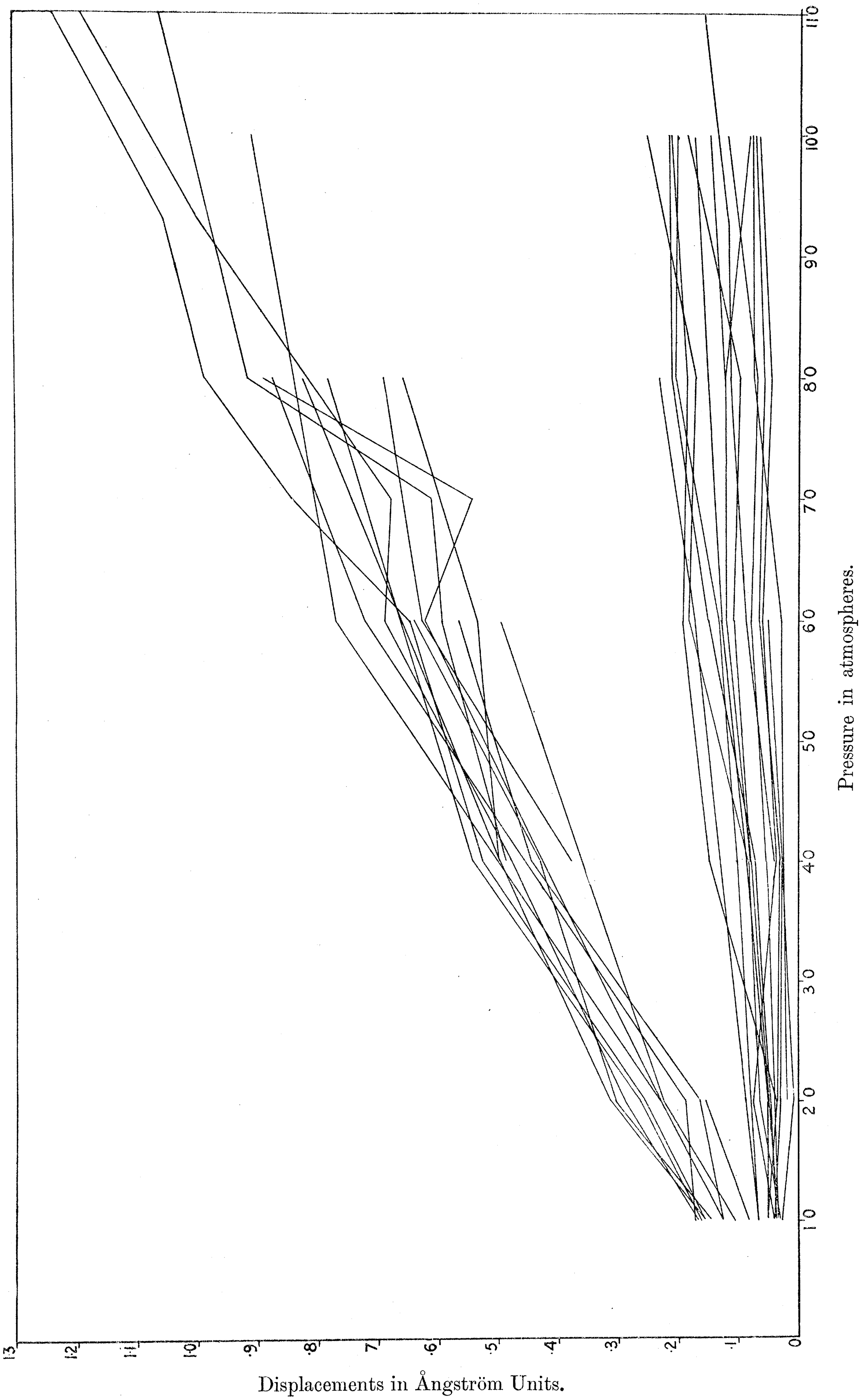
Diagram 1.



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atmospheres, and by HUMPHREYS* at pressures of 42, 69, and 101 atmospheres. The results of these two researches are given in full in the following tables.

The displacements per atmosphere have been calculated from their measurements and are set out in subsequent columns. The mean displacements per atmosphere have been inserted, and may be compared with the similar values obtained in the present research.

The agreement is reasonable considering that in the previous investigations the means for a large proportion of the lines are not based upon a very large number of observations. The lines 172, 176, 178, &c., are, however, assigned larger displacements by the writer than by HUMPHREYS.

TABLE VI.

λ.	Displacements in thousandths of an Ångström Unit. (HUMPHREYS.)						Displacements per atmosphere in thousandths of an Ångström Unit. (HUMPHREYS.)						Mean displacement per atmosphere. (HUMPHREYS.)
	Atmospheres.						Atmospheres.						
	$9\frac{3}{4}$.	$12\frac{1}{2}$.	$14\frac{1}{2}$.	42.	69.	101.	$9\frac{3}{4}$.	$12\frac{1}{2}$.	$14\frac{1}{2}$.	42.	69.	101.	
3002·60		·		·	·	107	·	·	·	·	·	1·1	1·1
03·73		·		·	·	103	·	·	·	·	·	1·0	1·0
12·10		·		·	·	105	·	·	·	·	·	1·0	1·0
38·05		·		·	·	97	·	·	·	·	·	1·0	1·0
50·88		·		32	77	101	·	·	·	0·8	1·1	1·0	1·0
54·40		·		41	·	102	·	·	·	1·0	·	1·0	1·0
57·72		·		50	90	127	·	·	·	1·2	1·3	1·3	1·3
3161·61		·		48	·	·	·	·	·	1·2	·	·	1·2
02·00		·		59	·	·	·	·	·	1·4	·	·	1·4
34·26		·		60	·	122	·	·	·	1·4	·	1·2	1·3
3233·11		·		49	·	115	·	·	·	1·2	·	1·2	1·2
3369·66		·		77	·	·	·	·	·	1·9	·	·	1·9
72·12		·		48	·	·	·	·	·	1·2			1·2
74·35		·		29	·	·	·	·	·	0·7			0·7
80·70		·		96	·	·	·	·	·	2·3			2·3
91·21		14		70	·	·	·	1·1	·	1·7			1·4
93·10		·		63	·	·	·	·	·	1·5			1·5
3413·64		19						1·5	·				1·5
14·96		19		77	·	·	·	1·5	·	1·9			1·7
23·80		·		84	·	·	·	·	·	2·0			2·0
33·71		·		94	·	·	·	·	·	2·3			2·3
37·45	20	·	34	63	·	·	2·0	·	2·3	1·5			1·9
46·34		·		71	·	·	·	·	·	1·7			1·7

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* HUMPHREYS, 'Astrophysical Journal,' vol. XXVI., p. 36, 1907.

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TABLE VI. (continued).

Line.	λ.	Displacements in thousandths of an Ångström Unit. (HUMPHREYS.) Atmospheres.				Displacements per atmosphere in thousandths of an Ångström Unit. (HUMPHREYS.) Atmospheres.				Mean displacement per atmosphere. (HUMPHREYS.)	Mean displacement per atmosphere. (Present Research).
		9¾.	12½.	14½.	42.	9¾.	12½.	14½.	42.		
1	3453·04	·	·	·	62	·	·	·	1·5	1·5	·
3	58·59	·	27	29	91	·	2·2	2·0	2·2	2·1	·
4	61·78	16	23	·	67	1·6	1·8	·	1·6	1·7	·
·	67·63	·	·	·	63	·	·	·	1·5	1·5	·
·	69·64	·	·	·	95	·	·	·	2·3	2·3	·
5	72·68	·	·	·	80	·	·	·	2·0	2·0	·
7	93·10	·	·	·	81	·	·	·	2·0	2·0	·
8	3501·00	·	24	35	50	·	1·9	2·4	1·2	1·8	(1·5)
10	10·47	·	·	·	83	·			·	2·0	·
11	15·17		34	41	·	·	2·7	2·8	2·0	2·7	·
13	19·90	·	·	·	75	·			1·8	1·8	1·4
14	24·65	·	30	·	96	·	2·4	·	2·3	2·3	·
15	48·34	·	·	·	80	·	·	·	2·0	2·0	1·2
18	61·91	·	·	·	63	·	·	·	1·5	1·5	0·7
19	66·50	·	·	·	91	·	·	·	2·2	2·2	2·1
21	71·99	·	·	·	100	·	·	·	2·4	2·4	1·9
25	88·08	·	·	·	92	·	·	·	2·2	2·2	1·1
26	97·84	·	·	·	102	·	·	·	2·4	2·4	2·1
27	3602·41	·	·	·	82	·	·	·	2·0	2·0	1·8
28	09·44	·	·	·	72	·	·	·	1·8	1·8	1·0
29	10·60	·	·	·	101	·	·	·	2·4	2·4	2·2
30	12·86	·	·	·	80	·	·	·	2·0	2·0	1·4
31	19·52	·	·	·	65	·	·	·	1·6	1·6	(2·6)
32	24·87	·	·	·	60	·	·	·	1·5	1·5	0·8
38	62·10	·	·	·	53	·	·	·	1·3	1·3	1·1

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TABLE VI. (continued).

Line.	Wave-length.	Displacements in thousandths of an Ångström Unit. (HUMPHREYS.)			Displacements per atmosphere in thousandths of an Ångstsöm Unit. (HUMPHREYS.)			Mean displacement per atmosphere. (HUMPHREYS.)	Mean displacement per atmosphere. (Present Research.)
		Atmospheres.			Atmospheres.				
		42.	69.	101.	42.	69.	101.		
39	3664·24	·	110	·	·	1·6	·	1·6	1·7
41	70·57	·	88	·	·	1·3	·	1·3	2·1
42	74·28	·	70	·	·	1·0	·	1·0	1·7
43	88·58	·	68	·	·	1·0	·	1·0	1·8
46	3722·63	·	111	·	·	1·6	·	1·6	2·2
50	36·94	·	83	·	·	1·2	·	1·2	1·6
63	75·71	·	88	·	·	1·3	·	1·3	1·5
65	83·67	·	58	·	·	0·9	·	0·9	1·3
68	3807·30	·	76	·	·	1·1	·	1·1	1·5
81	58·40	·	117	·	·	1·7	·	1·7	2·1
101	3972·31	·	75	·	·	1·1	·	1·1	0·8
102	73·70	·	140	176	·	2·1	1·8	2·0	1·9
165	4330·85 31·78	88	150	204	2·1	2·2	2·0	2·1	3·0
172	4401·70	·	·	480	·	·	4·8	4·8	12·0
176	59·21	·	·	625	·	·	6·2	6·2	10·9
178	70·61	·	580	·	·	8·5	·	8·5	11·0
182	4520·20	·	120	·	·	1·8	·	1·8	1·7
188	92·69	320	620	·	7·8	9·1	·	8·5	10·3
189	4600·51	464	·	·	11·3	·	·	11·3	9·3
190	05·15	280	600	·	6·8	8·8	·	7·8	9·5
193	48·82	270	660	·	6·6	9·7	·	8·1	11·4
197	86·39	325	557	·	7·9	8·2	·	8·0	11·7
201	4714·59	274	·	·	6·7	·	·	6·7	11·1
207	56·70	297	·	·	7·2	·	·	7·2	11·3
—	5155·94	24 at 9¾ atmospheres			2·5 at 9¾ atmospheres			2·5	—

(7) *Relation between the Pressure and the Displacement.*—That the relation between the pressure and displacement is approximately a linear one is evident from Diagram 1, in which these two quantities are plotted. But the displacements per atmosphere are almost invariably greater at low pressures than at high ones (see Table III.) which seriously challenges the existence of an exact linear relationship. This is clearly brought out by Diagram 2, in which the mean displacement per atmosphere form the ordinates and the pressure the abscissæ of the curves, each of which represents the behaviour of one particular spectrum line whose identity can be traced from the number assigned to it. There is a general downward trend as the pressure increases, which is in favour of the rate of displacement decreasing with increase of pressure. This tendency is apparent in each of the two groups into which

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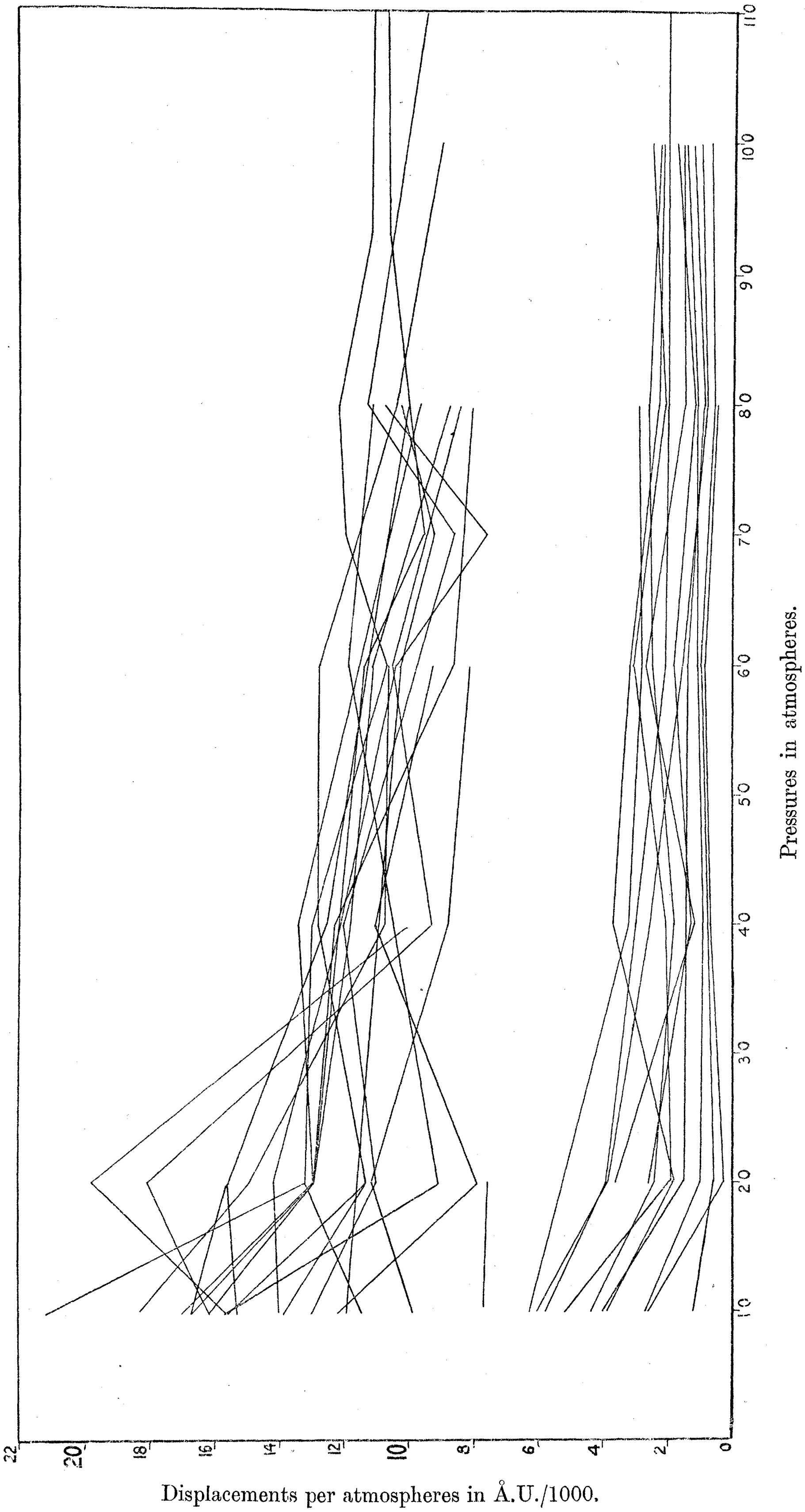
Diagram 2.



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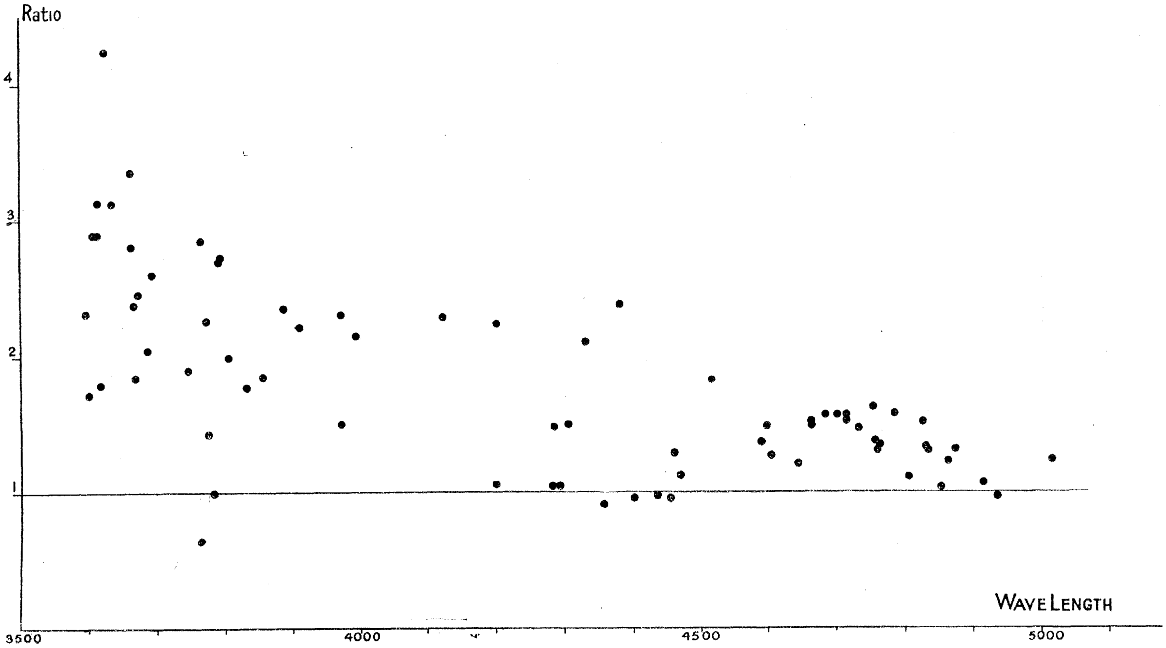
the lines are obviously divisible, but it is more pronounced in the case of the group with the greater displacement.

If the decrease of the displacement per atmosphere with the pressure were linear throughout the whole range, it would lead to an equation between the displacement d_0 and the pressure p of the parabolic form $d_0 = \mathrm{A}p - \mathrm{B}p^2$ in which the constant B is small. But though a linear relationship may reasonably represent the graph of d_0/p and p over the small range of pressure from 20 to 80 atmospheres, there is an indication that the descent of the graph is more rapid at first and that with increasing pressure it becomes more gradual, suggesting a curve of an exponential form. This is emphasized by Table VII., in which are given the ratios of the displacements per atmosphere at 10 atmospheres to the displacements at higher pressures, the data being taken from Table III. The former are generally greater than the latter, and the mean value of the ratio is 1·8. In Diagram 3 these ratios are plotted against wave-length; if the relationship between the pressure and displacement were precisely linear, the dots would group themselves about the line marked 1·0, but it is very obvious that the readings at 10 atmospheres are too large for this relationship to hold. The diagram also shows the curious fact that the departure from a linear relation is much more pronounced for lines of small wave-length. For large wave-lengths the ratio is nearly equal to unity. This is partly, but not entirely, due to the fact that the lines of great wave-length have not been examined over the full range of pressures. There is a

Diagram 3.



Ratio of displacements per atmosphere at 10 atmospheres to displacements per atmosphere at higher pressures.

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Table VII.—Ratio of Displacement per Atmosphere at 10 Atmospheres Pressure to Displacement per Atmosphere at Higher Pressures.

Line.	λ.	Ratio.	Line.	λ.	Ratio.
26	3597·84	2·33	165	30·85 31·78	2·10
27	3602·41	1·72			
28	09·44	2·90	167	59·73	0·92
29	10·60	2·90	172	4401·70	0·96
30	12·86	3·14	174	37·17	0·98
31	19·52	1·80	176	59·21	0·93
32	24·87	4·25	177	62·59	1·29
36	35·10	3·13	178	70·61	1·12
38	62·10	3·36	182	4520·20	1·82
39	64·24	2·82	188	4592·69	1·36
40	69·38	2·38	189	4600·51	1·48
41	70·57	1·85	190	05·15	1·26
42	74·28	2·47	193	48·82	1·22
43	88·58	2·05	195	67·16	1·49
44	94·10	2·60	196	67·96	1·52
55	3749·15	1·90	197	86·39	1·57
61	69·58	2·85	199	4701·72	1·57
62	72·70	2·27	201	14·59	1·54
63	75·71	0·66	202	15·93	1·57
64	78·22	1·44	203	32·00	1·47
65	83·67	1·00	206	54·95	1·64
66	92·48	2·70	207	56·70	1·38
67	93·75	2·73	208	62·78	1·31
68	3807·30	2·00	209	64·07	1·35
73	31·82	1·77	211	86·44	1·58
74	32·44	3·50	212	4807·17	1·41
81	58·40	1·85	213	29·18	1·51
87	89·80	2·36	214	31·30	1·34
91	3913·12	2·21	215	32·86	1·31
101	72·31	1·50	217	55·57	1·04
102	73·70	2·31	219	66·42	1·23
106	95·45	2·15	221	73·60	1·31
112	4019·20	4·33	226	4918·53	1·06
137	4121·48	2·29	228	36·02	0·98
148	4200·61	1·06	238	5017·75	1·24
149	01·88	2·24	247	5477·13	1·01
159	84·83	1·05			
160	88·16	1·48			
161	96·06	1·05	Mean value for Ratio		1·83
163	4307·40	1·50			

doubt as to whether this is a subjective or an objective phenomenon. To the general difficulties of measuring the displacement of spectrum lines reference has already been made; in particular it is not easy to compare the displacements of lines of different width and whose intensity curves are of different shapes, but inasmuch as both Mr. Pearse and the writer agree in assigning values to the displacements at high pressure which are smaller than they should be if a linear relationship exists, there is good reason for regarding the pressure-displacement relation as not quite linear. This is in accord with the results of the investigation of the gold spectrum under

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pressures from 1 to 200 atmospheres, where it was shown that the pressure-displacement curves were slightly concave to the axis of pressures and where the curves representing the mean displacements per atmosphere had a general downward tendency as the pressure increased—as in this research. Dealing with the spectrum produced by the copper arc when subjected to the highest pressure, the same features appeared, so that the evidence favours the general conclusion : "That though the relationship between the pressure and the displacement is approximately linear, the displacement does not increase quite as rapidly as the pressure."

(8) *The Relation between Displacement and Wave-length* :—In Diagrams 4 and 5 each black circle represents the mean displacement per atmosphere of the nickel line whose wave-length is given by the horizontal scale, the data being derived from Table III. Inasmuch as the displacements at 10 atmospheres pressure are disproportionately large they are treated separately in Diagram 5, whereas they are excluded from the calculations of the mean displacements which are plotted in Diagram 4. The prominent feature of these diagrams is the increase of the displacements as the wave-lengths increase, but the division of the lines into two groups is also indicated.

Treating the diagrams critically it is scarcely open to doubt that the displacement is dependent upon the wave-length, though Diagram 4 alone is perhaps not conclusive in this respect as there are not many lines in the region λ 3900 to λ 4200. Many more lines have been measured at 10 atmospheres pressure than at higher pressures, so Diagram 5 is able to provide more information about this region of the spectrum, though on the whole the values are not so reliable since they are derived from readings at only one pressure.

Granted then that the occurrence of larger displacements in the less refrangible parts of the spectrum is not fortuitous, it remains to discuss the actual relationship between these two variables. The diagram at 10 atmospheres points to a steep descent which might be regarded as approximately linear if it were not that it would involve the displacements becoming zero and subsequently negative in the more refrangible regions of the spectrum.

Though negative values for displacements due to pressure have been recorded, the crossing of the axis has not been observed in any spectrum, and the asymptotic trend of the black dots in Diagram 4 is contrary to this occurring in the case of nickel. This conclusion is supported by HUMPHREYS' measurements of lines of smaller wave-length down to $\lambda = 3000$ which are included as open circles in the diagram. Though the majority of these readings are based upon observations at only one high pressure (either 42 or 101 atmospheres) they are in such good agreement with the results of the present research as to leave no doubt that the axis is not crossed in this region of the spectrum. If we make the assumption that the origin is on the curve relating to displacement and wave-length, we can at least say that it is not contradicted by the results of this research. On the assumption that the graph is of the form $d = a\lambda^n$ the

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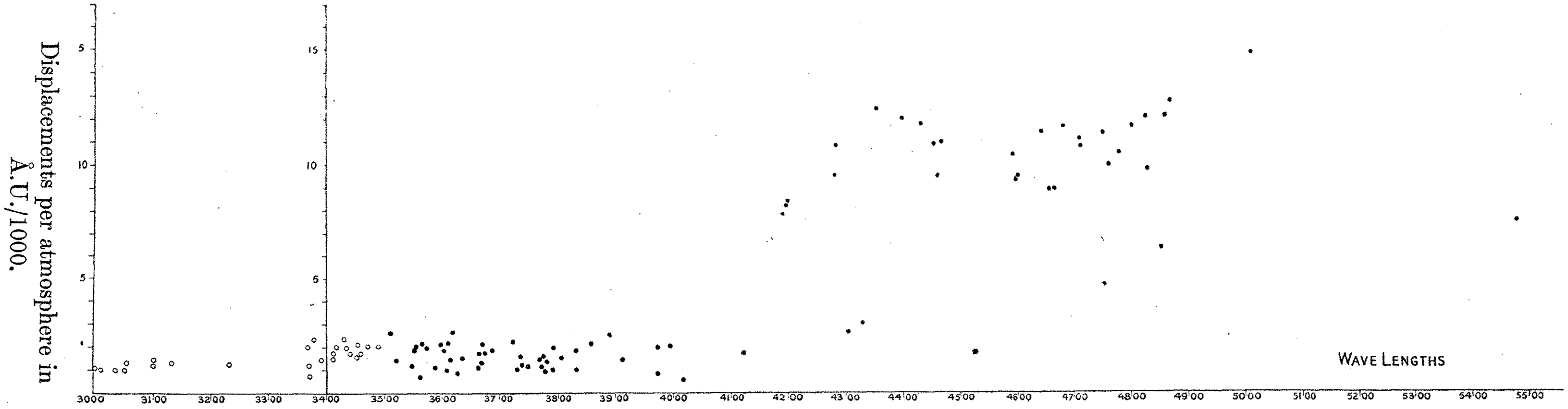
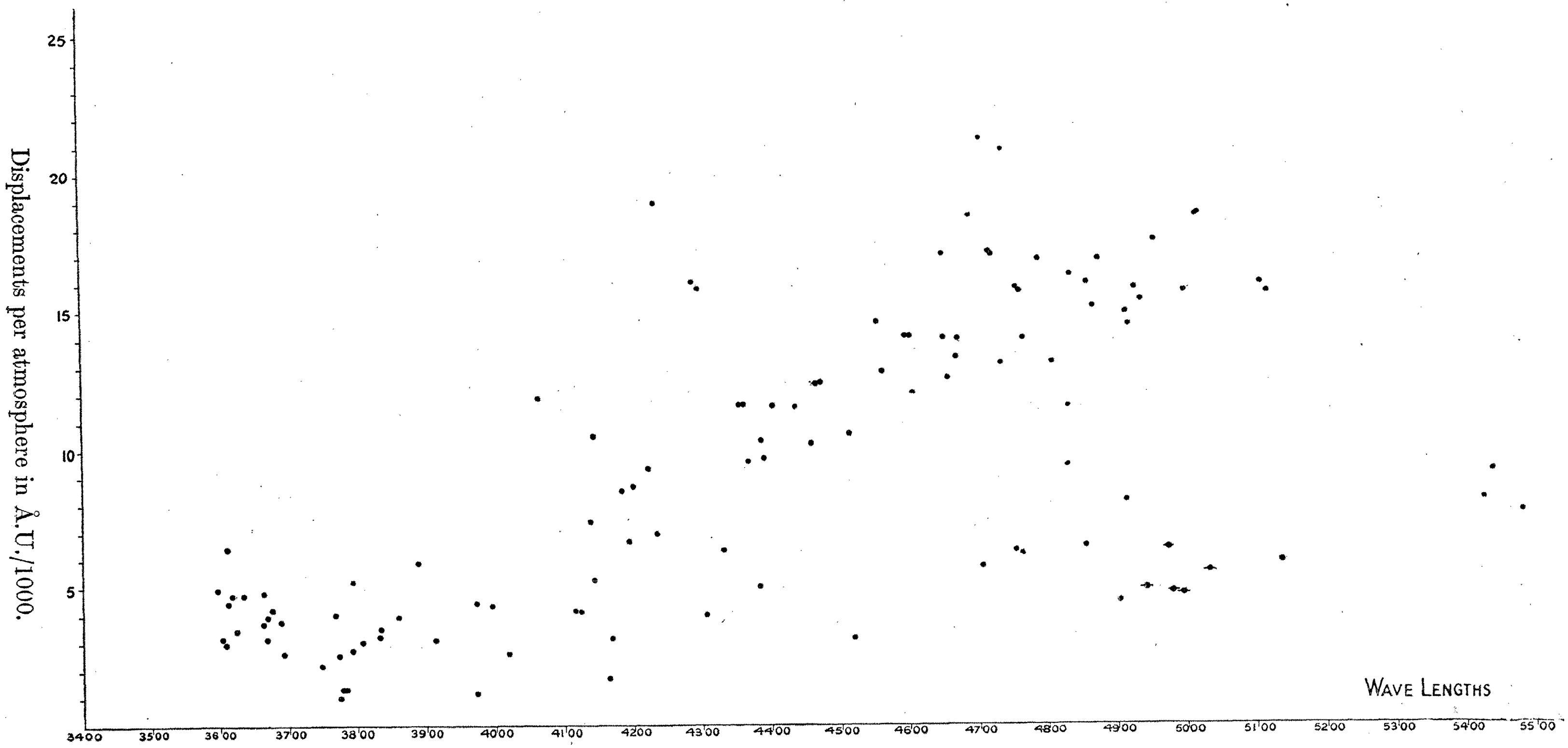
Diagram 4.



Variation of displacement with wave-length. (Readings at 10 atmospheres excluded.)

Diagram 5.



Variation of displacement with wave-length. (Values of displacements at 10 atmospheres.)

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values of d/λ, $d/\lambda^2 \times d/\lambda^3$ have been calculated (excluding measurements at 10 atmospheres); they will be found in the final columns of Table III.

In the discussion upon the copper arc, a test of the rate of displacement with wave-length was made by finding the value of n which enabled the quantities d/λ^n to be most distinctly separated into groups. This did not appear so likely to yield promising results in the case of nickel, because in Diagram 1 two groups are remarkably distinct without reference to the wave-length, a point which is further illustrated in Diagram 6, fig. 1, in which each number represents the presence in the spectrum of a line with a mean displacement corresponding to its position upon the horizontal scale. The distribution resolves itself into a well-defined group with a mean displacement per atmosphere of about 1·75 thousandths of an Ångström Unit and another very diffuse and ill-defined group with a flat-topped maximum extending from about 9 to 12 thousandths of an Ångström Unit. It might be argued that the probable errors of the measurements of the different types of line are in accord with this grouping, because those lines whose displacements are small have a smaller probable error than those with larger values, the latter being in general (but not invariably) associated with a greater width of the lines. But though this is a consideration which must be given due weight, to regard it as satisfactorily accounting for the distribution in fig. 1 would be to disregard the significance of the tendency for the displacement to increase with wave-length which has been demonstrated in Diagrams 4 and 5.

It is further important to note that lines as *208* ($\lambda = 4762·87$), *213* ($\lambda = 4829·18$), *217* ($\lambda = 4856·57$), *228* ($\lambda = 4936·02$) and *238* ($\lambda = 5017·75$) do not clearly fall within either group, also that the line *247* ($\lambda = 5477·13$) is assigned to the group with large displacement in spite of the fact that it is reversed unsymmetrically, and would not be expected, in accordance with previous experience of similarly reversed lines in the iron spectrum, to belong to a group with the highest rate of displacement.

Plotting d/λ against wave-length, fig. 2 is obtained, and again the lines *208*, *213*, *217*, *228* and *247* occupy anomalous positions. There is still less reason for regarding this distribution as satisfactory. Fig. 3 shows the distributions of the values of d/λ^2 when the lines *247*, *213*, and *217* form a group by themselves, though *208* has attached itself to the outskirts of the first group.

In fig. 4, in which the values of d/λ^3 are given, these lines have been absorbed by Group 1, and the resolution into two groups is clearer. We note also that the second group is more compact; this is obviously the most satisfactory diagram, and we may therefore conclude that as far as values above 10 atmospheres are concerned, the rate of displacement is not far removed from that of the cube of the wave-length. It may appear remarkable that any order can be arrived at considering the apparently chaotic distribution of dots in Diagram 4 in the region of wave-lengths λ 4200 to λ 4500, and it is necessary to emphasize the fact that the method consists in the elimination of the dots with displacements varying from 5 to 8 thousandths of an Ångström Unit from

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the cloud of dots above them, and that we draw the above conclusion from the fact that the group of dots representing high values of the displacement in

Diagram 6. Frequency distribution of spectrum lines.

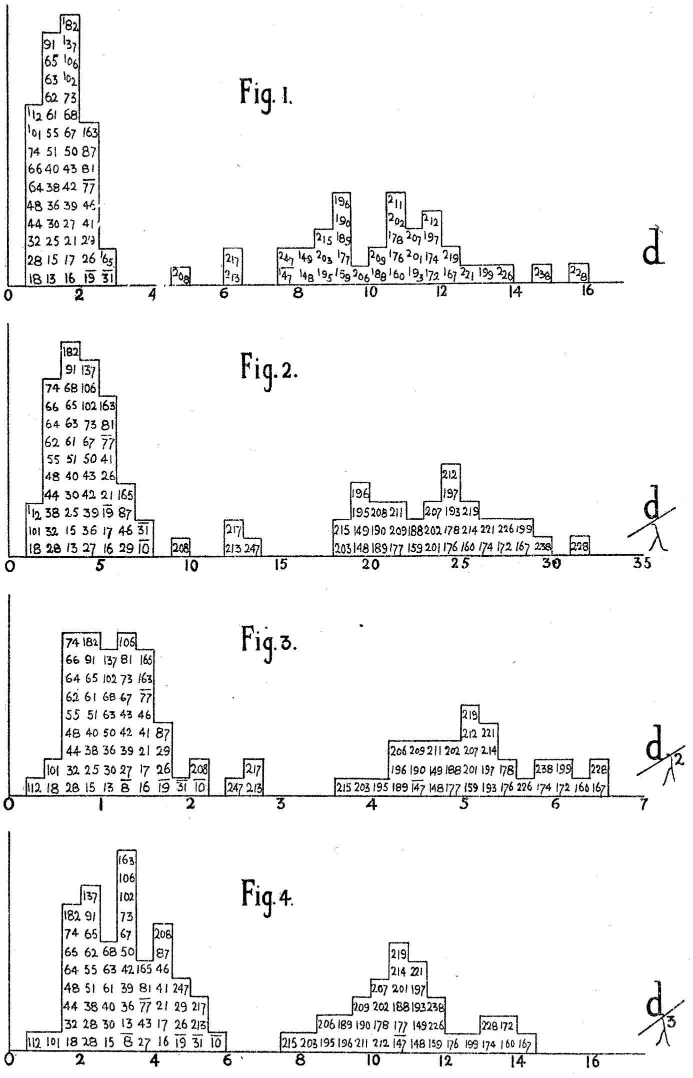

Fig. 1. According to values of the displacement per atmosphere.

,, 2. ,, ,, ,, $\frac{\text{displacement per atmosphere}}{\text{wave-length}}$.

,, 3. ,, ,, ,, $\frac{\text{displacement per atmosphere}}{(\text{wave-length})^2}$.

,, 4. ,, ,, ,, $\frac{\text{displacement per atmosphere}}{(\text{wave-length})^3}$.

(Readings at 10 atmospheres excluded.)

[Numbers overlined are of doubtful accuracy. The horizontal scale is proportionate, not absolute.]

Diagram 6, figs. 1 to 4, is more compact when the displacements are assumed to depend upon a high value of the wave-length. The group might be more compact still if an

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adequate correction could be applied to the measurement of the lines in the neighbourhood of λ = 4300 to 4400, which appear abnormally high in the diagram, and there is little doubt that the readings are in fact rather too large. It has been stated that for the sake of uniformity Mr. PEARSE's readings have been used almost exclusively in preparing the tables, my own readings of the lines serving as a check upon them. The check readings in this region indicate that the measurements of the lines in region 4800 to 4900 are to those in region 4400 as 5 is to 4. This would improve Diagram 4, and also make the second group in Diagram 6, fig. 4, more compact by reducing the displacements of lines *160*, *167*, *172*, *174* and *176*.

The above argument is based upon the resolution of the nickel spectrum into only two groups, but reasons will be given in the next section for distinguishing between three groups. If this is the case we must consider whether the isolated lines between the two main groups could form a group by themselves. If the displacement varies with the square of the wave-length, Diagram 6, fig. 3, indicates that the following lines would constitute it:—*213*, λ = 4829·18; *217*, λ = 4855·57; and *247*, λ = 5477·13. The last-named is not of the same nature as the first two, and there is a considerable separation between *213*, *217*, and the similar lines *87* and *165* which should be associated with them according to their behaviour and general appearance. Five more lines, *10*, *19*, *21*, *26*, *31*, which resemble them by being nebulous at atmospheric pressure, may also be associated with them. It will be seen from what follows that they form a more compact group when classified according to the cube of the wave-length. Though the determination is by no means conclusive, the balance of evidence favours this rate of variation of the displacement.

It is important to see to what extent the readings at 10 atmospheres confirm the above conclusion.

TABLE VIII.—Displacements at 10 Atmospheres Pressure over Wave-length Squared and Cubed.

Line.	λ.	Displacement at 10 atmospheres.	$\frac{d \text{ (at 10)}}{\lambda^2}$.	$\frac{d \text{ (at 10)}}{\lambda^3}$.
26	3597·84	4·9	378	1052
27	3602·41	3·1	240	663
28	09·44	2·9	223	618
29	10·60	6·4	492	1360
30	12·86	4·4	337	933
31	19·52	4·7	358	990
32	24·87	3·4	258	713
36	35·10	4·7	354	976
38	62·10	3·7	276	752
39	64·24	4·8	356	972
40	69·38	3·1	232	628
41	70·57	3·9	290	788
42	74·28	4·2	312	846
43	88·58	3·7	271	735
44	94·10	2·6	190	514

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TABLE VIII. (continued).

Line.	λ.	Displacement at 10 atmospheres.	$\frac{d\text{ (at 10)}}{\lambda^2}$.	$\frac{d\text{ (at 10}}{\lambda^3}$.
52	44·68	10·5	749	1999
55	49·15	2·1	148	398
61	69·58	4·0	282	746
62	72·70	2·5	175	465
63	75·71	1·0	70	186
64	78·22	1·3	91	242
65	83·67	1·3	91	240
66	92·48	2·7	187	495
67	93·75	5·2	361	950
68	3807·30	3·0	206	545
73	31·82	3·2	217	568
74	32·44	3·5	238	621
81	58·40	3·9	261	678
82	63·21	5·0	335	867
87	89·80	5·9	390	1000
91	13·12	3·1	203	518
101	72·31	1·2	76	192
102	73·70	4·4	278	702
106	95·45	4·3	269	672
112	4019·20	2·6	161	399
126	64·55	(11·9)	(720)	(1772)
133	4104·37	3·0	178	434
135	16·14	(4·1)	242	588
137	21·48	3·9	230	557
140	38·67	7·4	452	1044
141	42 {·34 ·47}	10·5	612	1477
143	50·55	5·3	307	741
144	64·82	1·7	98	235
145	67·16	3·1	178	428
146	84·65	8·5	485	1160
147	95·71	6·7	380	910
148	4200·61	8·7	494	1172
149	01·88	(18·6)	1052	2500
151	21·87	9·3	522	1236
153	31·23	18·9	1056	2495
155	36·55	6·9	384	907
159	84·83	10·0	546	1270
160	88·16	16·2	925	2160
161	96·06	15·8	855	1990
162	98·68	15·7	849	1976
163	4307·40	3·9	211	487
164	25 {·49 ·75}	8·8	470	1088
165	{30·85 31·78}	6·3	335	776
166	56·07	11·6	611	1403
167	59·73	11·5	605	1390
168	68·45	9·6	503	1152
170	84·68	10·3	536	1222
171	90·00	9·8	508	1158
172	4401·70	11·6	600	1360
174	37·17	11·5	580	1305
176	59·21	10·2	514	1148
177	62·59	12·3	618	1380
178	70·61	12·4	620	1390
181	4513·20	10·6	520	1153

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TABLE VIII. (continued).

Line.	λ.	Displacement at 10 atmospheres.	$\frac{d\ (\text{at } 10)}{\lambda^2}$.	$\frac{d\ (\text{at } 10)}{\lambda^3}$.
182	20·20	3·1	152	335
186	51·45	14·6	704	1548
187	60·10	12·8	615	1349
188	92·69	14·1	671	1460
189	4600·51	13·8	650	1410
190	05·15	12·0	569	1222
192	47·47	17·1	792	1703
193	48·82	14·0	648	1390
194	55·85	12·6	581	1248
195	67·16	13·3	610	1306
196	67·96	14·0	642	1378
197	86·39	18·4	835	1788
199	4701·72	21·2	960	2040
200	03·96	5·8	262	558
201	4714·59	17·1	770	1630
202	15·93	17·0	766	1620
203	32·00	13·1	585	1236
204	32·66	20·8	928	1962
205	52·58	(6·3)	(279)	(587)
206	54·95	15·8	700	1470
207	56·70	15·7	693	1460
208	62·78	6·2	273	573
209	64·07	14·0	617	1290
211	$86 \left\{ \begin{matrix} \cdot 42 \\ \cdot 46 \end{matrix} \right\}$	16·8	733	1530
212	4807·17	13·1	566	1180
213	29·18	9·4	404	835
214	31·30	16·3	700	1442
215	32·86	11·6	497	1024
216	38·80	24·7	1055	2180
217	55·57	6·5	275	568
218	57·57	16·0	678	1395
219	66·42	15·1	638	1310
220	70·97	(7·6)	(320)	(657)
221	73·60	16·8	708	1455
222	87·16	13·2	552	1130
223	4904·56	4·5	187	381
224	12·22	14·9	617	1257
225	14·15	8·1	335	682
226	18·53	14·5	600	1220
227	25·74	15·8	651	1322
228	36·02	15·4	632	1280
229	37·51			
231	53·34	17·6	717	1448
232	71·54	(6·5)	(263)	529
233	80·36	4·8	193	388
234	84·30	1·4	56	113
235	98·42	15·7	628	1257
236	5000·48	(4·7)	(188)	(376)
237	12·62	18·4	732	1461
238	17·75	18·5	735	1465
239	35·55	5·6	221	438
243	80·70	(6·5)	(252)	(495)
244	81·30	(2·5)	(97)	(190)
245	5424·85	7·9	266	490
246	36·10	8·9	300	553
247	77·13	7·7	257	479

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In Table VIII. the values of the mean displacements at 10 atmospheres have been divided by the square and cube of the wave-lengths, and in Diagram 7, figs. 1 and 2, these are shown in statistical form. Many more values are now included, and each diagram is now very irregular. They are not as trustworthy as the previous diagrams for the purpose of ascertaining the rate of displacement with wave-length, but they serve as a guide to the classification of lines which cannot be measured at pressures higher than 10 atmospheres.

The separation into groups is clearer in the d/λ^2 diagram, which consequently favours this ratio. If, however, the lines be sorted out from the d/λ^3 diagram in accordance with their grouping at pressures *above* 10 atmospheres, it becomes much clearer, as in fig. 2, and we see that the confusion between values 8 and 10 on the horizontal scale is due to the overlapping of two frequency curves with rather large variations. The distributions for d/λ^2, d/λ^3 now appear about equally probable for the readings made above 10 atmospheres.

Diagram 7.

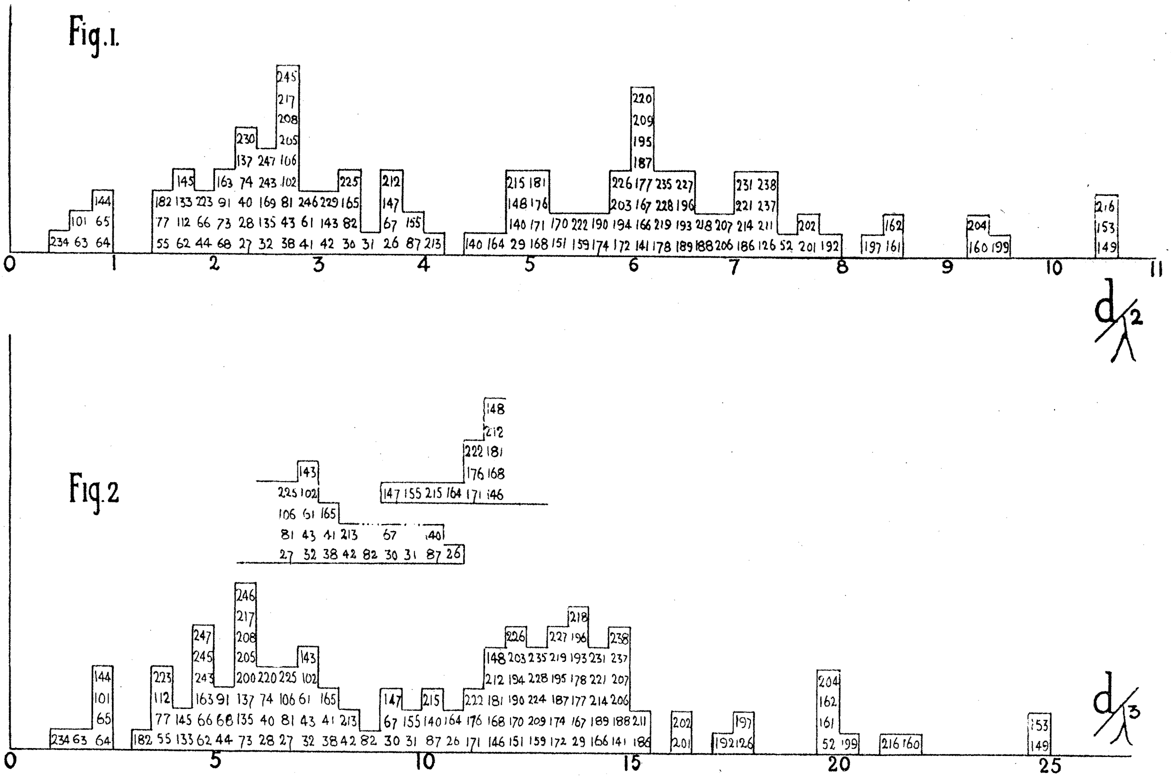

Fig. 1. Frequency distribution of spectrum lines according to values of $\frac{\text{displacements per atmosphere}}{(\text{wave-length})^2}$.

,, 2. ,, ,, ,, ,, ,, ,, $\frac{\text{displacements per atmosphere}}{(\text{wave-length})^3}$.

(Readings are at 10 atmospheres only.)

The rate of increase of the displacement with the wave-length has been a matter

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of previous investigation by the writer; the copper arc spectrum* yielded the result that the displacement was proportional to a power of the wave-length "at least as great as the third power and possibly as high as the sixth." The experiments upon the gold arc under pressure† favoured a dependence upon third power of the wave-length.

Subsequent important experiments by GALE and ADAMS‡ upon an extended region of the iron spectrum under a pressure of 9 atmospheres support this conclusion, and so do the results of the present research.

The bearing of this upon the spectra of novae has been discussed by the writer in a paper entitled "The Spectra of Novae and the Pressure Effect."§ It is there shown how the Doppler and pressure effects may be distinguished.

An interesting feature of the nickel lines is the gregarious tendency of lines with large displacements, almost all of which occur within a region of the spectrum between $\lambda = 4200$ and $\lambda = 5000$. Reference to Table X. which gives lists of lines of similar appearance—reversed lines, nebulous lines, &c., indicates that they occupy only limited regions of the spectrum. A similar tendency for the iron lines of the same group to congregate was recorded.

8. *Resolution of the Nickel Spectrum into Groups.*—The lines may be grouped in different ways—according to their displacement, broadening, intensity, reversal, &c., but of these the most important is the first-named. It has already been seen in the previous section that it is possible to resolve the nickel arc spectrum into two main groups according to their displacement, and that the first of these may be capable of further sub-division.

The following table has been compiled from the available data to indicate the general nature of the lines belonging to the two groups.

The line and its wave-length are given in the first two columns, in the third column "n" denotes that the line was nebulous at atmospheric pressure, in the fourth column N indicates that it became nebulous or diffuse under increasing pressure; "sh" in the next column indicates that the line was classified by HASSELBERG as "sharp" at atmospheric pressure. The changes in relative intensity are given by "wk" or "str" in the next two columns. The broadening and reversal are treated in the two following columns, and the last two indicate the group into which the line falls in the d/λ^3 diagrams, Diagram 6, fig. 4, and Diagram 7, fig. 2. The first of these is the more reliable as it includes a larger number of readings, but the second is useful in supplementing the information supplied by the preceding column; it is derived from observations made at 10 atmospheres only.

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* DUFFIELD, 'Phil. Trans. Roy. Soc.,' vol. 209, p. 205, 1908.

† DUFFIELD, 'Phil. Trans. Roy. Soc.,' vol. 211, p. 33, 1910.

‡ GALE and ADAMS, 'Astrophysical Journal,' vol. XXXV., p. 10, 1912. Through a misapprehension, these authors quote experiments upon vanadium by ROSSI as supporting this conclusion.

§ DUFFIELD, 'Monthly Notices, R.A.S.,' 73, p. 631, 1913.

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TABLE IX.

Line.	λ.	Nebulous.		Sharp at 1 atmosphere (HASSELBERG).	Changes in relative intensity.		Prominent features as regards				Grouping according to displacement.	
		1 atmosphere, (HASSELBERG).	Higher pressures.		Weakened.	Strengthened.	Broadening.		Reversals.		Above 10 atmospheres.	At 10 atmospheres.
						Group I.						
3	3458·59	n					m	b_s	r	.		
4	61·78	n					m	b_s	r	.		
5	72·68	n					c	b_s	r	.		
7	93·10	n					g	b_s	r	g		
8	3501·00						c	b_s	r	.	1	
9	02·76						c	b_s	r	.		
10	10·47	n					g	b_s	r	g	1	
11	15·17	n					vg	b_s	r	vg		
12	18·80						s	b_s	.	.		
13	19·90						c	b_s	r	s	1	
14	24·65	n					G	b_s	r	vg		
15	48·34						s	b_s	r_s	m	1	
16	51·66						s	b_s	.	.	1	
17	53·63						s	b_r	.	.	1	
18	61·91			sh			s	b_s	r_s	s	1	
19	66·50	n					vg	b_s	r_s	vg	1	
21	71·99	n					c	b_s	r_s	c	1	
25	88·08			sh			s	b_s	r_s	s	1	
26	97·84	n					c	b_r	r_v	c	1	
27	3602·41						m	b_r	r_v	s	1	1
28	09·44						m	b_s	r_s	s	1	1
29	10·60						g	b_s	r_s	c	1	
30	12·86						c	b_r	r_v	m	1	
31	19·52	n					G	b_r	r_v	vg	1	
32	24·87			sh			s	b_r	r_v	s	1	1
34	30·04		N				m	b_v	.	.		
36	35·10			sh			s	b_r	.	.	1	
38	62·10			sh			s	b_r	.	.	1	1
39	64·24			sh			m	b_r	r_v	s	1	
39α	68·35		N				m	b_v	.	.		
40	69·38			sh			s	b_r	r_v	s	1	1
41	70·57			sh			m	b_r	r_v	s	1	1
42	74·28			sh			m	b_r	r_v	m	1	1
43	88·58			sh			m	b_r	r_v	s	1	1
44	94·10						s	b_s	.	.	1	1
46	3722·63						m	b_s	r_s	s	1	
47	24·95		N				m	b_v	.	.	1	
48	30·88						s	.	.	.	1	
50	36·94			sh			m	b_s	r_s	m	1	
51	39·36						s	.	r	s	1	
55	49·15			sh			s	b_r	.	.	1	1
61	69·58					str	s	.	.	.	1	1
62	72·70			sh			s	.	.	.	1	1
63	75·71						g	b_s	r	g	1	1
64	78·22						s	.	.	.	1	1

The following abbreviations are used to express the width of bright lines and of reversals in columns 8 and 9:—s = slight, m = moderate, c = considerable, g = great, vg = very great, G = very very great.

Other abbreviations are:—r = reversed, r_s = reversal nearly symmetrical, r_v = reversal on violet side of centre of bright line, b_s = broadening nearly symmetrical, b_r = broadening greater towards red, b_v = broadening greater towards violet, V = line has vanished under pressure.

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TABLE IX. (continued).

Line.	λ.	Nebulous.		Sharp at 1 atmosphere (HASSELBERG).	Changes in relative intensity.		Prominent features as regards		Grouping according to displacement.	
		1 atmosphere (HASSELBERG).	Higher pressures.		Weakened.	Strengthened.	Broadening.	Reversals.	Above 10 atmospheres.	At 10 atmospheres.
				Group I. (continued).						
65	3783·67						g b_s	r g	1	1
66	92·48			sh			s .	. .	1	1
67	93·75			sh			s b_r	. .	1	
68	3807·30						g b_s	r g	1	1
73	31·82						m b_s	r_v s	1	1
74	32·44						s .	. .	1	1
77	44·40 44·71	n					. .	. .	1	1
81	58·40						vg b_s	r_v g	1	1
82	63·21		N		wk		c b_r	. .		[1]
87	89·80		N	(sh)	wk		g b_r	. .	1	
89	3909·10	n			wk V		. .	. .		
90	12·44	n			wk V		. .	. .		
91	13·12						s .		1	1
96	44·25	n			wk V		. .			
98	54·61	n			wk V		. .			
99	62·00	n			wk V		. .			
100	70·65	n			wk V		. .			
101	72·31						s .		1	1
102	73·70						m b_r		1	1
103	74·83	n			wk V		m .			
104	84·18	n			wk V		. .			
105	94·13	n			wk V		. .			
106	95·45						m b_r		1	1
110	4017·65	n			wk V		. .			
112	19·20					str	s .		1	1
133	4104·37		N			str	c b_r	(r_v)		1
135	16·14		N		wk		m .			1
137	21·48					str	m .		1	1
140	38·67		N		wk		. b_r			[1]
143	50·55		N		wk		m b_r			1
144	64·82					str	s .		.	1
145	67·16	n	N		wk		m .		.	1
163	4307·40						s .		1	1
165	30·85 31·78		N		wk		m .		1	1
166	56·07	n	N		wk		c b_r		.	.
179	4481·30	n	N				c .		.	.
180	90·71	n	N				m b_v		.	.
181	4513·20						m b_r		.	.
182	20·20			sh		str	s .		1	1
200	4703·96	n	N		wk		m b_v		.	1
205	52·58		N		wk		m b_v		.	1
208	62·78						s .		1	1
213	4829·18		N		wk		c b_r		1	1

The following abbreviations are used to express the width of bright lines and of reversals in columns 8 and 9:—s = slight, m = moderate, c = considerable, g = great, vg = very great, G = very very great.

Other abbreviations are:—r = reversed, r_s = reversal nearly symmetrical, r_v = reversal on violet side of centre of bright line, b_s = broadening nearly symmetrical, b_r = broadening greater towards red, b_v = broadening greater towards violet, V = line has vanished under pressure.

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TABLE IX. (continued).

Line.	λ.	Nebulous.		Sharp at 1 atmosphere (HASSELBERG).	Changes in relative intensity.		Prominent features as regards		Grouping according to displacement.	
		1 atmosphere (HASSELBERG).	Higher pressures.		Weakened.	Strengthened.	Broadening.	Reversals.	Above 10 atmospheres.	At 10 atmospheres.
					Group I. (continued).					
217	4855·57		N		wk		c .		1	1
220	70·97						. .		.	1
223	4904·56		N		wk		m b_v		.	1
225	14·15	n					. .		.	1
229	37·51	n	N		wk		m .		.	.
230	45·63	n					. .		.	.
232	71·54		N				c b_v		.	1
233	80·36		N				c b_v		.	1
234	84·30		N				c b_v		.	1
236	5000·48	n	N				c b_v		.	1
239	35·55		N				c b_v		.	1
241	42·35	n							.	.
242	49·01	n							.	.
243	80·70		N		wk		c b_v	r c		1
244	81·30	n	N				s			1
245	5424·85						s b_r			1
246	36·10			sh			s b_r			1
247	77·13						g b_r	r_v g	1	1
					Group II.					
52	3744·68			sh	wk V		.			2
126	4064·55						m b_r			2
141	4142·34 42·47						c b_r			2
146	84·65						m b_r			2
147	95·71				wk		g b_r		(2)	(2)
148	4200·61			sh			g b_r		2	2
149	01·88			sh			g b_r		2	2
151	21·87						s b_r			2
153	31·23		N		wk		c b_r			2
155	36·55		N				m b_r			2
159	84·83						g b_r		2	2
160	88·16						g b_r		2	2
161	96·06						vg b_r			2
162	98·68						g b_r			2
166	4356·07	n	N		wk		c b_r			2
167	59·73			sh			g b_r		2	2
168	68·45					str	s b_r			2
170	84·68						m b_r			2

The following abbreviations are used to express the width of bright lines and of reversals in columns 8 and 9 :—s = slight, m = moderate, c = considerable, g = great, vg = very great, G = very very great.

Other abbreviations are :—r = reversed, r_s = reversal nearly symmetrical, r_v = reversal on violet side of centre of bright line, b_s = broadening nearly symmetrical, b_r = broadening greater towards red, b_v = broadening greater towards violet, V = line has vanished under pressure.

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TABLE IX. (continued).

Line.	λ.	Nebulous.		Sharp at 1 atmosphere (HASSELBERG).	Changes in relative intensity.		Prominent features as regards		Grouping according to displacement.	
		1 atmosphere (HASSELBERG).	Higher pressure.		Weakened.	Strengthened.	Broadening.	Reversals.	Above 10 atmospheres.	At 10 atmospheres.
					Group II. (continued).					
171	4390·00						m b_r			2
172	4401·70						G b_r		2	2
174	37·17				wk		g b_r		2	2
176	59·21						vg b_r		2	2
177	62·59						vg b_r		2	2
178	70·61						vg b_r		2	2
181	4513·20		N				m b_r			2
186	51·45						m b_r			2
187	60·10		N ?				s b_r			2
188	92·69						vg b_r		2	2
189	4600·51				wk		vg b_r		2	2
190	05·15						vg b_r		2	2
192	47·47				wk		m b_r	} merged	{ 2	2
193	48·82						vg b_r			2
194	55·85						s .			2
195	67·16		N ?				m .		2	2
196	67·96						m			2
197	86·39						m b_r		2	2
199	4701·72						m b_r		2	2
201	14·59						g b_r		2	2
202	15·93						g b_r		2	2
203	32·00						s b_r		2	2
204	32·66		N				s b_r			2
206	54·95					str	s b_r		2	2
207	56·70						c b_r		2	2
209	64·07						s b_r		2	2
211	86·42 } 86·46 }						c b_r		2	2
212	4807·17						m b_r		2	2
214	31·30						m b_r		2	2
215	32·86						s b_r		2	2
216	38·80		N		wk		m b_r			2
218	57·57						m b_r			2
219	66·42						c b_r		2	2
221	73·60						m b_r		2	2
222	87·16						.			2
224	4912·22	n					.			2
226	18·53			sh			m b_r		2	2
227	25·74						m b_r			2
228	36·02			sh			m b_r		2	2
231	53·34		N				m b_r			2
235	98·42						m b_r			2
237	5012·48			sh			m b_r			2
238	17·75						m b_r		2	2

The following abbreviations are used to express the width of bright lines and of reversals in columns 8 and 9:—s = slight, m = moderate, c = considerable, g = great, vg = very great, G = very very great.

Other abbreviations are:—r = reversed, r_s = reversal nearly symmetrical, r_v = reversal on violet side of centre of bright line, b_s = broadening nearly symmetrical, b_r = broadening greater towards red, b_v = broadening greater towards violet, V = line has vanished under pressure.

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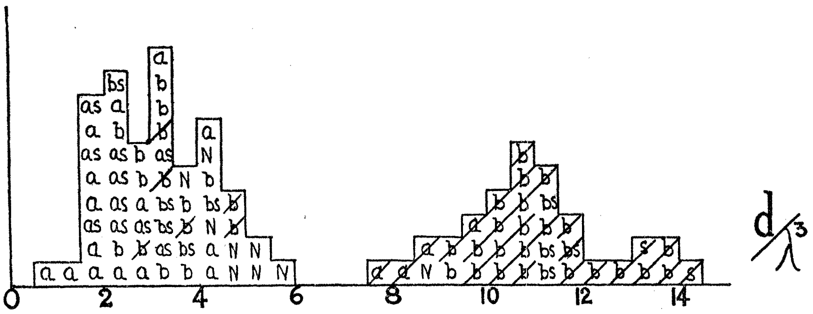
For the purpose of comparing the characteristics of lines belonging to these two groups Diagram 8 has been prepared. It closely resembles Diagram 6, fig. 4, but instead of denoting the lines by means of numbers, their characteristics are quoted in accordance with the abbreviations given below the diagram. It deals only with lines whose displacements above 10 atmosphere have been determined. It is clear that Group I. is by no means homogeneous, and that it may be divided into two Sub-groups IA. and IB. The characteristics of the lines falling into the first part of Group I. (Group IA.) are :—

1. Slight broadening. Nearly symmetrical.
2. Sharp at atmospheric pressure.
3. Reversed lines are very nearly symmetrical.
4. Two lines are strengthened, none are weakened.

Diagram 8.



a = slightly broadened.
b = greater broadening (includes moderate, considerable, great, &c.).
s = sharp at atmospheric pressure.
N = nebulous at atmospheric pressure or under high pressures.
/ = broadening or reversal is unsymmetrical.
Lines 8 and 31 not included in this diagram (*cf.* Diagram 6, fig. 4).

The characteristics of lines falling into the second part of Group I. (Group IB.) are :—

1. Greater broadening. [Many are described as moderately broadened, some as greatly broadened, though several are described as slightly broadened.]
2. Nebulous at one atmosphere or nebulous at 10 atmospheres.
3. The reversed lines are less symmetrical.
4. Tendency to weaken under pressure.

The characteristics of the lines falling into Group II. are :—

1. Great broadening.
2. Their unsymmetrical appearance under pressure. They are all broadened greatly to the red side.
3. None are reversed under pressure.

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If we include in our survey the readings made at 10 atmospheres more lines come under observation; among them are several that are nebulous, of these most are weakened, *e.g.*, 82, 135, 140 and 145, &c., but one, 133, has been classed as strengthened. We also note that certain other lines which are nebulous under pressure are included in Table IX., namely, those which are broadened towards the violet, 232, 233, 239, &c. These nebulous lines all occur in Group I. Group II. is similarly extended by this process, and it now appears to include some lines which become nebulous under pressure; these differ from those assigned to Group I. in appearing to be broadened to the red side, but there is a certain amount of doubt about the accuracy of their measurements, and therefore of their position in Group II.

Adopting the law that the displacement varies as the cube of the wave-length for lines of the same group, we see from Diagram 6, fig. 4, that the maxima in the distribution curves occur at 10·75 and 3·0, which gives a ratio of 1 to 3·6 for the maximum displacements of the two groups, a result very different from that found for the groups in the iron spectrum. If, however, Group I. be sub-divided into Group IA. and Group IB., we may take the similar nebulous lines 19, 21, 26, 31, 87, 165, 213, 217, as forming the more displaced group for which the value of d/λ^3 is about 5×10^{-14}. The corresponding value for the remainder is not very different from $2{\cdot}5 \times 10^{-14}$. This would give a ratio of displacement for the three groups 2·5 : 5 : 10·75, which is close to that found for the iron spectrum, namely, 1 : 2·2 : 4·5, and not far from 1 : 2 : 4, but it would only be justified if the division into three groups were an established fact.

It may be pointed out that the d/λ^2 diagram (fig. 2), favours this relationship (the ratios would be 1·3 : 2·7 : 5·2), but, as has already been discussed, the diagram labours under the disadvantage of including 247 in the intermediate group, dissociating it from lines which it more strongly resembles, and it separates the similar lines 87, 165, 213, and 217. These difficulties are obviated in the d/λ^3 frequency curves.

We are thus faced with the possibility of the following representations of the groups:—

Group I.
$$d = 3{\cdot}0 \times 10^{-14}\lambda^3.$$
Group II.
$$d = 10{\cdot}75 \times 10^{-14}\lambda^3,$$

in which case the ratio is 1 : 3·5, or if there be three groups:—

Group IA.,	$d = 2{\cdot}5 \times 10^{-14}\lambda^3$	or	$d = 1{\cdot}3 \times 10^{-10}\lambda^2$,
,, IB.,	$d = 5{\cdot}0 \times 10^{-14}\lambda^3$		$d = 2{\cdot}7 \times 10^{-10}\lambda^2$,
,, II.,	$d = 10{\cdot}75 \times 10^{-14}\lambda^3$		$d = 5{\cdot}2 \times 10^{-10}\lambda^2$.

In either case the ratio is approximately 1 : 2 : 4. The writer inclines to the view that this is the more probable ratio between the different groups, but the determination is open to doubt.

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The existence of another group is indicated by the occurrence of five lines which are displaced towards the violet. The amount of their displacement is approximately the same as that of Group IB. if no allowance be made for the fact that all the measurements were made at 10 atmospheres pressure.

We may designate the nickel groups as follows :—

Group 0, $d = -\ 4\cdot3 \times 10^{-14}\lambda^3$.
,, IA., $d = +\ 2\cdot5 \times 10^{-14}\lambda^3$.
,, IB., $d = +\ 5\cdot0 \times 10^{-14}\lambda^3$.
,, II., $d = +10\cdot75 \times 10^{-14}\lambda^3$.

In the above groups several lines are included whose displacements under pressure have not been measured; their classification is based upon their general behaviour and resemblance to lines whose grouping has been ascertained.

In addition to the two main groups, further sub-division is possible as inspection of the photographs will show. In the following table are given those lines which bear close resemblances to one another; it may be of service in the resolution of the nickel spectrum into the usual spectrum series.

TABLE X.

Line.	λ.	
2	3453·64	All strong lines. Very greatly broadened under pressure. Their broadening is nearly symmetrical. All are strongly reversed under pressure. The reversals are placed nearly symmetrically upon the bright lines. 2, 3, 4 are very similar. 10, 11, 14 are very similar. 19, 31 are very similar. It does not appear likely that 10, 11, 14, 19, 31 form a series, because there is a break in the rate at which the breadth of the reversal increases with wave-length. In the recognized iron triplets which have been examined there was a regular decrease with wave-length.
3	58·59	
4	61·78	
7	93·10	
10	3510·47	
11	15·17	
14	24·65	
19	66·50	
31	3619·52	
39	3664·24	Moderately strong lines. Moderately broadened. Unsymmetrically reversed, the reversal being on the violet of centre. 39 and 42, 43 and 46 are more closely related.
42	74·28	
43	88·58	
46	3722·63	
63	3775·71	All strong lines. Greatly broadened under pressure. Broadening nearly but not quite symmetrical. Reversals strong and nearly symmetrical. The continuous increase in separation, in breadth and in width of reversal suggests that these lines are related in some intimate way.
65	83·67	
68	3807·30	
81	58·40	
89	3909·10	All nebulous at atmospheric pressure. All weakened under pressure and invisible at high pressure. 100, 103, 104, 110 have the appearance of converging series.
90	12·44	
96	44·25	
98	54·61	
99	62·00	
100	70·65	
103	74·83	
104	84·18	
105	94·13	
110	4017·65	

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TABLE X. (continued).

Line.	λ.	
87	3889·80	Moderately broadened, nearly symmetrical. Small displacement. Diffuse under pressure. All fall in Group I., except 147, whose measurements are doubtful. Weakened under pressure.
135	4116·14	
140	38·67	
143	50·55	
145	67·16	
147	95·71	
165	4331·—	
213	4829·18	
217	55·57	
149	4201·88	All belong to Group II., are broadened considerably and unsymmetrically. The last few lines have somewhat the appearance of a converging series.
159	84·83	
160	86·16	
167	4359·73	
172	4401·70	
176	59·21	
177	62·59	
178	70·61	
185	4547·14 47·44	
188	92·69	
189	4600·51	
190	05·15	
193	48·82	
201	4714·59	
207	56·70 56·42	
211	86·46	
214	4831·30	
219	66·42	
221	73·60	

Line.	λ.		Line.	λ.	
195	4667·16	—	196	4667·96	These constitute "couples" of lines which occur near another. The members of each couple are dissimilar, one being slightly stronger than the other, one being rather more broadened than the other. No simple relationship has been found between the frequency differences of the different couples.
199	4701·72	—	200	4703·96	
201	14·59	—	202	15·93	
203	32·00	—	204	32·66	
205	52·58	—	207	56·70	
208	62·78	—	209	64·07	
213	4829·18	—	214	4831·30	

Line.	λ.	
47	3724·95	Nebulous at atmospheric pressure and under high pressure. Broadened to the violet. Small displacements. Many of these lines are obviously weakened under pressure. Lines 232, 233, 236, 239 are recorded with negative displacements.
200	4703·96	
205	52·58	
223	4904·56	
232	71·54	
233	80·36	
234	84·30	
236	5000·48	
239	35·55	
243	80·70	
244	81·30	

9. *Relation between the Intensity of a Line and its Displacement.*—In Diagrams 9 and 10 the values of d/λ^3 for the two groups are plotted against the intensity of each line at atmospheric pressure. There is a distinct upward drift of the black dots with increasing intensity, which is made more apparent when the mean value for each

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Diagram 9.

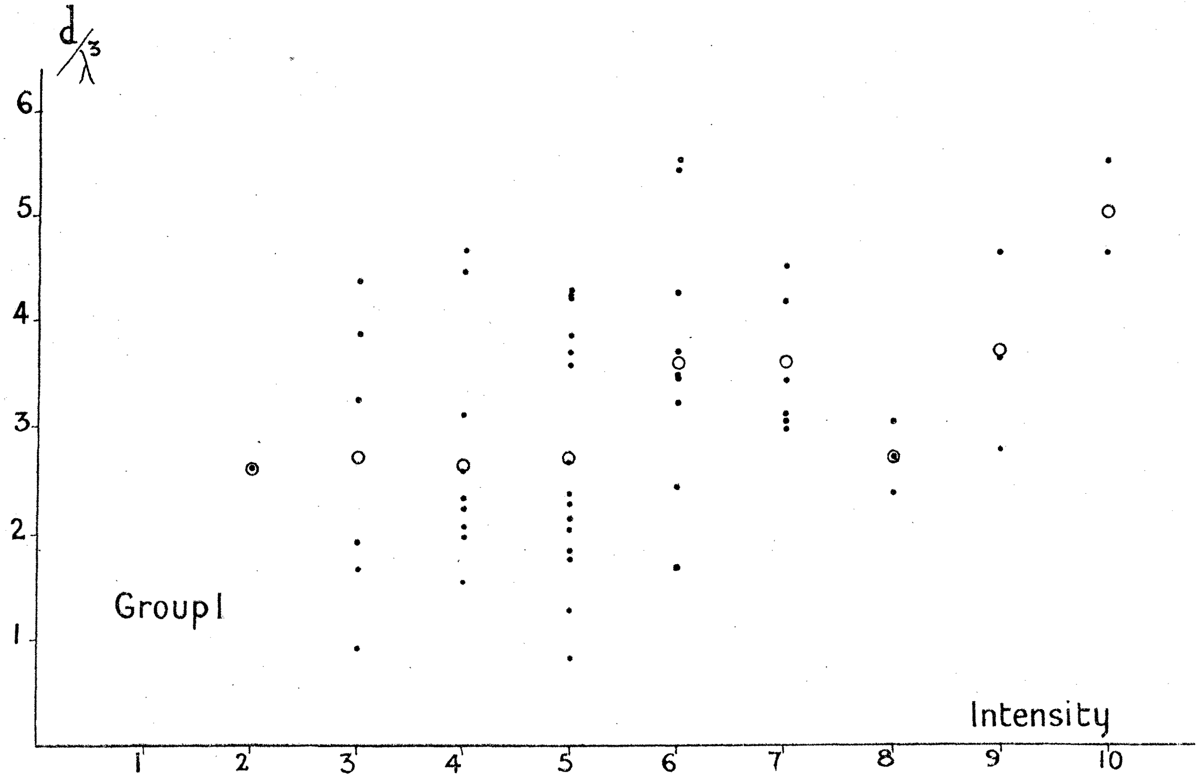
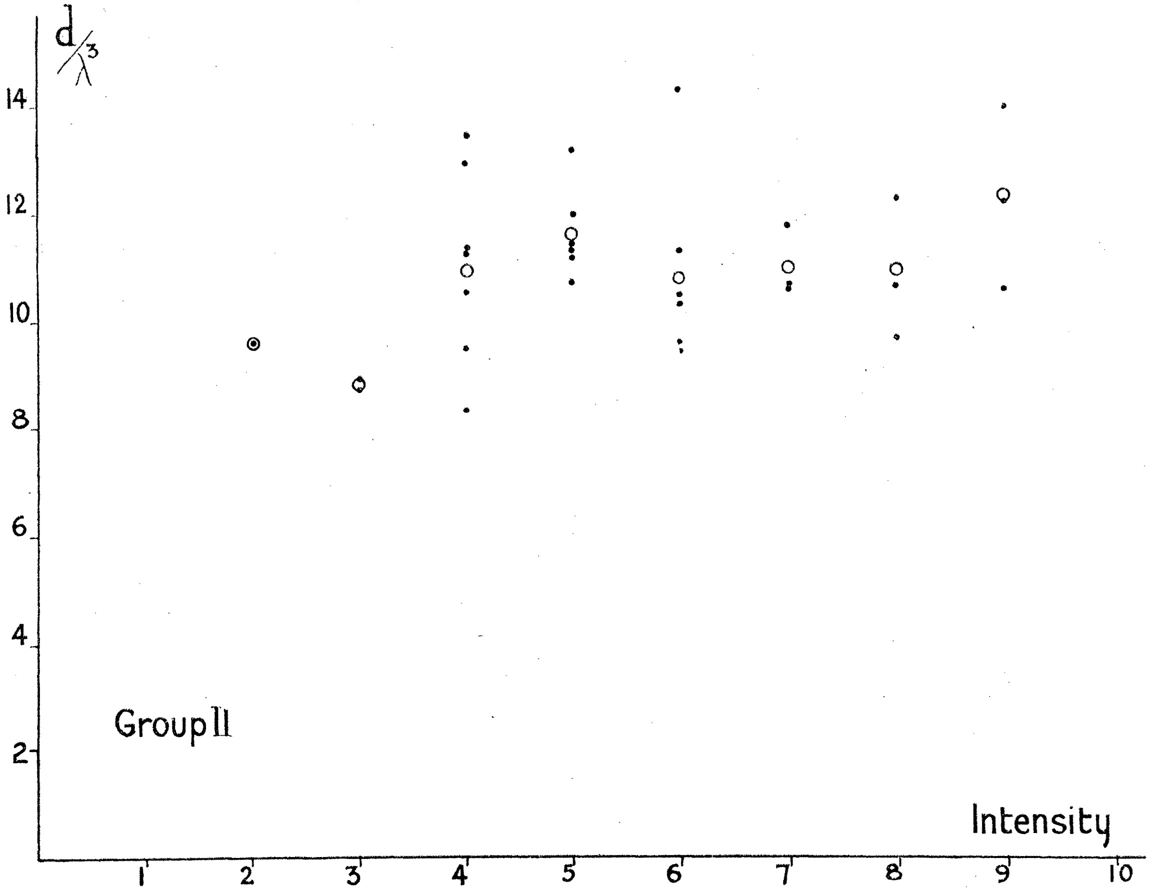


Diagram 10.



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intensity is calculated, these are shown by the circles. Since the high-valued lines 10, 247, 213, 217, and 87 possibly form a separate sub-group, more cogent evidence is perhaps afforded by the absence of low values for the displacement of lines of great intensity.

It remains to be proved whether the phenomenon is subjective or objective, whether it may be explained by a tendency for the computor to read high values when the density of the silver deposit is great, or whether the amount of energy involved in a line does actually influence the displacement. One reason which may be urged for regarding the phenomenon as independent of the observer is that intense lines are usually broad and consequently more closely resemble lines under higher pressure; these have, however, been shown to be relatively less displaced than lines at lower pressure, hence there would not seem to be any satisfactory reason for regarding the measurements of the displacements of intense lines as being too large. If the energy is responsible for the magnitude of the displacement one further enquires whether the increased intensity is due to a larger number of vibrating particles, or to their possessing greater amplitudes or to a combination of the two; thus if the phenomenon is objective it involves the dependence of the displacement either upon (1) the density of the particular atom or modification of the atom responsible for each line, or (2) upon the amplitude of its vibration. In any case the dependence of the displacement upon the energy involved in a line is not the only factor concerned, since some faint lines have very large displacements.

The former would seem the more probable, but attempts to show that the displacement of the line of an element is due to partial pressure have hitherto not been successful. This will be discussed elsewhere; the present discussion suggests that the partial pressure effect due to the density of similar atoms is superposed upon an effect due to the total pressure.

10. *Foreign Metals in the Spectrum of Nickel.*—In addition to the nickel lines whose displacements have been measured, a large number of lines due to impurities appear in the spectrum, especially between $\lambda = 3800$ and $\lambda = 4100$. They have been measured, and their displacements will be found in the following table. As they have been examined at several pressures, it should be possible to ascertain whether the "density" of the element has any effect upon the displacement by comparing the displacements of the lines produced respectively by pure poles and by small traces of the element.

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TABLE XI.—Foreign Metals in Nickel Spectrum.

Line.	Wave-length.	Mean displacements in thousandths of an Ångström unit. Atmospheres.									Displacements per atmosphere in thousandths of an Ångström unit. Atmospheres.									Mean displacement per atmosphere in $\frac{1}{1000}$ Å.U.	d/λ^2.	d/λ^3.
		10.	20.	40.	60.	70.	80.	93.	100.	110.	10.	20.	40.	60.	70.	80.	93.	100.	110.			
6	3483·55 (6r) Co.		(56)									(2·8)								(2·8)	(231)	(662)
23	3581·32 (10) Fe.		49	91	158		110					2·5	2·3	2·6		1·4				2·2	171	479
24	87·30 (10nr) Co		47	81	119		138					2·3	2·0	2·0		1·7				2·0	155	433
33	3627·96 (7) Co .		28	26								1·4	0·6							1·0	76	209
35	31·55 (6) Co .		34	67	129							1·7	1·7	2·1						1·8	136	376
45	3707·18 (4) Fe ?.		19	57	80		(59)		(41)			1·0	1·4	1·3		(0·7)		(0·4)		0·9	65	177
49	35·00 (8) Fe .		41	69	116		124		150			2·1	1·7	1·9		1·5		1·5		1·7	122	326
53	45·61 (7) Co .	37	39	50	94		128				3·7	1·9	1·3	1·6		1·6				1·6	114	304
54	48·39 (6) Fe .	23	26	58	81		62				2·3	1·3	1·4	1·3		0·8				1·2	86	227
56	50·06 (5) Co .	30	53	74	129		135				3·0	2·6	1·8	2·1		1·7				2·0	142	379
57	58·36 (8) Fe .	35	35	91	127		136		157		3·5	1·7	2·3	2·1		1·7		1·6		1·9	135	357
59	63·90 (8) Fe .	40	54	72	144		133				4·0	2·7	1·8	2·4		1·7				2·1	148	394
60	67·31 (8) Fe .	27	52	96	109		123				2·7	2·6	2·4	1·8		1·5				2·1	148	393
69	3815·97 (8) Fe .	53	61	109	190						5·3	3·0	2·7	3·2						2·9	206	540
70	20·56 (8) Fe .	40	54	79	150		151		242		4·0	2·7	2·0	2·5		1·9		2·4		2·3	158	412
71	26·04 (8) Fe .	22	54	91	142		150		261		2·2	2·7	2·3	2·4		1·9		2·6		2·4	164	427
72	27·96 (8) Fe .	61	49	102	195						6·1	2·5	2·5	3·2						2·7	184	481
75	34·37 (8) Fe .	44	57	80	126		106		163		4·4	2·8	2·0	2·1		1·3		1·6		2·0	136	355
76	38·4 (10) Mg .																					
78	45·59 (9n) Co.	32	36	59	126		142		232		3·2	1·8	1·5	2·1		1·8		2·3		1·9	128	334
79	50·11 (8) Fe .	37	44								3·7	2·2								2·2	149	385
80	56·49 (8) Fe .	37	34	53							3·7	1·7	1·3							1·5	101	262
83	73·25 (9n) Co.	26	36	50	76		100		123		2·6	1·8	1·3	1·3		1·2		1·2		1·4	93	241
84	74·10 (7n) Co.	25	35	41	79		104		175		2·5	1·7	1·0	1·3		1·3		1·7		1·4	93	241
85	82·04 (7) Co .	13	32	37	59		48		92		1·3	1·6	0·9	1·0		0·6		0·9		1·0	66	171
86	86·38 (6) Fe 86·4 (5) Mn	36	27	19	44		52				3·6	1·4	0·5	0·7		0·6				0·8	53	136

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TABLE XI (continued).

Line.	Wave-length.	Mean displacements in thousandths of an Ångström Unit.									Displacements per atmosphere in thousandths of an Ångström Unit.									Mean displacement per atmosphere in $\frac{1}{1000}$ Å.U.	d/λ^2.	d/λ^3.
		Atmospheres.									Atmospheres.											
		10.	20.	40.	60.	70.	80.	93.	100.	110.	10.	20.	40.	60.	70.	80.	93.	100.	110.			
88	3894·21 (10nr) Co	41	41	84	115		153		195		4·1	2·1	2·1	1·9		1·9		1·9		2·0	132	338
92	3920·36 (6) Fe .	32	62	36	76						3·2	3·1	0·9	1·3						1·8	118	298
93	23·00 (8) Fe .	19	30	(0)	63						1·9	1·5	(0·0)	1·0						0·8	52	132
94	28·05 (8) Fe .	27	45	40	59						2·7	2·3	1·0	1·0						1·4	91	230
95	36·12 (8) Co .	59	34	70	109		145		230		5·9	1·7	1·7	1·8		1·8		2·3		1·9	122	312
97	53·05 (7) Co .	36	30	39	(98)						3·6	1·5	1·0	(1·6)						1·4	89	226
107	98·04 (8) Co .	61	47	62	150		150		155		6·1	2·3	1·5	2·5		1·9		1·5		1·9	119	297
108	4005·33 (8) Fe .	37	34								3·7	1·7								1·7	106	264
111	18·2 (7) Mn .	48	50	78	110						4·8	2·5	1·9	1·8						2·1	130	324
114	27·21 (6) Co ?																					
115	30·9 (10) Mn .	23	25	43	69		52		116		2·3	1·2	1·1	1·1		0·6		1·2		1·0	62	152
116	33·2 (10) Mn .	19	25	41	66		87		97		1·9	1·2	1·0	1·1		1·1		1·0		1·1	68	168
117	34·6 (10) Mn .	37	27	44	92		96		181		3·7	1·4	1·1	1·5		1·2		1·8		1·4	86	213
118	35·73 (7) Co .	41	28	71	107		198				4·1	1·4	1·8	1·8		2·5				1·9	116	289
119	41·5 (10) Mn .	34	27	65	127		120		208		3·4	1·4	1·6	2·1		1·5		2·1		1·7	104	257
120	45·2 (6) Mn } ·5 (8) Co }	39	21								3·9	1·0								1·0	63	151
121	45·90 (10) Fe.	40	37	74	115		168		175		4·0	1·9	1·8	1·9		2·1		1·7		1·9	116	286
122	48·8 (8) Mn .	43	40	36	114						4·3	2·0	0·9	1·9						1·6	97	241
123	55·63 (4) Fe ?	35	44	92	120		175			144	3·5	2·2	2·3	2·0		2·2			1·3	2·0	122	300
125	63·63 (10) Fe.	30	47	79	113		162			185	3·0	2·3	2·0	1·9		2·0			1·7	2·0	121	298
127	71·79 (10) Fe.	34	62	81	128		126			149	3·4	3·1	2·0	2·1		1·6			1·3	2·0	121	296
128	77·55 (5) Co ?	14	34				84				1·4	1·7				1·0				1·3	78	192
132	92·55 (8) Co .	19	56	47	129		109			91	1·9	2·8	1·2	2·1		1·3			0·8	1·6	95	233
134	4110·69 (8) Co .	26	62		111		56				2·6	3·1		1·8		0·7				1·9	112	274

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Line.	Wave-length.	Mean displacements in thousandths of an Ångström unit.									Displacements per atmosphere in thousandths of an Ångström unit.									Mean displacement per atmosphere in $\frac{1}{1000}$ Å.U.	d/λ^2.	d/λ^3.
		Atmospheres.									Atmospheres.											
		10.	20.	40.	60.	70.	80.	93.	100.	110.	10.	20.	40.	60.	70.	80.	93.	100.	110.			
136	4118·62 (10) Fe.	32	47	61	69	126	103	101		153	3·2	2·3	1·5	1·1	1·8	1·3	1·1		1·4	1·5	88	214
139	31·2 (5) Mn .	4		71							0·4		1·8							1·8	150	247
142	43·50 (10) Fe ·96 (10) Fe	34	22	58							3·4	1·1	1·4							1·2	70	169
150	4215·66 (10r) Sr?	15									1·5											
152	26·91 (10r) Ca	47		72							4·7		1·8							(1·8)	(100)	(238)
154	35·2 (6) Mn? ·4 (6) Mn	25	41	45	(189)		(237)				2·5	2·1	1·1	(3·1)		(3·0)				2·3	128	303
156	50·2 (10) Fe ·9 (10) Fe?	39	110								3·9	5·5								(5·5)	(304)	(717)
157	60·64 (10) Fe	93									9·3											
158	71·30 (10) Fe ·93 (10) Fe	35	65	88	102		185				3·5	3·2	2·2	1·7		2·3				2·4	132	308
169	4383·70 (10) Fe	50	65	85	138	(59)	88			349	5·0	3·2	2·1	2·3	(0·8)	1·1			3·2	2·1	109	249
173	4415·27 (10) Fe	30									3·0											
175	51·7 (7) Mn?	70									7·0											
183	4528·78 (10) Fe	122									12·2											
184	31·14 (10) Co ·25 (8) Fe	136									13·6											
198	4698·60 (6) Co?	199									19·9											
210	4783·6 (10) Mn	144									14·4											

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(1) *The Influence of the Density of the Material in the Arc.*—In Table XII. the measurements made during the present research upon the lines due to traces of iron in the nickel poles are compared with the displacements of the same lines produced in an arc between solid iron rods.

At the top of each column will be found the pressure at which the examination was made, and opposite each spectrum line the ratio of the displacement of the diluted to that of the undiluted material. It will be seen that if the readings at 10 atmospheres be left out of account (they are unduly high in nickel as we have already shown) there is a smaller reading when the material is diluted.

TABLE XII.

Line.	Wave-length.	Ratio of displacements $\frac{\text{iron as impurity in Ni}}{\text{iron in pure iron-arc}}$.						
		10 atmospheres.	20 atmospheres.	30 atmospheres.	60 atmospheres.	70 atmospheres.	80 atmospheres.	100 atmospheres.
121	4045·90	[1·6]	0·48	0·72	0·78		0·91	0·66
125	4063·63	[1·2]	0·84	0·96	0·82		0·88	
127	4071·79	[1·36]	1·03	0·93	0·90		0·70	
136	4118·62	[1·52]	0·66	0·62	0·67	0·89	0·82	
142	4143·96	[1·31]	0·37	0·59				
156	4250·9	[1·77]	1·90					
157	4260·64	[1·45]						
158	4271·93	[1·67]	1·02	1·28	0·72		0·91	
173	4415·27	[0·73]						
183	4528·78	[1·63]						
Mean values		[1·42]	0·90	0·85	0·78	0·89	0·84	0·66

The measurements of the displacements of the lines due to pure iron were made some years ago both by the writer and by assistants, while those due to a small trace of iron in the nickel poles were made Mr. PEARSE. In order to see if a comparison between these readings was legitimate, Mr. PEARSE measured one of the original pure iron arc photographs (at 70 atmospheres pressure), and his readings agreed so excellently with the earlier ones that there was no hesitation in regarding the two sets as strictly comparable.

The ratio of the displacements with diluted to those with pure iron is, with the exception noted above, less than unity, suggesting that the density of similar atoms influences the displacement; if the displacement depends upon the proximity of similar vibrating centres it is to be expected that the displacements would be more

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marked at high pressures, since increasing the pressure reduces the mean free path between similar molecules just as increasing the total number of molecules does.

The evidence thus favours the amount of the displacement being dependent in part, at least, upon the amount of material present, a conclusion which is in keeping with that arrived at from the consideration of the variation of the displacement with the intensity of the line.

The chief sources of contamination of the nickel poles are iron, cobalt, and manganese. There is some doubt in one or two instances as to the origin of the lines; lines 136 and 137 for instance are very much alike under pressure, both in amount of displacement and in their intensities, but one is ascribed to nickel and the other to iron.

The feature of the lines due to impurities is that they remain fairly compact even at very high pressures, and do not spread out to the same extent or become so foggy as the nickel lines.

It is interesting to note that all the lines of the highest intensity due to iron do not appear in the nickel spectrum. Some lines seem to characterize the spectrum due to only a small quantity of material. For example, of the two iron lines (*142*) 4143·50 (10) and 4143·96 (10), only one, the latter, appears in the nickel spectrum. Of the two iron lines (*156*) at 4250·2 (10) and 4250·9 (10), both classed as of intensity 10, only the latter appears, similarly, only the last-named of the two iron lines 4271·30 (10), 4271·23 (10) is visible upon the plate. It is important to note that it is the line which is self-reversed which most readily shows itself, it is the less refrangible line in the pairs quoted.

It has always been surprising to the writer that no dependence upon the density of the material manifested itself in previous experiments. On one view one might expect the general magnetic field of the surrounding atoms to influence the frequency of any particular atom, and since, presumably, this general field depends upon the nature of the atom the amount of material present or the nature of the surrounding gas should have some effect, but nothing definite has hitherto been observed. On another view, the specific inductive capacity of the medium in which the atom under consideration is immersed should similarly affect the frequency, but this has been tested without positive result.

The explanation seems to be that in the arc the isolation of a molecule is never actually accomplished, that the vaporization of the metal, even if only a trace of it be present, involves the liberation of an immense number of atoms of that element all in close proximity, so that this incandescent mass behaves very much as though it were isolated from the other materials in the arc, rendering it very difficult to influence the immediate environment of an atom, since only the few atoms on the outskirts of this mass are affected by the inductive properties of the surrounding gas (or other metallic vapour produced by the vaporization of the poles), consequently the predominant frequency is that of the atom surrounded by similar atoms.

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Decreasing the amount of impurity present would make the outer portions of its incandescent vapour relatively more important, and increase of pressure would achieve the same end by decreasing the average distance of each vibrating centre from the molecules of the surrounding gas which might then exert an influence which is negligible when the pressure is low. We thus expect to find a reduced displacement when the material is greatly diluted and a relative reduction with increased pressure. The former is supported, and the latter suggested, by Table XII. We have assumed that the surrounding atmosphere is less effective in producing displacement than an atmosphere of similar molecules, but it should not be impossible for the opposite to be the case, according to the nature of the substances employed, unless it can be proved that similar molecules alone have influence upon a radiating molecule.

Approaching the problem of the structure of the arc from a different direction, the writer has been impressed by the importance of the part played by the surrounding gas in maintaining the arc; it would seem to require that each metallic atom is, for a brief interval at least, associated with one of the atoms of the surrounding gas so that something akin to chemical action takes place between them (or at least involves the influence of what may be called chemical affinity). If this is the case it would appear contrary to the view of the density effect just put forward, since that does not contemplate the commingling of the individual atoms of the metal with those of the surrounding gas. But it is further possible that the spectrum line is due, not to single atoms but to a system, such as one consisting of a metallic atom combined or interacting with one atom of the surrounding gas (the function of the latter being, by its interactions with the atom, to excite it to emit its characteristic radiation), and that such systems form the aggregate already alluded to, and that the frequency of the resultant spectrum line is characteristic of this particular atom system in its environment of similar systems. These systems would not be interfered with by foreign systems until either the reduction of the amount of material below a certain minimum amount or the increase of pressure made the proximity of foreign atomic systems relatively more important.

Possibly this consideration is responsible for the decrease in the rate of increase of displacement with pressure when the latter is high.

The writer is indebted to Dr. SCHUSTER, at whose suggestion the series of experiments upon the effect of pressure upon spectra were begun some years ago, and to Sir ERNEST RUTHERFORD in whose laboratory the photographs were taken, and expresses his thanks to them for having placed the necessary apparatus at his disposal.

The photographs were measured by Mr. PEARSE in a careful and thorough manner. Part of the expense of this research was defrayed by a grant from the Government Grant Committee.

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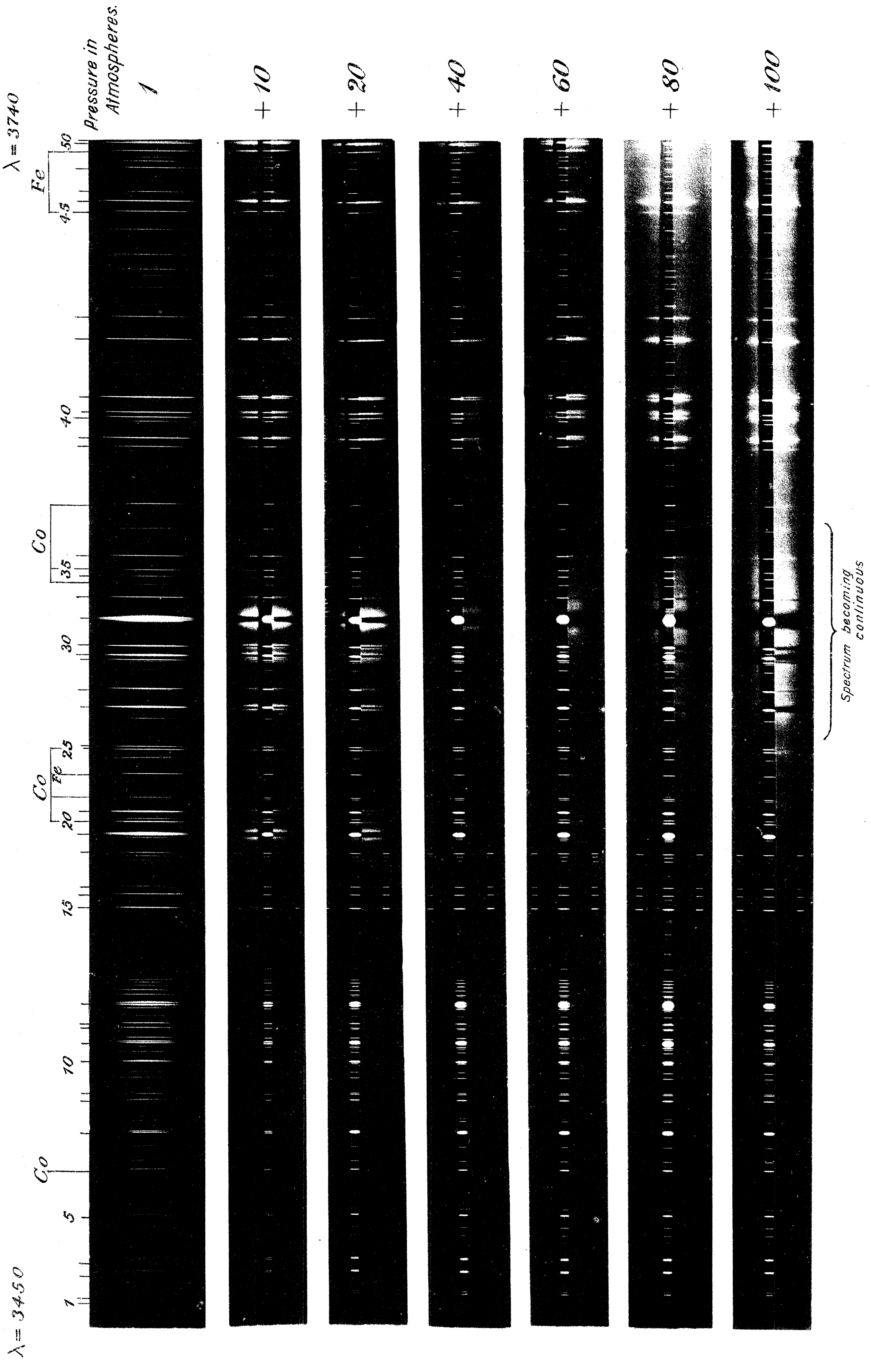

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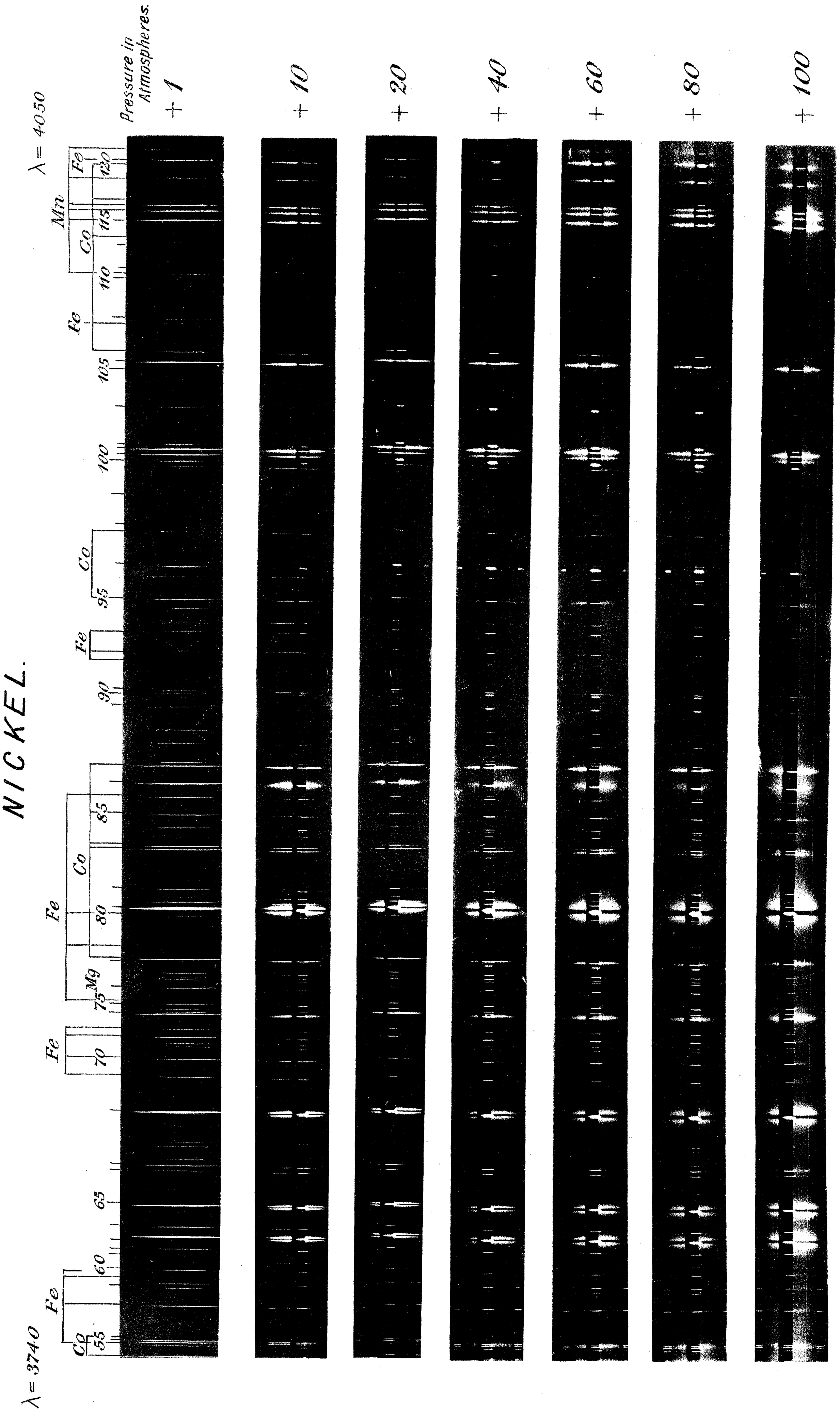

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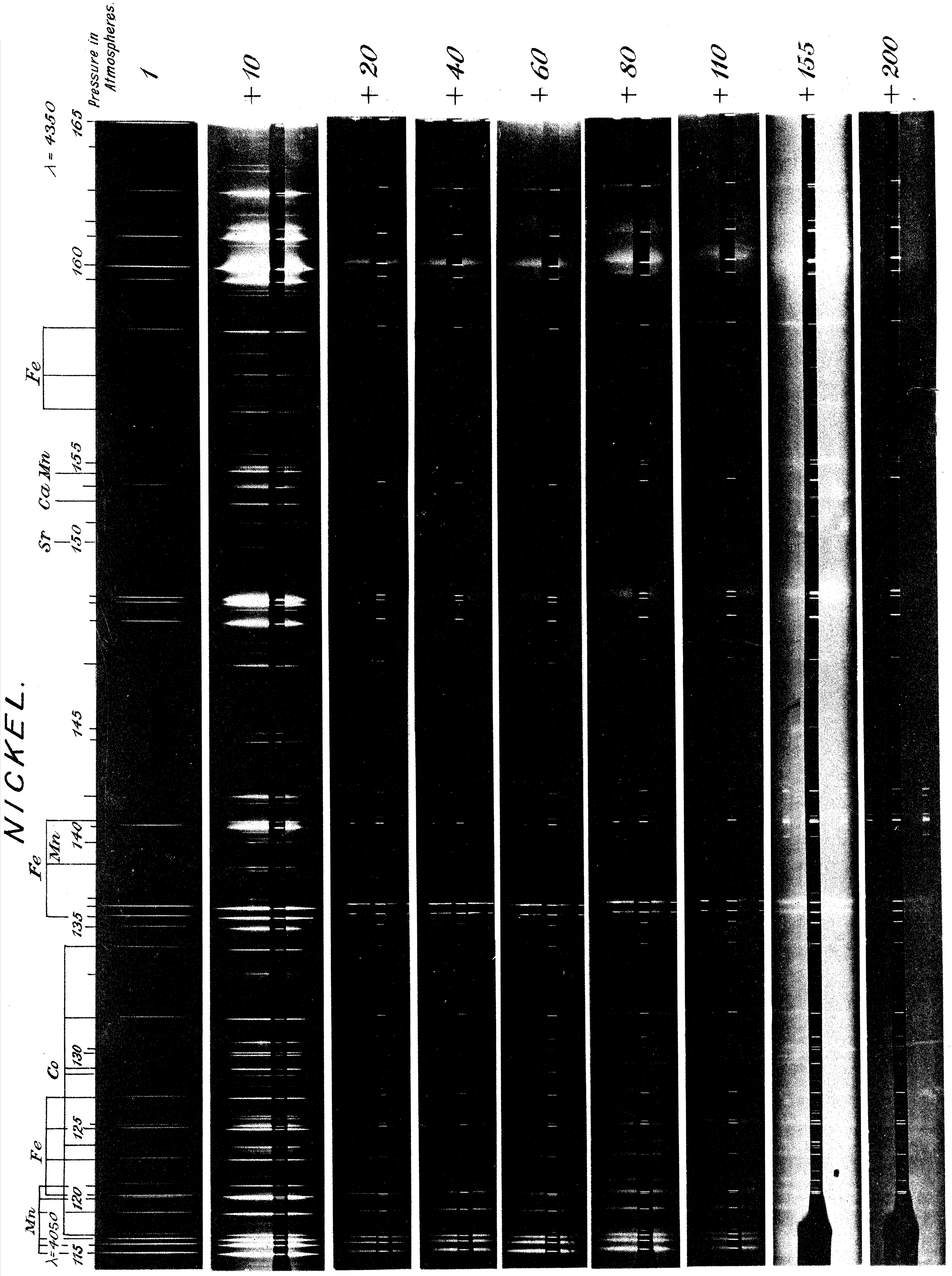

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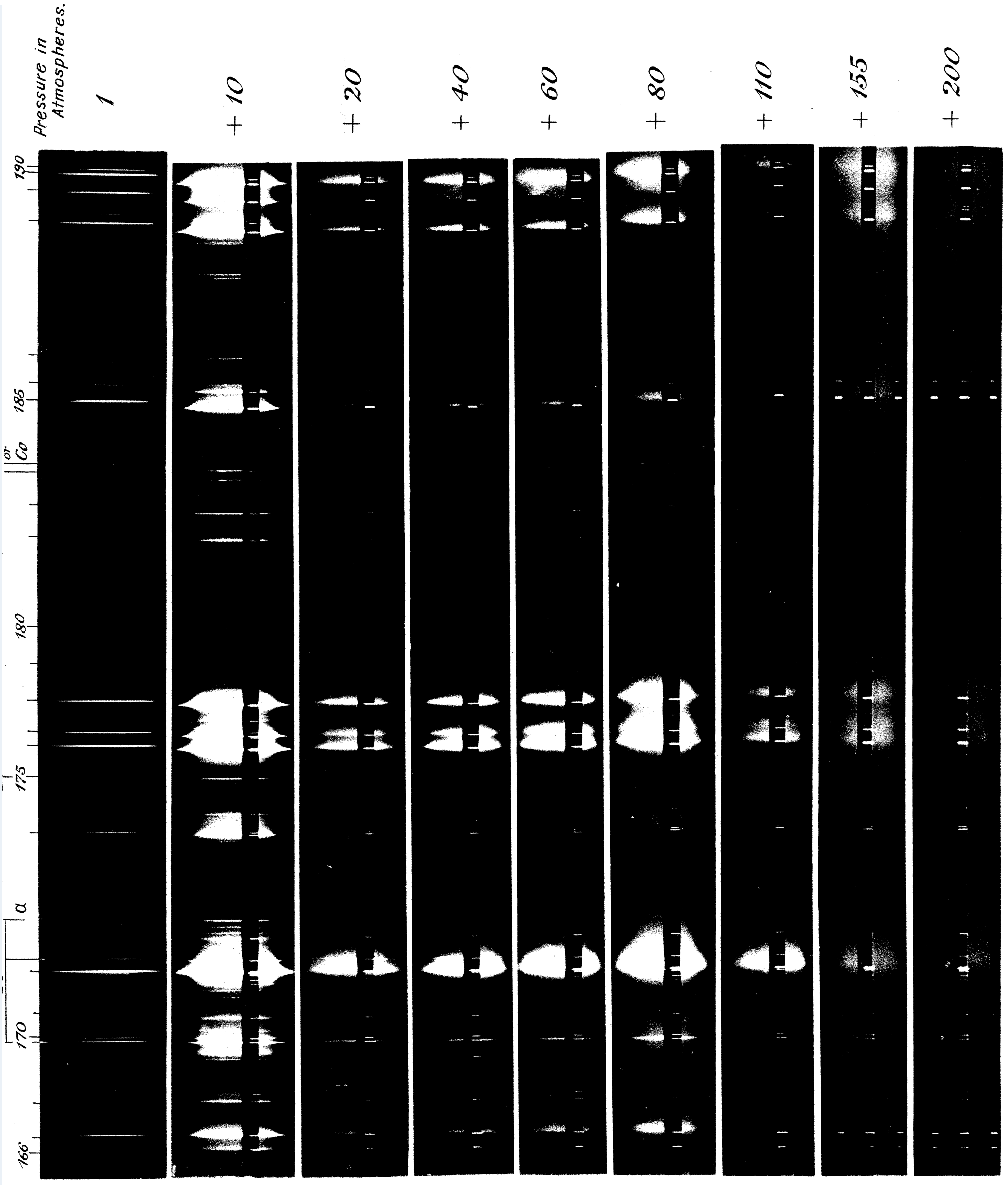

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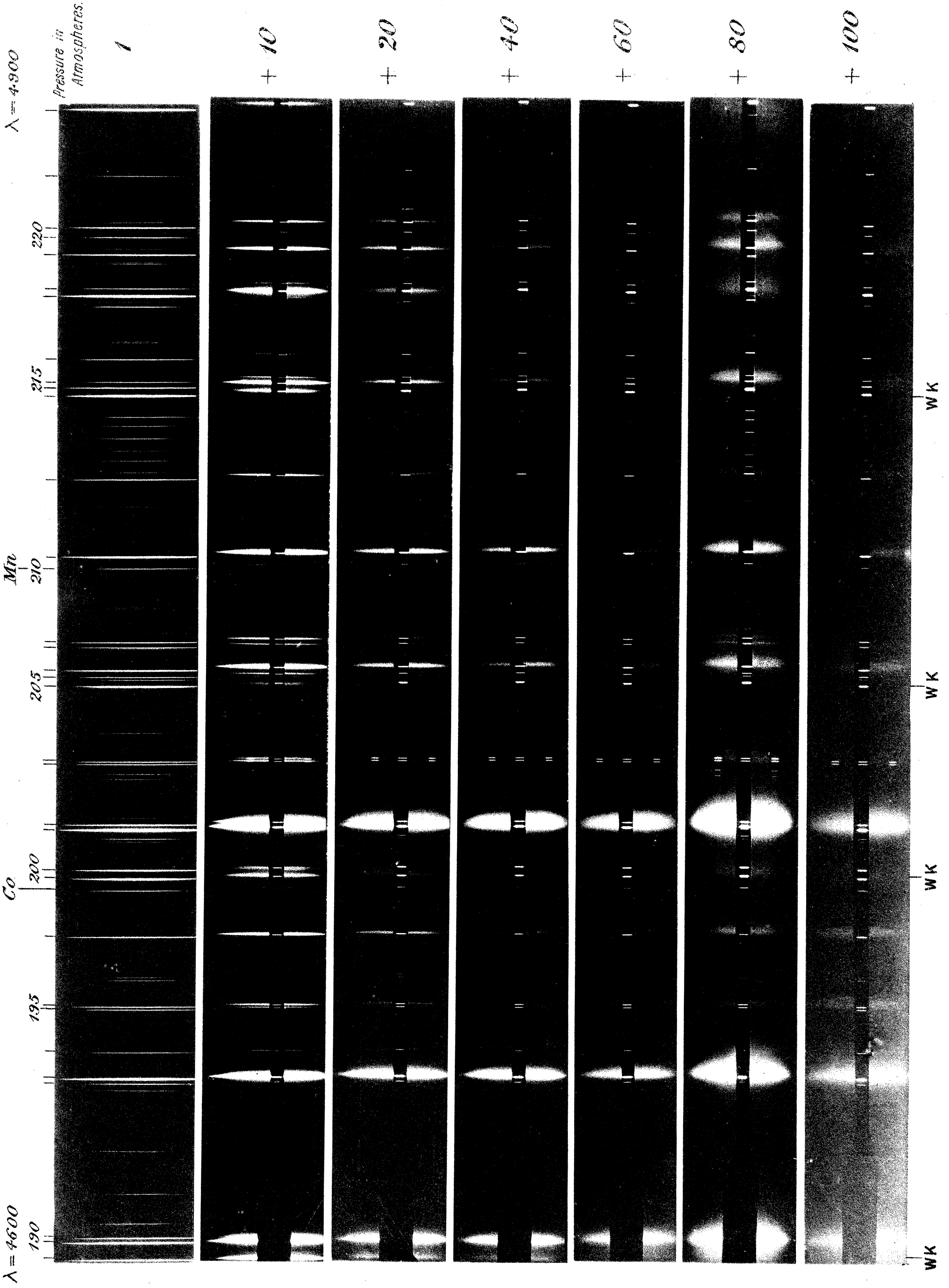

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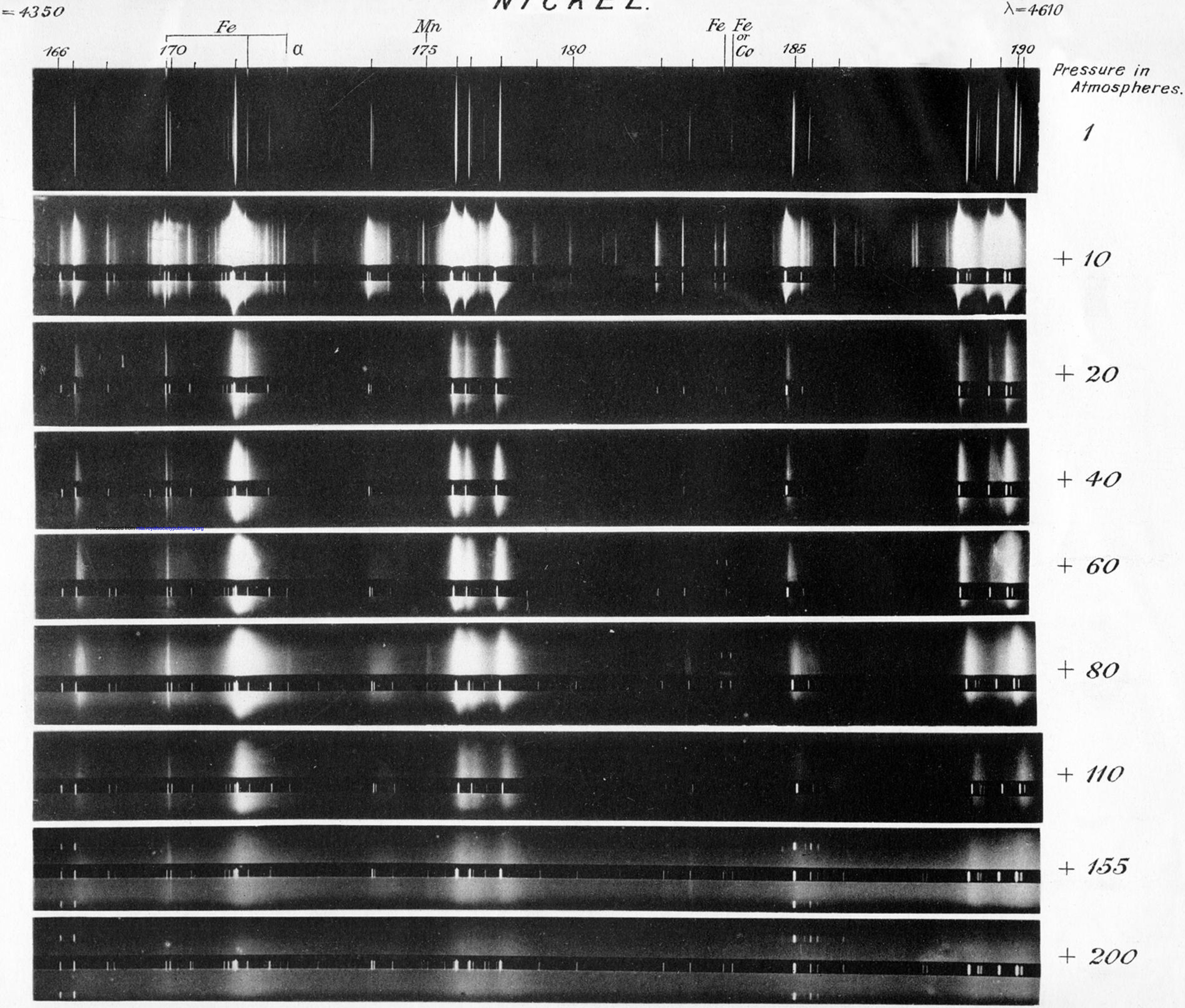

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