X. *Optical Rotatory Dispersion. Part* III.—*The Rotatory Dispersion of Quartz in the Infra-Red, Visible and Ultra-Violet Regions of the Spectrum.*

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(PLATES 17, 18.)

1. *Introduction.*

In an earlier paper on "Optical Rotatory Dispersion" ('Phil. Trans.,' 1912, A, vol. 212, pp. 261–297) a description was given of the measurement of the rotatory power of quartz for 24 wave-lengths in the visible region of the spectrum from Li 6708 to Hg 4358. Two important features of this research were :—

(1) The discovery, after several years of work on inferior material, of a crystal of quartz* of extraordinary optical purity, in which none but mechanical flaws could be detected in a plate 58 mm. in thickness and 150 mm. in diameter.

(2) The use of long columns of quartz, made up of cylinders drilled from this crystal, giving even in the visible region rotations of the order of 10,000°, which could be read with an average error amounting only to a few parts per million.

With this unique material it was possible to secure measurements of a degree of accuracy not previously attained. These measurements could, therefore, be used in order to study with a new degree of precision the exact form of the curve of rotatory dispersion, and, in particular, for making a crucial test of the validity of DRUDE's general equation in the simplified form in which he applied it to transparent media.

$$\alpha = \Sigma \frac{k_n}{\lambda^2 - \lambda_n^2}. \qquad \text{(i)}$$

It was then found immediately that the new series of visual readings could no longer be represented by the two-term equation

$$\alpha = \frac{12{\cdot}2}{\lambda^2 - 0{\cdot}010627} - \frac{5{\cdot}046}{\lambda^2}, \qquad \text{(ii)}$$

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* This crystal was described in Part I of this series of papers (see a Note at the foot of p. 263) as lævorotatory, following HERSCHEL's convention, according to which the rotation is described as it would appear if viewed along the path of the beam. It is, however, now generally agreed that crystals as well as liquids should be named according to BIOT's convention, in which a left-handed spiral is described as *dextrorotatory*, because the rotation is to the right as viewed from the analyser (compare 'Nature,' vol. 110, p. 807, Dec. 16, 1922). This crystal should, therefore, now be described as *dextro* quartz, but in order to avoid ambiguity it is referred to in this paper as *the "lævo" quartz of Part I.*

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which had been used by DRUDE to express the optical rotatory power of quartz. A three-term equation of the type

$$\alpha = \frac{k_1}{\lambda^2 - \lambda_1^2} + \frac{k_2}{\lambda^2 - \lambda_2^2} + \frac{k}{\lambda^2}, \quad \ldots \ldots \ldots \quad \text{(iii)}$$

however, gave a much more satisfactory agreement. In this equation, the first dispersion-constant $\lambda_1^2 = 0 \cdot 010627$ was the square of the wave-length in microns of a hypothetical absorption band in the remote ultra-violet region of the spectrum, the existence and position of which had been deduced by DRUDE from measurements of the refractive power of quartz, and had been used by him in deducing his formula for its optical rotatory power. The final term k/λ^2, also copied from DRUDE's two-term equation, represented the influence of another natural frequency in the far ultra-violet region; but its region of selective absorption was so remote, and the corresponding dispersion-constant λ_n^2 was so small, that no appreciable error was introduced by omitting this constant altogether from the formula. The new equation, therefore, differed from DRUDE's only as a result of the introduction of a middle term, dominated by a characteristic wave-length in the infra-red, of which the value ($\lambda_2^2 = 78 \cdot 22$) had been determined from observations of the selective reflection of "residual rays" by plates of quartz, but which had been found by DRUDE not to be sufficiently important to require a term in his equation. Although this additional term seems to be essential, it represents a partial rotation in the visible and ultra-violet regions of less than 0·2° per mm., on total rotations ranging from 16° to over 180°, so that DRUDE was not seriously in error in asserting "that the kinds of ions whose natural rotations lie in the infra-red are inactive" (compare Part I, p. 291).

Since the dispersion-constants λ_1^2 and λ_2^2 were deduced from measurements of other properties of quartz, the equation finally adopted* in the preceding paper,

$$\alpha = \frac{11 \cdot 6064}{\lambda^2 - 0 \cdot 010627} + \frac{13 \cdot 42}{\lambda^2 - 78 \cdot 22} - \frac{4 \cdot 3685}{\lambda^2}, \quad \ldots \ldots \quad \text{(iv)}$$

contained only three arbitrary constants, so far as the calculation of rotatory dispersion was concerned. It gave, however, a series of calculated values which, in the case of 22 out of 24 wave-lengths, showed an average difference from the observed figures of only 0·001° per mm., or about 1 part in 25,000. The three-term equation therefore represented in a very satisfactory way the rotatory power of quartz throughout the range within which visual observations of optical rotatory powers can be made.

At a very early stage, however, the importance was recognised of extending the new series of measurements into the ultra-violet and infra-red regions of the spectrum. Measurements of rotatory dispersion had already been made in the ultra-violet region

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* This equation applies only to the visible spectrum; an equation which fits the whole of the observations now recorded is given below (p. 395).

by SORET and SARASIN,* and in the infra-red region by CARVALLO,† and by DONGIER,‡ and a later series of infra-red readings has since been given by INGERSOL,§ but it was anticipated that, with the unique material that was now available, it would be possible to make an advance in the accuracy of the measurements at least as great as that which had been accomplished within the limits of visual observation. It was also hoped at one time that it would be possible to extend the measurements in both directions almost up to the limits of transmission of light by quartz; but experience showed that this would be a task of exceptional difficulty, and that sufficient obstacles would be encountered if the work were restricted to a fresh examination of the properties of quartz in and near the regions, already covering by far the larger proportion of the available range, in which a preliminary survey had been made by other workers. The present paper, therefore, describes observations with light ranging in wave-length from 25,000 to 2263 Ångström units, leaving over for future consideration the possibility of making measurements in the more distant outlying regions.

As regards the possibility of making these further extensions, it should be noted that work in the more distant infra-red regions is rendered difficult, not only by the increasing weakness of the radiation, but also by the extreme smallness of the optical rotatory power of quartz, which we have now followed to a point at which it has fallen to less than 1° per mm. The long columns of quartz which are required to produce any substantial rotation in this region will obviously begin to absorb the radiation long before the wave-length of the "residual rays" is reached, and in our opinion new methods of working will have to be invented before any important further advance can be looked for in this direction. In the ultra-violet, on the other hand, the optical rotations increase with remarkable rapidity, and already exceed 180° per millimetre before the iron-arc suddenly loses its brilliance at wave-length 2327 A.U. Beyond this point, in the absence of measurements made with the interferometer, the wave-lengths are probably less accurate than the readings of the optical rotations; and the rotations would be of more value as a check upon the wave-lengths than as a test of the validity of the dispersion-formula. We have, however, found it unexpectedly difficult to secure satisfactory readings beyond 2327 A.U., partly because the choice of lines is very limited, but also because many lines, which are narrow enough to be used in spectroscopy, are not sufficiently homogeneous to give a sharp "extinction" when each Ångström unit adds over 100° to the observed rotation. The wave-length at which these new difficulties make themselves felt, although about 500 A.U. longer than the limit of transmission of light by quartz, is only about 150 A.U. from the limit of transmission by calcite. No very substantial advance could therefore be made unless all the calcite were eliminated from the apparatus, *e.g.*, by replacing the Foucault by Rochon prisms, and the quartz-

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* 'Geneva Archives' (iii), vol. 8, pp. 97–132, 201–229 (1882).

† 'Comptes Rendus,' vol. 114, p. 288 (1892).

‡ 'Comptes Rendus,' vol. 125, p. 228 (1897).

§ 'Phys. Review,' vol. 9, p. 262 (1917).

calcite lenses by quartz or quartz-fluorite. This would involve a complete recasting of the optical system ; and it might even be necessary to abandon also the use of the very long columns of quartz, to which the present series of observations owe so large a proportion of their accuracy, since it is not at all certain that half a metre of quartz might not be nearly as absorbent as a few centimetres of calcite in the region under consideration. The study of the rotatory-power of quartz for light of wave-lengths less than 2200 A.U. therefore presents a totally distinct problem from its study in the region of longer wave-lengths ; and, although Rochon prisms, made for the purpose of this extension, have been in existence for some years, no attempt has yet been made to explore this more distant region.

The experiments now described have been in progress since 1908, when an account was given of the methods which it was proposed to use for measuring rotatory powers in the ultra-violet as well as in the visible spectrum.* The observations finally recorded can be grouped under four headings as follows :—

(1) Visual readings of line spectra.
(2) Photographic readings of continuous spectra in the green, yellow and red regions.
(3) Galvanometric readings of a continuous infra-red spectrum.
(4) Photographic readings of ultra-violet line spectra—
    (i) Through glass, with Nicol prisms.
    (ii) Through quartz and calcite, with Foucault prisms.

The experiments show—

(i) That the infra-red term, which was added in 1912 to DRUDE's equation, is of so little importance that it can be replaced by a single small constant, less than $-0\cdot 2^\circ$ mm., which need not be varied even in the region of longest wave-length.

(ii) That, on the other hand, it is necessary to alter not only the numerators or "rotation-constants" of the ultra-violet terms of DRUDE's equation, but also their "dispersion-constants," in order to express the new series of ultra-violet rotations.

(iii) That, whereas DRUDE treated one of these dispersion-constants as negligible, and deduced the other from measurements of refractive dispersion, it is possible with the help of the new rotation data to deduce independent values for both of these constants.

The final equation contained *five* independent constants, where DRUDE's equation contained only *two*. It was used in two forms. The rotations of the column of quartz which was used for the visual readings described in 1912 can be expressed, to the extreme limit of the ultra-violet readings as well as in the visible and infra-red, by the equation

$$a = \frac{9\cdot 5644}{\lambda^2 - 0\cdot 012742} - \frac{2\cdot 3114}{\lambda^2 - 0\cdot 000974} - 0\cdot 1915 ; \quad . \quad . \quad . \quad . \quad . \qquad (\text{v})$$

but as a result of greater accuracy in the orientation of the optic axis the rotatory power in degrees per millimetre was increased by regrinding to an extent which varied from

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* 'Roy. Soc. Proc.,' A, vol. 81, p. 472 (1908).

1 part in 25,000 in the visible spectrum to about 1 part in 6,000 in the ultra-violet. The rotatory power of the reground quartz was therefore expressed by a slightly modified equation, as follows :—

$$a = \frac{9\cdot5639}{\lambda^2 - 0\cdot0127493} - \frac{2\cdot3113}{\lambda^2 - 0\cdot000974} - 0\cdot1905. \quad . \quad . \quad . \quad . \qquad \text{(vi)}$$

The square-roots of these dispersion-constants probably represent the characteristic wave-lengths of two bands of selective absorption at 1130 A.U. and at 310 A.U. Neither of these bands has yet been detected, as they are beyond the range within which direct measurements of absorption have been made. Their existence was, however, postulated by DRUDE, although he was only able to give an approximate value for the characteristic wave-length of *one* of them, the other being placed provisionally in a region of negligible wave-lengths. The new series of measurements make it possible for the first time to assign definite wave-lengths to both bands ; and the validity of these numbers has been confirmed by deducing from them an accurate formula for the refractive dispersion of quartz.

It will be noticed that, in the formula finally adopted, the infra-red term is almost negligible, so that the optical rotation is dominated by two ultra-violet frequencies, exactly as in the case of the many optically-active organic compounds which give rise to two-term dispersion-equations. In the case of quartz, these two terms are of opposite sign ; but they do not give rise to anomalous dispersion, since the (positive) low-frequency term predominates over the (negative) high-frequency term throughout the range of the spectrum within which measurements of optical rotatory power can now be made. The rotatory dispersion of quartz is, therefore, " quasi-anomalous,"* since it is only the small magnitude of the high-frequency term which prevents the development of all the anomalies that are found in substances (such as tartaric acid or α'-bromocamphor) where the relative magnitude of two opposite partial rotations is reversed at intermediate wave-lengths, giving rise to rotations of opposite sign in different portions of the spectrum.

2. *Materials.*

The material used throughout was the " lævo " quartz of Part I, of which a column, 226·366 mm. in length, made up from four cylinders of similar length, had already been used, with a column of " dextro-quartz " 181·438 mm. in length, for the visual readings described in 1912. In the observations now recorded the same column was used at first both for the infra-red and for the ultra-violet observations ; but a very full series of ultra-violet readings was afterwards obtained by using two of these columns in series. Finally, all the nine available cylinders, including one which had been broken and then cut into two shorter lengths, were reground true to axis by a new method, remeasured at the National Physical Laboratory, and calibrated by observing their individual rotatory powers and calculating their rotations per millimetre. The whole

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* LOWRY and CUTTER, ' J. Chem. Soc.,' vol. 127, p. 608, footnote (1925).

column was then put together in optical contact, giving an aggregate length of 496·474 mm., and enclosed in a special jacket; and this column was used for the final series of observations in the infra-red, visible and ultra-violet regions. The final series of ultra-violet and visual readings owe their greater value, in comparison with the preceding readings, mainly to the greater accuracy of grinding of the quartz; but the infra-red readings were carried out under much more favourable conditions, with a carefully-adjusted Paschen galvanometer, and were not only more accurate, but covered a greater range than the preliminary series of observations which were referred to in the 1912 paper (Part I, p. 291). The way in which the recalibration of the quartz was carried out and the method by which a new value was established for the standard rotation for the mercury green line are described below.

The individual cylinders, after regrinding, were first set up one by one, by means of a reflecting eye-piece, in a water-jacket at 20°. Their individual rotations were then read both with a "positive" and with a "negative" half shadow (H.S. + 3° and — 3°), since this simple device provides a most useful test, both for the quality of the quartz and for the correctness of the experimental conditions (see Part I, pp. 279–281). The results of this preliminary examination are shown in Table I.

TABLE I.—Rotations of Individual Cylinders of "Lævo" Quartz at 20°.

Cylinder No.	Observed rotations.			Total rotation mean.	Length in cm. at 20°.	Rotation per millimetre.
	H.S. + 3.	H.S. − 3.	Diff.			
1	$n\pi$ — 6·07°	— 6·04°	0·03°	1433·95°	5·61460	25·5397°
2	$n\pi$ — 7·05°	— 6·93°	0·12°	1433·00°	5·61112	25·5386°
3	$n\pi$ — 7·02°	— 7·09°	0·07°	1432·95°	5·61099	25·5383°
4	$n\pi$ — 6·95°	— 6·91°	0·04°	1433·07°	5·61124	25·5393°
5	$n\pi$ — 6·68°	— 6·67°	0·01°	1433·32°	5·61238	25·5385°
6	$n\pi$ — 7·00°	— 7·06°	0·06°	1432·97°	5·61112	25·5381°
7	$n\pi$ — 7·08°	— 7·01°	0·07°	1432·96°	5·61099	25·5384°
8	$n\pi$ — 10·61°	—10·57°	0·04°	1429·41°	5·59676	25·5399°
9	$n\pi$ — 21·02°	—20·92°	0·10°	560·97°	2·19660	25·5382°
10	$n\pi$ — 63·35°	—63·24°	0·11°	656·70°	2·57155	25·5370°
					49·64735	

The rotations with a half-shadow angle of +3° and —3° showed a satisfactory concordance, three of the cylinders giving a difference of about 0·1°, whilst the other seven gave an average difference of only 0·05°. The rotations per millimetre range from 25·537° to 25·540°, mean 25·5386°; but these are of less value than the aggregates set out below, and need not be discussed further.

The whole of the 10 cylinders were then put into optical contact by Messrs. A. Hilger and left for three weeks for the contacts to harden. When set up in the polarimeter and examined with a reflecting eye-piece, the complete column showed only a very slight lack of parallelism between the front and back faces, although these were half a metre apart; and the 9 intermediate surfaces were so accurately in contact that the reflections from them gave rise only to two or three faint "ghosts." The aggregate rotations were then determined with the utmost care and gave the results which are shown in Table II.

TABLE II.—Aggregate Rotation of Cylinders of "Lævo" Quartz at 20° C.

Observed rotation.	Temperature (corrected).	Rotations reduced to 20°.
	°C.	
$70\pi + 78\cdot97°$	19·97	$70\pi + 79\cdot00$
$70\pi + 78\cdot91°$	20·005	$70\pi + 78\cdot91$
$70\pi + 78\cdot97°$	19·97	$70\pi + 79\cdot00$
	Mean	$70\pi + 78\cdot96$

Total rotation at 20° = 12678·96°
Total length at 20° = 496·474 mm.
Rotation per millimetre = 25·5380° (First Series as above)
= 25·5382° (Second Series, a week later)
Mean = 25·5381°

The temperature recorded in each case was the mean of that of the inflowing and outflowing water, corrected for the error of the thermometer and for the cooling of its exposed stem.

The value for the rotation of the green mercury line Hg 5461, as finally reached in the former investigation, was

25·537° per mm.

for the "lævo" quartz, whilst the less perfect "dextro" quartz gave a slightly lower value,

25·536° per mm.

The present series of observations on the "lævo" quartz after regrinding the cylinders has raised the former figure by only 0·001 to

25·538° per mm.

It therefore appears that these figures are not likely to be in error to the extent of more than one or two thousandths of a degree, and that it is most unlikely that further work will raise the figure above 25·540° per mm.

3. *Visual Readings.*

After making arrangements, as described in § 2 above, for using to the fullest advantage the whole of the perfect material that was available, it was decided to make a fresh series of readings of the lines in the visible spectrum for which rotatory powers had already been given in Part I. The methods used were similar to those already described, but whereas the earlier numbers were obtained by reading the difference between the rotations of 181·438 mm. of "dextro" and 226·366 mm. of "lævo" quartz, total 407·804 mm., the new readings were obtained by reading a single column of 496·474 mm. of "lævo" quartz against a zero. The new measurements covered 18 of the 24 lines on which observations were made previously, the omissions being the yellow sodium and mercury doublets and the green silver doublet. The remaining 18 lines were read repeatedly, using both positive and negative half-shadow angles, the average values only being recorded in Table III. Since, as has been shown under (2) above, the new readings for mercury green, after regrinding the quartz, were only 1 part in 25,000 (0·001° per mm.) higher than the old, it was considered that a fair comparison of the two series could be made by adding this small fraction to the earlier readings. The results of this comparison are shown in Table III, where the values used to deduce the difference O – C are calculated from formula (vi), with the exception of column iii, where the differences O – C′ are calculated from formula (v).

With the exception of three standard cadmium lines, the wave-lengths quoted in Part I belonged to the ROWLANDS series, and were based upon measurements of grating spectra. The wave-lengths now quoted, however, with the single exception of the thallium line, Tl 5351, are based directly on measurements with the interferometer, as indicated by the references at the foot of the table, and they are, therefore, much more accurate than the earlier values. It is gratifying to record that the change from the less accurate wave-lengths used in Part I not only got rid of a kink between the readings for the visible spectrum and for the standard ultra-violet iron lines, but also reduced to one-half (from 0·0014° to 0·0007° per mm.) the average error in the visual readings, showing that the rotations had been read more accurately than all but the latest series of wave-lengths. It was, however, disappointing to find that the new readings showed no further improvement, since, in spite of the omission of three most troublesome doublets from the series of lines, the average error was 0·0009 for 18 lines, as compared with 0·0008 for the whole of the 24 lines previously read. It is clear that the almost endless multiplication of readings, which was characteristic of the earlier work, had given results which could only with great difficulty be improved until some better method of reading becomes available. The errors, are, however, distributed in a very casual way and are probably due in the main to incidental causes such as impurity in the light; certainly, there is no evidence of systematic deviations from the formula.

TABLE III.—Rotatory Power of Quartz for Light in the Visible Spectrum.

Wave-length.	Old.	O–C′.	Old (corr.).	O–C.	New.	O–C.	Diff.	Mean.	Calc.	O–C.
Li 6707·846 F_1	16·5359	– 4	16·5366	– 1	16·5352	–15	–14	16·5359	16·5367	– 8
Cd 6438·470 F_2	18·0225	–11	18·0232	– 7	18·0254	+15	+22	18·0243	18·0239	+ 4
Zn 6362·345 F_1	18·4786	–18	18·4793	–15	18·4800	– 8	+ 7	18·4797	18·4808	–11
Na 5895·932 F_1	21·7001	–13	21·7010	– 9	—	—	—	21·7010	21·7019	– 9
Na 5889·965 F_1	21·7483	+ 3	21·7492	+ 4	—	—	—	21·7492	21·7488	+ 4
Hg 5790·659 F_1 5790·664 E	22·5455	+ 1	22·5465	+ 8	—	—	—	22·5465	22·5457	+ 8
Cu 5782·159 F_1 5782·158 H	22·6157	±	22·6166	+ 6	22·6174	+14	+ 8	22·6170	22·6160	+10
Hg 5769·598 F_1 5769·603 E	22·7201	±	22·7211	+ 5	—	—	—	22·7211	22·7206	+ 5
Cu 5700·248 H	23·3101	– 3	23·3111	+ 3	23·3118	+10	+ 7	23·3115	23·3108	+ 7
Ag 5471·551 K	25·4318	+15	25·4328	+21	—	—	—	25·4328	25·4307	+21
Ag 5465·489 F_1 5465·490 K	25·4911	+ 7	25·4921	+13	—	—	—	25·4921	25·4908	+13
Hg 5460·742 F_1	25·5371	– 5	25·5381	±	25·5387	+ 6	+ 6	25·5384	25·5381	+ 3
Tl 5350·65	26·6718	+ 6	26·6729	+13	26·6721	+ 5	– 8	27·6725	27·6716	+ 9
Cu 5218·202 F_1 5218·170 H	28·1353	[–35]	28·1364	[–29]	28·1386	– 7	+22	28·1375	28·1393	[–18]
Ag 5209·081 F_1 5209·084 K	28·2447	+ 4	28·2458	+12	28·2444	– 2	–14	28·2451	28·2446	+ 5
Cu 5153·251 F_1 5153·226 H	28·9036	– 2	28·9048	+ 6	28·9050	+ 8	+ 2	28·9049	28·9042	+ 7
Cu 5105·543 F_1	29·4851	– 7	29·4863	– 1	29·4860	– 4	– 3	29·4861	29·4864	– 3
Cd 5085·822 I 5085·824 M	29·7308	–10	29·7320	– 1	29·7327	+ 6	+ 7	29·7323	29·7321	+ 2
Zn 4810·535 F_1	33·5154	–15	33·5167	– 8	33·5168	– 6	+ 1	33·5168	33·5175	– 7
Cd 4799·909 I 4799·911 M 4799·922 E	33·6761	–14	33·6774	– 6	33·6763	–17	–11	33·6769	33·6780	–11
Zn 4722·164 F_1	34·8875	–13	34·8889	– 6	34·8881	–14	– 8	34·8885	34·8895	–10
Zn 4680·138 F_1	35·5712	– 3	35·5726	+ 4	35·5716	– 6	–10	35·5721	35·5722	– 1
Cd 4678·163 E	35·6043	±	35·6057	+ 8	35·6057	+ 8	±	35·6057	35·6049	+ 8
Hg 4358·343 F_1 4358·342 C	41·5487	–10	41·5505	+ 1	41·5507	+ 3	+ 2	41·5506	41·5504	+ 2

M = MICHELSON, 'Mem. bur. inter.,' 1895, vol. 11.
F_1 = FABRY and PEROT, 'Ann. Chim. Phys.' [7], vol. 25, p. 138 (1902).
F_2 = BENOIT, FABRY and PEROT, 'C. R.,' vol. 144, p. 1082 (1907).
E = EVERSHEIM, 'Zeit. f. wiss. Phot.,' vol. 8, p. 150 (1910).
K = KASPER, 'Zeit. f. wiss. Phot.,' vol. 10, p. 58 (1911).
H = HASBACH, 'Zeit. f. wiss. Phot.,' vol. 13, p. 399 (1914).
C = CARDAUN, 'Zeit. f. wiss. Phot.,' vol. 14, p. 90 (1914).

4. *Photographic Readings in the Green, Yellow and Red Regions.*

(*a*) *Use of Continuous Spectra.*—In the deep-red and infra-red regions it is difficult to find a sufficient number of strong spectrum lines to give the desired data. Even the red zinc and cadmium lines, in the arc spectra of alloys of these metals with copper or silver, are difficult to read on account of the continuous radiation from the electrodes. The lithium line Li 6708 can, indeed, be read, although with no great ease; but the deep-red potassium lines, K 7669 and K 7702, are too near the limits of visibility to be read with the eye. It was, therefore, necessary in the deep-red and infra-red regions of the spectrum to fall back upon continuous spectra, and to use methods for recording the rotatory power which did not involve visual observations. The present section contains the results of a series of photographic observations whereby the range was extended beyond the limits of visual observation in a polarimeter (although not beyond the extreme limits of visibility) by the use of Ilford panchromatic plates specially sensitised for the red region of the spectrum. The results obtained in the infra-red region by analogous methods, but with a thermopile and galvanometer instead of a camera, are given in the following section. The methods of working with continuous spectra were, however, very similar in the two cases. Thus, in each case the column of quartz was set up between Nicol prisms which were in a fixed position, *e.g.*, either crossed or parallel; and the wave-lengths of maximum or minimum transmission of light were recorded. This is the converse of the ordinary process, in which the wave-length is fixed and the rotation is measured.

When the light which has passed through a polarimeter, containing a medium of small rotatory power and normal dispersion, is examined with a spectroscope, a single dark band is seen which moves across the spectrum from red to blue as the analyser is turned to correspond with rotations of larger magnitude. When, however, the light which has passed through a long column of quartz is examined in this way, several dark bands are seen simultaneously in the field of view. If the Nicols are crossed, each of these extinctions corresponds to an integral number of half-rotations of the light, *i.e.*, to rotations of $n\pi$ degrees. If the Nicols are inclined at an angle α to one another, the extinctions correspond to rotations of $n\pi + \alpha$. The rotations at successive extinctions differ by 180°; and, if the rotation for one extinction is known, the rotations for all the others can be calculated by adding or abstracting $n\pi$ from the known rotation. The method of working with continuous spectra, therefore, depends on locating, on a scale of wave-lengths, the positions of a series of extinctions for a given setting of the polariser and analyser.

(*b*) *Experimental Methods.*—In the deep-red region the extinctions were located by photographing, in a spectrograph provided with a quartz-calcite lens and two glass prisms, the spectrum of the light transmitted by the polarimeter with the long column of quartz (500·8 mm. before regrinding) in position. By focussing the polariser of the polarimeter on the slit of the spectograph, it is possible to use a real image of the triple field as the effective source of light. When the image in the spectrograph is examined, the triple field is seen to divide the spectrum into three strips, the extinctions of the top and bottom strips being slightly displaced to the left or right of those on the central strip, to correspond with the unequal rotations required to produce complete extinction of the different parts of the triple field. The triple field also produces, on the spectrum as photographed, a horizontal ruling, which is of value when the plate is submitted to measurement (fig. 2, Plate 17).

The measurement consists in reading off, on the scale of a micrometer, the positions of the extinctions relatively to certain fixed reference lines. These lines were superposed on a continuous spectrum by using a carbon arc as a source of light, and saturating the electrodes with salts of lithium, sodium and potassium. In some cases a mercury arc was also flashed on to the system, in order to produce additional reference lines.

(*c*) *Calibration.*—By making use of these reference lines, a limited number of points can be plotted on the calibration curve which connects the wave-length of the light with the readings of the micrometer; but the lines are much too few to give a complete curve. An etalon was, therefore, used to complete the calibration (fig. 3, Plate **17**). This provides a natural scale *at equal increments of frequency*, and thus serves to bridge the gaps between the reference lines. The air gap in the etalon was made of such a thickness as to give bands of similar width to those which separate the successive extinctions produced by the quartz in an independent series of exposures. In order to use it, however, it was necessary to determine the number of wave-lengths of retardation corresponding with each ripple in the spectrum of the light from the etalon. This was readily done by noticing the positions of the reference lines relatively to the ripples. A constant was then deduced which, when multiplied by the serial number of the ripple, gave the corresponding frequency of the light. After photographing the spectrum, first through the etalon and then (in another exposure on the same plate) through the quartz, the positions of the *maxima* on the etalon-spectrum, relatively to one of the reference lines, were read off by means of a micrometer; and a precisely similar series of measurements was made of the *minima* (or extinctions) produced by the quartz in another spectrum on the same plate.

(*d*) *Experimental Results.*—The results of the final series of observations are set out in Table IV, where the first part of the table gives the data for the etalon in two series, A and B, whilst the second part gives the data for quartz, also in two series, A and B.

(i) *Etalon Data.*—Column (i) shows the readings of the micrometer in fractions of a millimetre for the maxima of the etalon; the corresponding readings for the reference lines are shown at the foot of the table. Column (ii) shows the differences between successive maxima, as observed directly. When these were plotted out, however, it was seen that greater accuracy could be obtained from a smoothed calibration curve. Column (iii), therefore, shows the smoothed maxima and Column (iv) shows the smoothed differences. Column (v) shows the number of half wave-lengths in the air-gap of the etalon, and Column (vi) shows the corresponding wave-number ($1/\lambda$) of the light.

(ii) *Quartz Data.*—The second part of Table IV contain the corresponding data for quartz. Column (i) shows as before the readings of the extinctions in fractions of a millimetre. These were obtained by setting the cross-wire of the micrometer midway between the minima for the central strip of the spectrum and for the adjacent upper or lower strip. The distances between the successive extinctions are shown in column (ii) and were not smoothed. The corresponding wave-number $1/\lambda$ of the light as deduced from the etalon-calibration is shown in column (iii), and its wave-length in column (iv). Column (v) shows the number of half-rotations ($n\pi$) of the light, which preceded its extinction by the analysing Nicol. The corresponding rotations per millimetre for a length of 500·82 mm. of quartz are shown in column (vi), and can be compared with a series of calculated values in column (vii); the differences are recorded in column (viii).

The extinctions produced by the quartz were very sharp when a long exposure was given. The intervals between successive extinctions was a little less than a millimetre and could be measured within a few thousandths of a millimetre; but since the etalon readings could not be relied on within less than 0·01 mm., this latter figure is approximately the limit of accuracy of the measurements. It corresponds to an error of 2° in the readings, or of 0·004° per millimetre in the final table of rotations. This estimated error agrees very closely with the actual errors shown in Table IV, where the average error both in series A (omitting the value for the longest wave-length) and in series B is seen to be 0·004° per millimetre. This error is four times as great as in the visual readings described in § 3, of which the observations by the photographic method provide a modest extension over an additional range of about 1000 A.U.; but they are of much the same order of magnitude as in the infra-red readings described in § 5, and the ultra-violet photographic readings of § 6. The results are sufficiently good to vindicate the method of working with continuous spectra, but the accuracy attained was not sufficient to make it necessary to introduce a correction, for the fact that the measurements were made before the column of quartz had been reground.

5. *Infra-Red Rotations.*

(*a*) *Apparatus.* (i) *Polarimeter.*—The infra-red measurements were made by a similar method to that described in § 4, but without using a triple field. The polariser and analyser were, therefore, single Nicol prisms of large aperture. These were mounted in a small movable polarimeter, graduated only in degrees, since the intervals between successive extinctions could scarcely be read more closely than would correspond to a rotation of 5° (1/36 of the distance between the extinctions).

(ii) *Light Sources.*—A few observations were made with an enclosed mercury arc, but the principal source of light was a Nernst lamp. Since INGERSOL* noticed that the Nernst lamp required a shield in order to keep the radiation steady, the lamp was enclosed in a case, with a fluorite lens to focus it on the slit of the spectrometer.

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* 'Phil. Mag.,' vol. 11, p. 41 (1906); vol. 18, p. 74 (1909).

Table IV.—Rotatory Power of Quartz in the Red Region of the Spectrum.

Series A.—Etalon.

(i) Maximum.	(ii) Difference.	(iii) Smoothed maximum.	(iv) Smoothed difference.	(v) *n*.	(vi) Wave-number.
30·016	0·855	30·027	0·435	130	129514
29·567		29·592	0·436	131	130511
29·161	0·438	29·156	0·438	132	131507
28·723	0·445	28·718	0·440	133	132503
28·278	0·441	28·278	0·443	134	133499
27·837	0·445	27·835	0·446	135	134495
27·392	0·448	27·389	0·449	136	135492
26·944	0·456	26·940	0·452	137	136488
26·488	0·460	26·488	0·455	138	137484
26·028	0·453	26·033	0·458	139	138480
25·575	0·453	25·575	0·462	140	139477
25·122	0·476	25·113	0·466	141	140473
24·646	0·464	24·647	0·470	142	141469
24·182	0·479	24·177	0·474	143	142466
23·703		23·703		144	143462

Reference lines :

Wave-length.		Etalon.	Quartz.
K 7699·01	=	29·858	29·855
K 7664·94	=	29·610	29·607
K 6938·98	=	23·418	23·415
K 6911·30	=	23·142	23·142

Table IV. (continued).

Series B.—Etalon.

(i)	(ii)	(iii)	(iv)	(v)	(vi)
Maximum.	Difference.	Smoothed maximum.	Smoothed difference.	*n*.	Wave-number.
24·994		24·994		141	142856
	0·447		0·479		
24·547		24·515		142	143867
	0·519		0·482		
23·028		23·033		143	144882
	0·467		0·486		
22·561		22·547		144	145895
	0·502		0·490		
22·059		22·057		145	146908
	0·500		0·494		
21·559		21·563		146	147921
	0·490		0·498		
21·069		21·065		147	148934
	0·499		0·502		
20·570		20·563		148	149947
	0·513		0·506		
20·057		20·057		149	150960
	0·509		0·510		
19·548		19·547		150	151973
	0·509		0·514		
19·039		19·033		151	152986
	0·527		0·519		
18·512		18·514		152	153999
	0·522		0·523		
17·990		17·991		153	155013
	0·515		0·527		
17·475		17·464		154	156026
	0·544		0·531		
16·931		16·933		155	157039
	0·527		0·535		
16·404		16·398		156	158052
	0·554		0·539		
15·850		15·859		157	159065
	0·532		0·544		
15·318		15·315		158	160079
	0·562		0·548		
14·756		14·767		159	161092
	0·551		0·552		
14·205		14·215		160	162105
	0·558		0·557		
13·647		13·658		161	163118
	0·553		0·561		
13·094		13·097		162	164131
	0·568		0·565		
12·526		12·532		163	165144
	0·570		0·570		
11·956		11·962		164	166158
	0·574		0·574		
11·382		11·388		165	167171
	0·563		0·579		
10·819		11·809		166	168184

TABLE IV. (continued).

Series B.—Etalon (continued).

(i) Maximum.	(ii) Difference.	(iii) Smoothed maximum.	(iv) Smoothed difference.	(v) *n*.	(vi) Wave-number.
	0·579		0·584		
10·240		10·225		167	169197
	0·615		0·589		
9·625		9·636		168	170210
	0·587		0·595		
9·038		9·041		169	171223
	0·581		0·600		
8·457		8·441		170	172237
	0·579		0·606		
7·878		7·835		171	173250
	0·650		0·611		
7·228		7·224		172	174263
	0·617		0·617		
6·611		6·607		173	175276
	0·646		0·623		
5·965		5·984		174	176289
	0·624		0·628		
5·341		5·356		175	177302
	0·628		0·634		
4·713		4·722		176	178316
	0·632		0·640		
4·081		4·082		177	179329
	0·620		0·646		
3·461		3·436		178	180342
	0·664		0·653		
2·797		2·783		179	181355
	0·655		0·659		
2·142		2·124		180	182368
	0·693		0·666		
1·449		1·458		181	183382
	0·624		0·673		
0·825		0·785		182	184395
	0·678		0·680		
0·147		0·105		183	185408

Reference lines :

Wave-length.		Etalon.	Quartz.
K 6938·98	=	23·415	—
K 6911·30	=	23·138	—
Li 6707·85	=	20·996	21·005
Li 6103·53	=	13·263	13·261
Na 5895·93	=	9·979	9·966
Na 5889·96	=	9·877	9·869
Hg 5790·49	=	8·163	8·151
Hg 5760·25	=	7·785	7·783
Hg 5460·74	=	1·640	1·633

Table IV. (continued).

Series A.—Quartz.

(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
Extinction.	Difference.	Wave-number.	Wave-length.	π.	Rotation per mm.		
					Observed.	Calculated.	O–C.
30·173	0·745	129179	7741·2	34	12·219	12·252	[—0·033]
29·428	0·755	130866	7641·4	35	12·578	12·589	—0·011
28·673	0·768	132607	7541·4	36	12·938	12·940	—0·002
27·905	0·767	134341	7443·7	37	13·297	13·296	+0·001
27·138	0·772	136052	7350·1	38	13·657	13·653	+0·004
26·366	0·767	137756	7259·0	39	14·016	14·015	+0·001
25·599	0·771	139429	7172·2	40	14·376	14·371	+0·005
24·828	0·766	141087	7087·8	41	14·735	14·734	+0·001
24·062	0·758	142734	7006·0	42	15·095	15·095	±0·000
23·304	0·769	144294	6930·3	43	15·454	15·442	+0·012
22·535							±0·004

Series B.—Quartz.

i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
Extinction.	Difference.	Wave-number.	Wave-length.	nπ.	Rotation per mm.		
					Observed.	Calculated.	O–C.
24·064	0·760	142707	7007·4	42	15·095	15·090	+0·005
23·304	0·757	144312	6929·4	43	15·454	15·447	+0·007
22·547	0·775	145895	6854·2	44	15·814	15·804	+0·010
21·772	0·767	147492	6780·0	45	16·173	16·169	+0·004
21·005	0·756	149055	6708·9	46	16·533	16·531	+0·002
20·249	0·766	150576	6641·2	47	16·892	16·884	+0·008
19·483	0·762	152099	6574·7	48	17·252	17·247	+0·005

Table IV (continued.)

Series B.—Quartz (continued).

(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
Extinction.	Difference.	Wave-number.	Wave-length.	$n\pi$.	Rotation per mm.		
					Observed.	Calculated.	O–C.
18·721		153594	6510·8	49	17·611	17·604	+0·007
	0·774						
17·947		155097	6447·6	50	17·971	17·969	+0·002
	0·766						
17·181		156566	6387·1	51	18·330	18·329	+0·001
	0·759						
16·422		158006	6328·9	52	18·690	18·686	+0·004
	0·764						
15·658		159440	6271·9	53	19·049	19·046	+0·003
	0·766						
14·892		160792	6219·2	54	19·409	19·406	+0·003
	0·768						
14·124		162273	6162·5	55	19·768	19·766	+0·002
	0·774						
13·350		163674	6109·7	56	20·128	20·127	+0·001
	0·768						
12·582		165054	6058·6	57	20·487	20·488	—0·001
	0·765						
11·817		166414	6009·3	58	20·847	20·845	+0·002
	0·772						
11·045		167771	5960·5	59	21·206	21·207	—0·001
	0·773						
10·272		169115	5913·1	60	21·566	21·568	—0·002
	0·771						
9·501		170440	5867·2	61	21·925	21·927	—0·002
	0·785						
8·716		171772	5821·7	62	22·285	22·293	—0·008
	0·757						
7·959		173046	5778·8	63	22·644	22·646	—0·002
	0·789						
7·170		174351	5735·6	64	23·002	23·000	+0·002
	0·787						
6·383		175640	5693·5	65	23·361	23·370	—0·009
	0·785						
5·598		176912	5652·0	66	23·721	23·735	—0·014
	0·773						
4·825		178151	5613·2	67	24·080	24·084	—0·004
	0·783						
4·042		179392	5574·4	68	24·440	24·442	—0·002
	0·787						
3·255		180623	5536·4	69	24·799	24·802	—0·003
	0·798						
2·457		181861	5498·7	70	25·159	25·163	—0·004
	1·572						
0·885		184245	5427·6	72	25·878	25·871	+0·007
	0·796						
0·089		185429	5392·9	73	26·237	26·228	+0·009
							±0·004

(iii) *Spectrometer.*—The light from the polarimeter was examined in a Hilger's infra-red spectrometer. In this apparatus the usual lenses are replaced by concave mirrors of polished steel, the constant-deviation prism is replaced by a 60° prism and a steel mirror, and a sensitive thermopile is fitted in the focus of the eyepiece of the telescope. The instrument was provided with a rock-salt prism; but in order to secure greater dispersion the first series of readings was taken with a glass prism, and the second series with a quartz prism, since the greater transparency of rock-salt to infra-red radiation was of no value in experiments which involved the passage of the light through half a metre of quartz. In each case the best readings were obtained in the region of high dispersion which precedes the region of absorption by the prism.

(iv) *Galvanometer.*—The radiation falling on the thermopile was detected by means of a Paschen galvanometer, enclosed in a heavy iron case. This was separated by rubber stoppers from a very heavy concrete block, which in its turn was supported by another layer of rubber stoppers on a concrete foundation in the floor. This support was so good that no marked vibration of the galvanometer was caused by stamping on the floor; but, since the outer case of the galvanometer was insufficient to shield it from external magnetic disturbances, four extra shields of sheet iron were introduced between the outer case and the galvanometer, and insulated from one another with cardboard. These iron shields had magnetic fields of their own, but by adjusting them carefully their combined field was made to neutralise the earth's magnetic field. The period of swing of the galvanometer was thus increased to about 12 seconds, and its sensitivity was of the order of 10^{-9} volt per mm. of scale-deflection at 1 metre.

(v) *Heat-Insulation.*—Great difficulty was found in getting the spot of light sufficiently steady to take accurate readings, and various remedies were tried without success; but a marked improvement followed when a small condenser of about 0·001 microfarad capacity was introduced in parallel with the thermopile and a small choking coil in series with it. In order to maintain a steady temperature the thermopile was lagged with cotton wool and the whole spectrometer was also enclosed in a case, having a little window with a movable shutter in front of the slit, and a second glass window through which the drum could be read from the outside; a handle was also provided whereby the drum could be rotated without removing the case. The spot of the galvanometer was observed by means of a telescope, and all the readings were done at night. The method of working was to raise the shutter and to note quickly the "kick" of the galvanometer for a given reading of the drum, and then to plot a curve showing positions on the scale of the drum of the maxima and minima down the spectrum.

(*b*) *Calibration.*—The infra-red spectrometer was calibrated, for use with a glass prism, by means of an etalon consisting of two lightly-silvered quartz plates separated by an air-gap. Considerable difficulty was here encountered because a very thin layer of silver stops the infra-red radiation, whilst if the silvering is too light no interference bands are observed in the visible region. A compromise was finally reached in the degree of silvering so as to make the etalon suitable for use in both regions. The air-gap was much smaller than in the etalon used for calibrating the photographic plates for the deep-red readings described in § 4 above, since the extinctions produced by the quartz in the infra-red were much farther apart than in the visible spectrum. The maxima and minima of the etalon really form two series, but these were combined in the form $n\lambda = 4d$, where the wave-length λ may give either a maximum or a minimum. The distance d was found by taking readings of the fringes in the visible, where the wave-lengths were known, and the number n for the first infra-red fringe was found by extrapolating the calibration-curve of the instrument in the visible region.

The following results were obtained :—

Visible Region.

Wave-length.	No. of fringe.	$4d$.
6220×10^{-8} cm.	$n = 24$	149280
6000	25	150000
5740	26	149240
5560	27	150120
5350	28	149800
		Mean 149690

From this mean value the wave-lengths of the infra-red fringes were calculated as follows :—

No. of fringe.	Wave-length.
$n = 18$	8290×10^{-8} cm.
17	8780
16	9450
15	9930
14	10670
13	11480
12	12420
11	13580
10	14930
9	16590
8	18660

The drum readings for these fringes, when plotted against the corresponding wave-lengths, gave a preliminary calibration-curve for the instrument in the infra-red. In order, however, to check this and to obtain greater accuracy, the etalon was adjusted to bring the fringes closer together, and an independent set of readings of the new fringes was taken. The wave-lengths of these fringes were read off from the preliminary calibration-curve, and if correct should give a new constant $4d'$ when multiplied by the serial number n' of the fringe.

The following results were obtained :—

Drum reading.	Wave-length.	No. of fringe.	4d'.
52·3	18660	n = 16	298560
51·1	17570	17	298690
50·1	16670	18	300060
49·2	15860	19	301340
48·3	15100	20	302000
47·5	14460	21	303660
46·7	13730	22	302060
			Mean 300900

The wave-lengths of the various fringes were then recalculated from the new mean value $4d' = 300{,}900$, so as to give a final smooth calibration-curve as follows :—

Drum reading.	No. of fringe.	Wave-length.
53·4	15	20040
52·3	16	18800
51·1	17	17700
50·1	18	16710
49·2	19	15830
48·3	20	15050
47·5	21	14330
46·7	22	13700
46·0	23	13080
45·2	24	12540

The calibration was checked by reading off the wave-lengths of an infra-red line in the spectrum of the mercury vapour lamp. This line was found after some searching, and the wave-length was given correctly by the calibration-curve as 10140 A.U.

For the quartz prism no special calibration was necessary. The refractive indices of quartz are already known with sufficient accuracy, and a table of wave-lengths against drum readings was supplied by the makers of the instrument.

(*c*) *Measurement of Rotations.*—For the purpose of measuring its rotatory power, the long column of quartz (496·47 mm. in length, after regrinding) was set up by means of a reflecting eyepiece in the movable polarimeter referred to under (*a*) above. The filament of the Nernst lamp was focussed through this apparatus on the slit of the infra-red spectroscope, and the intensity of the transmitted radiation was measured by means of the galvanometer-deflections for different settings of the drum of the spectrometer. A periodic curve was obtained, showing the variations with wave-length of the intensity of the light transmitted through the polarimeter and quartz ; but this was not of the character of a simple sine-curve, since the ripples due to the alternate extinction and transmission of light by the polarimetric system were superposed on a single large wave representing the rise and fall of the radiating power of the filament, as modified only by the absorption of light by the intervening media. Since this large wave carried only a relatively small number of ripples, the wave-lengths of maximum and minimum transparency would be displaced appreciably by the rise or fall, with changing wave-length, of the intensity of the incident radiation. Since, however, the displacements would be in opposite directions for the maxima and minima, the correct wave-lengths of the extinctions could be determined by recording the positions of the maxima and minima *with the Nicols in two positions at right angles to one another* (*e.g.* first crossed and then parallel), so that the maxima of transmission in one series of readings coincided with the minima in the other series, and conversely. By averaging the readings of the two series, mean values could be obtained which should be practically independent of the changing intensity of the incident light.

The number of complete rotations for a given extinction was easily found, since the rotatory power for a given wave-length could be calculated approximately by extrapolation from the visible readings. The infra-red rotations were also known fairly well from an earlier series of experiments with a column of quartz only 226 mm. in length. These earlier experiments, which were completed in 1912 and were therefore mentioned in the earlier paper (Part I, p. 291), need not be described in detail, since, although they were probably in advance of any previous series of observations, they covered a narrower range and appear to have been less accurate than those now recorded for the complete column of 496·474 mm. of quartz.

(*d*) *Results*.—The results of these observations are set out in Table V, where column (i) shows the average wave-length of the maxima and minima for two settings of the analyser at an interval of 90°. Column (ii) shows the corresponding rotation $\frac{n\pi}{2}+\alpha$, where $\alpha = 43°$ for one series and 0° for the other series of experiments. Column (iii) shows the rotation per mm., whilst column (iv) shows the values calculated from the formula (vi) set out on p. 395. The differences between the observed and calculated values are shown in column (v).

(*e*) *Discussion of Results*.—Assuming that the position of a maximum or minimum can be located within 1/20th of the distance between them, the error in the readings would be about 1/20th of 90°, *i.e.*, $4\frac{1}{2}°$ for the complete column of quartz. Since the column was nearly 500 mm. long, this corresponds with an error of 0·01° per mm. in the rotatory power of the quartz. The calculated values shown in the table were derived from the new formula which was worked out to represent the ultra-violet readings (p. 395). The 13 readings with glass prisms show an average deviation from this formula of $\pm$ 0·011° per mm., corresponding closely with the estimated error of reading; but it is noteworthy that a group of four readings from 1·66 to 1·87 μ, in the region of maximum dispersion by the glass, and therefore of maximum sensitiveness of the method, gave an average casual error of only $\pm$ 0·001° and a systematic error of + 0·001° per mm. In the same way, although the six readings with quartz prisms show an average error of 0·014 per mm., again in close agreement with the estimate, the four middle readings gave an average casual error of only ± 0·005° and a systematic error of − 0·002° per mm. It is, therefore, clear that the formula fits the observations right up to the limits of experimental error, since the deviations are smallest where the readings are most accurate. Again, where the two series of observations overlap, at 1·9 μ, the errors are in opposite directions. This result might, perhaps, have been anticipated, in view of the fact that the observations are in one case on the *rising* and in the other case on the *falling* portions of the curve, showing the intensity of the light in the absence of the polarising system; but it affords further confirmation of the view that the formula used to express the ultra-violet readings applies without modification in the infra-red.

TABLE V.—Rotatory Power of Quartz in the Infra-Red Region of the Spectrum.

(i)	(ii)	(iii)	(iv)	(v)
Wave-length 10^{-8} cm.	Total rotation.	Rotation per mm.		
		Observed.	Calculated.	Difference.
		Glass Prism.		
13420	1933°	3·894	3·875	+0·019
13750	1843°	3·712	3·683	+0·029
14030	1753°	3·530	3·526	+0·004
14330	1663°	3·350	3·370	−0·020
14800	1573°	3·168	3·147	+0·021
15170	1483°	2·987	2·983	+0·004
15590	1393°	2·806	2·814	−0·008
16070	1303°	2·624	2·635	−0·011
16640	1213°	2·443	2·443	0·000
17250	1123°	2·261	2·260	+0·001
17920	1033°	2·080	2·078	+0·002
18670	943°	1·900	1·899	+0·001
19650	853°	1·718	1·696	+0·022
		Quartz Prism.		
19000	900°	1·812	1·826	−0·014
20000	810°	1·631	1·630	+0·001
21050	720°	1·450	1·452	−0·002
22200	630°	1·269	1·282	−0·013
23900	540°	1·087	1·082	+0·005
25170	450°	0·906	0·957	−0·051

This conclusion is remarkable since, in the revised formula finally adopted, the influence of the infra-red frequencies, which are known to exist at 8·5, 9·0 and 20·7 μ,* was

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* RUBENS and NICHOLS, 'Ann. d. Physik,' vol. 60, p. 418 (1897).

expressed only by a tiny constant term, $-0 \cdot 1905$, corresponding to less than 1 per cent. of the rotatory power of the quartz in the yellow region of the spectrum, or $0 \cdot 1$ per cent. of its rotatory power in the ultra-violet. Since the readings in the infra-red extend over nearly two octaves beyond the last readings with an eyepiece, and cover a region within which the rotatory power of the quartz falls from 16° to only 1° per mm., it would not have been surprising if this term, which now represents 20 per cent. of the total rotation, had required to be modified on approaching the limits of infra-red absorption. This modification was clearly not necessary, since even at $2 \cdot 2\ \mu$ the error recorded was only $0 \cdot 002°$ per mm. Although, therefore, it has been found necessary now, as in 1912, to introduce a term to express the influence of the infra-red frequencies, it appears that this term is so insignificant that it can be represented adequately by a small constant, which remains independent of the wave-length up to $2 \cdot 4\ \mu$. This wave-length is probably not far from the limit at which the absorption of light by very long columns of quartz would become appreciable, although it is still only about one-third of the wave-length of the nearest absorption band. It should also be remembered that any extension which carried the observations into the region at which the absorption of light is appreciable would be useless as a test of the validity of DRUDE's simplified equation, which is rigidly valid only in the region of complete transparency.

6. *A Photographic Method of Measuring Optical Rotations in the Visible and Ultra-Violet Regions.*

(*a*) *Apparatus.*—In their experiments on the rotatory power of quartz for ultra-violet rays, SORET and SASARIN, in 1882,* made use of sparks passing between cadmium electrodes. These acted as a linear source of light and served the same purpose as the illuminated slit of a spectroscope. The beam of light was rendered parallel by a collimating lens of quartz, and was polarised by a Foucault prism which had been mounted in the place usually occupied by the collimator of a spectroscope. The quartz plate was set up between this Foucault prism and a prism of Iceland spar which acted both as an analyser and as the dispersing system of the spectroscope. The light from the prism was received on a fluorescent screen placed in the focus of the eyepiece of the spectroscope, and the polariser was rotated until the images of the spark were extinguished one after another. From the various extinction-positions of the polariser the rotation produced by the quartz was determined for light of 24 wave-lengths in the ultra-violet spectrum of cadmium. Similar methods were used by VAN SCHAIK† and by A. BOREL‡ to measure magnetic rotations ; JOUBIN§ used a similar method, but replaced the fluorescent screen by a photographic plate. In the experiments which are now described a photographic method was used, in which a triple-field, illuminated by means

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* 'Geneva Archives' (iii), vol. 8, pp. 1–59 ; 97–132, 201–229 (1882).

† 'Archives Néerlandaises,' vol. 17, p. 373 (1882).

‡ 'Geneva Archives' (iv), vol. 16, p. 24 (1903).

§ 'Ann. Chim. Phys.,' vol. 16, p. 78 (1889).

of a line-spectrum, is utilised with just as much advantage in the ultra-violet as in the visible region. The apparatus used in the main series of experiments is shown in fig. 1.

In this apparatus A is an arc burning between metallic electrodes. The polariser B was a triple-field instrument, built up with Foucault prisms, in close imitation of the original set of Nicol prisms which had been used for the work in the visual region of the spectrum, and were now also used for photographic readings of the present series up to the limit of transmission of light by glass. A Foucault prism was also used instead of a Nicol prism in the analyser C. In the earlier experiments, two columns of quartz, G and H, mounted in brass water-jackets provided with a double flow of water at 20° (see fig. 3, Part I, p. 286), were set up between the polariser and analyser, with the help of a reflecting telescope, in such a position that the polished ends of the columns were accurately perpendicular to the beam of light passing through them; in the later experiments the quartz was in the form of a single column, and only one water-jacket was used. The telescope of the polarimeter was replaced by a quartz-calcite lens D of 13 inches focus, which was used to throw a real image of the triple field upon the slit of a spectroscope E. The light was there refracted by two pairs of Cornu prisms and focussed again upon a plate mounted in the camera F.

As in the infra-red observations described in § 4, two series of measurements were made, namely, one series with glass prisms, giving a high dispersion and good separation of the lines in the spectrograph, and a second series with quartz prisms, giving a much smaller separation, but making it possible to carry the observations out beyond the limits of transmission of light by glass. When glass prisms were used in the spectrograph, Nicol prisms were used in the polarimeter; but these were replaced by a complete set of Foucault prisms for use with the quartz prisms of the spectrograph.

(*b*) *Use of a Triple Field.*—On viewing with a lens the image that is formed in the camera (Plate 17, fig. 4; Plate 18, figs. 5, 6) the spectrum is seen to be divided horizontally into three portions, corresponding with the three divisions of the triple field of the polariser. The three parts into which each line is divided are usually of very different intensities. In some the upper and lower portions are bright and the centre extinguished; in others the centre is bright and the outer parts extinguished. Here and there a line may be found in which the three parts are weak, but are all equally illuminated. In these cases it is clear that light of that particular wave-length has been brought to the "extinction-position" by its passage through the quartz. This extinction-position may be varied by altering the setting of the analyser-prism. The use of a photographic plate (instead of a lens) to receive the image in the camera renders the method available throughout the whole range of the ultra-violet spectrum, so far as this can be transmitted through the long train from the arc to the plate.

This method of measuring rotatory dispersion was described in outline in a paper published in the 'Proceedings of the Royal Society' in November, 1908 (vol. 81, p. 473), and has been used systematically for investigating the optical rotatory power of organic

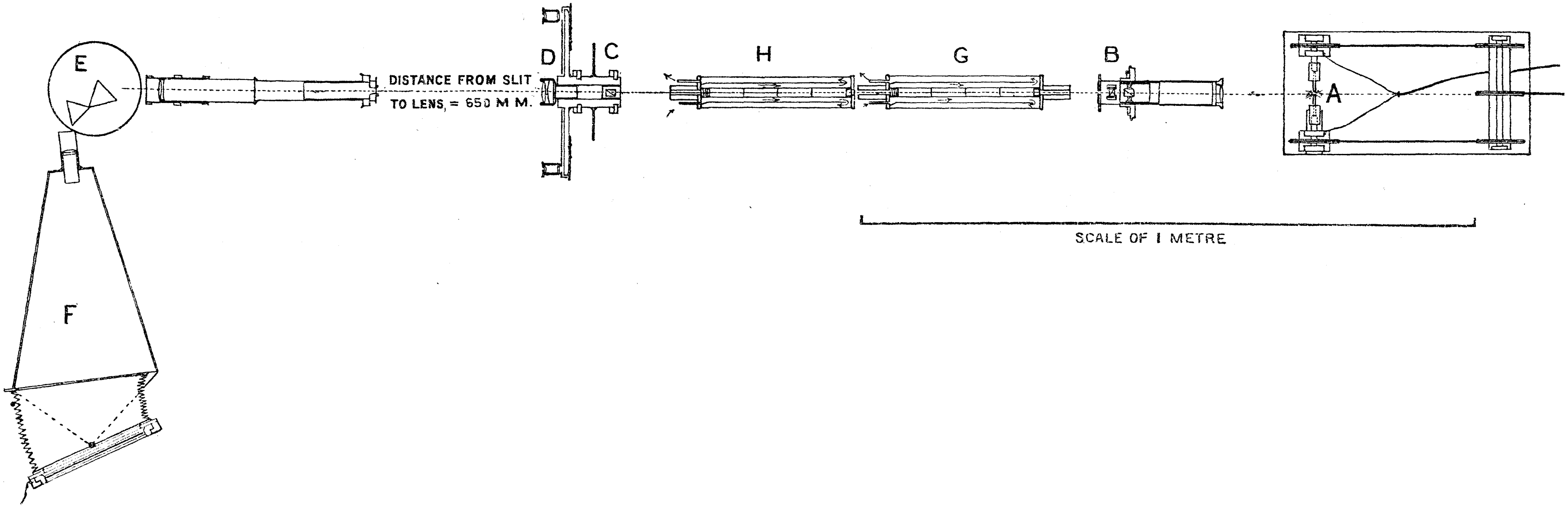

Fig. 1.—Apparatus for Measuring the Rotatory Power of Quartz in the Visible and Ultra-Violet Regions.
(Scale 1 : 10.)
Distance from slit to lens not drawn to scale.

compounds.* A similar method, in which a double field was used, was described a few months earlier in the same year by ST. LANDAU,† and was adopted, with some modifications, by DARMOIS‡ in his experiments on the validity of WIEDEMANN'S Law. The use of a triple-field system in place of a double-field has the advantage that any inequality of illumination is revealed at once by the unequal intensity of the top and bottom portions of the spectrum. Regarded as a whole, these two portions are less bright than the central strip, which is illuminated by light which has passed through only one Foucault prism in the polariser. This difference is specially marked when a large half-shadow angle is used, since the outer strips are then illuminated by light which has passed through two polarising prisms inclined at a considerable angle to one another. The easiest method of recognising the nearness of an extinction-position is, therefore, to look for lines which are stronger at the top and bottom than in the centre. On looking down a series of spectra, photographed with the analyser set at regular intervals round the circle, this feature can be recognised at once in the case of every important line in the spectrum. On following the line up or down the plate, the outer portions are seen to become weaker and the central portions stronger, until after passing through the extinction-position the relative intensities are reversed. Sometimes an exposure can be found for which the three portions are equally bright, indicating that the analyser has been set exactly to an extinction-position. More often the outer portions are stronger in one exposure and the inner portion in the next; the extinction-position can then be deduced from the appearance of the line in the two spectra, the error in locating it being perhaps one-fifth of the interval between two consecutive exposures. The appearance of the photographs is shown clearly in Plate **17**, fig. **4**, and Plate **18**, figs. **5** and **6**.

Throughout the greater part of the spectrum, the zero of the polarimeter may be assumed to be constant for light of different wave-lengths. But, at the extreme limit of transmission of light by calcite, the position of the zero might be influenced by an increased absorption of light in the upper and lower portions of the triple field, where the light has to pass through two polarising prisms instead of one. Under these conditions, it would be desirable to adopt a "half-shadow" device in which equal thicknesses of spar are used to produce the half-shadow effect. A Foucault prism, in which this principle is followed, has actually been constructed, with a fixed half-shadow angle of 5°; but it has not been used in the present experiments, as these have not yet been pushed sufficiently near to the limit of transmission to render this device necessary.

(*c*) *Sensitiveness of the Method.*—It will be seen that the general principle of the method is the same as that used for the deep-red and infra-red readings. It differs from the common visual method in that the wave-length corresponding to a given rotation is

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* 'Trans. Chem. Soc.,' vol. 107, pp. 1173, 1187 (1915); 'Phil. Trans.,' A, vol. 222, p. 249 (1922).

† "Beobachtungen über magnetische Rotationspolarisation im Ultra-violetten," 'Physik. Z.,' vol. 9, p. 419 (1908).

‡ 'Ann. Chim. Phys.,' vol. 22, pp. 247, 495 (1911).

determined, instead of the rotation corresponding to a given wave-length ; but whereas when using continuous spectra, in the deep-red and infra-red regions, it was only possible to estimate approximately the positions of the maxima and minima for one or two positions of the analyser, the use of line-spectra for the visible and ultra-violet readings made it worth while to make observations with the analyser set in a large number of positions, at angular intervals of only 2° or 3°, and thus to locate the extinctions much more accurately. It would, indeed, have been possible, by concentrating attention on a single line, and making a series of exposures with a small half-shadow and at intervals of less than a degree, to read the corresponding rotation to a fraction of a degree, just as we have done in the case of organic compounds of small rotatory power (see, for instance, 'J. Chem. Soc.,' vol. 125, p. 1595 (1924). Thus, in an extreme case, LANDAU, when measuring small magnetic rotations, ranging from 3° to 15°, made a series of exposures on the photographic plate for settings of the polariser* which differed only by 3′, and obtained readings which appear to have been correct within one or two minutes ; DARMOIS, on the other hand, in reading rotations up to 92°, was content to make exposures at intervals of 10′ in the immediate neighbourhood of the point where an extinction was to be expected. In the present series of experiments the rotations produced by half a metre of quartz were of a totally different order of magnitude, the smallest reading being about 12,000° and the largest 101,443°. It was, therefore, sufficient to read the rotation to 1°, by means of exposures made at intervals of 2° or 3° in the setting of the analyser, in order to give the rotations per millimetre to two units in the third decimal place, *i.e.*, 0·002° per mm., which corresponds in the case of the largest readings to an error of 1 part in 100,000. The accuracy of the results is, therefore, here of the same order as in the visible region, and the errors of reading are probably smaller than those caused by uncertainty as to purity of the light and the exact wave-lengths of the lines or by difficulties in setting up and adjusting the long column of quartz.

(*d*) *Sources of Light.*—The ease with which the photographic plates can be read varies very greatly according to the character of the spectrum selected, *e.g.*, whether the lines are strong or weak, scattered or crowded. Thus a weak line will often vanish completely at the extinction-position, which must then be located by interpolation from exposures at wider intervals where the line again becomes visible. Again, the lines are less easily seen, and are far more difficult to recognise with certainty, in a crowded than in an open spectrum. The latter difficulty could be overcome by using a more dispersive system to resolve the spectrum, but this would involve loss of light and a still further increase in the time of exposure. On the other hand, the photographic method has the great advantage that a single full series of exposures, extending over a range of 180° in the setting of the analyser circle, can be used to record the extinctions throughout the whole of the spectrum as received on the plate. It is, therefore, no more

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* The double field was used as *analyser*, a method recommended by Sir WILLIAM PERKIN as being specially advantageous in the case of cloudy solutions.

trouble to photograph the extinctions in a crowded spectrum than in one containing only a few lines. This consideration pointed clearly to the use of some of the more crowded line-spectra, provided that the lines were sufficiently clear, of known wave-length, and not too difficult to recognise. These conditions were satisfied most fully in the case of the iron arc. It was found that the lines of shortest wave-length were easy both to read and to identify, since the dispersion of the prisms was here at a maximum, and each line was separated completely from its neighbours. On the side of longer wave-lengths, however, a limit to the reading of the spectra was ultimately imposed by the crowding of the lines into an almost continuous spectrum as the dispersive power of the prism diminished.

When dealing with crowded spectra the problem of recognising the lines and determining their wave-length correctly was of predominant importance, since much more trouble was experienced in this process of identification than in locating the exact positions of the extinctions. We were, however, helped very greatly by the fact that two photographic enlargements of the arc spectrum of iron had already been prepared for use in measurements of absorption-spectra, and several hundred of the brighter lines had been identified (with the help of a copper spectrum photographed alongside) and labelled. One of these enlargements included the whole of the spectrum as transmitted through a dispersive system composed of two glass prisms, from the green at wave-length 5383 to the early ultra-violet wave-length 3491. The other spectrum, transmitted through a quartz-calcite train and dispersed by two pairs of quartz prisms, covered the range from wave-length 3542 to the point at wave-length 2327, at which the iron spectrum diminishes suddenly in intensity and becomes unsuitable for polarimetric work. The fact that these two enlargements were already available provided a very strong motive for using the iron spectrum as the basis of the new series of observations.

It was these considerations, together with the important part played by the iron arc in the development of standard series of wave-lengths, that led us finally to concentrate our efforts almost exclusively on determining the rotations produced by quartz in the lines of this spectrum. A larger number of lines, extending also somewhat farther into the ultra-violet, could have been obtained by using electrodes of nickel-steel instead of iron; but in view of the extra difficulty of identifying the nickel lines, and the fact that their wave-lengths were less certain than those of the iron lines, the idea of using this spectrum was abandoned after a trial, and no attempt was made to work up the photographs that had been taken with these electrodes.

The iron spectrum ceases to be of real value beyond a wave-length of 2327 A.U. In order to bridge the gap between this point and the ultimate limit of transmission of light through the calcite polarising-prisms and lenses, a few photographs were taken with electrodes of copper and of silver-cadmium alloy. The cadmium lines were regarded as of special interest in view of their employment by SORET and SARASIN in 1882, but in the region beyond the international series of standard iron lines the wave-lengths of the cadmium lines are still so uncertain that no value can be attached to a comparison of the observed and calculated rotations; in fact, if any use were to be made of the readings in this distant region, it would be as a means of predicting wave-lengths rather than rotatory powers. Only in the case of the silver lines have we found anything to compare with the close agreement of the observed and calculated rotations which is so marked a feature of all the calculations based on the new and accurate wave-lengths for the principal iron lines.

In the earlier experiments the arc was burnt between common iron bolts ($\frac{1}{4}$ inch in diameter and 3 inches long), with the heads sawed off. These were screwed into copper cylinders and mounted in an apparatus (see fig. 1, Part I, p. 268), whereby the two electrodes were made to rotate on their axes in opposite directions in order to keep the position of the arc steady. Dr. J. O. CUTTER has, however, since found that equally good results can be obtained by allowing the arc to burn between a small vertical electrode, forming the positive pole, and a large horizontal negative electrode placed above it in such a position that the tip of the small electrode nearly touches the side of the large electrode. The current used is about 3 amperes. This device greatly simplifies the taking of photographic readings, and its efficiency is proved by the fact that whereas exposures of 30 minutes were generally given in the earlier experiments, the later plates were taken with an exposure of only 5 minutes for a half-shadow angle of 10°.

(e) *Secondary and Tertiary Standards of Wave-Length.*—The value of the iron arc varies very greatly in different parts of the spectrum, according to the accuracy with which the wave-lengths of the lines have been determined. The principal series of data are as follows:—(i) FABRY and BUISSON in 1907* published a series of 106 wave-lengths from 2373·737 to 6494·994 of lines in the iron-arc spectrum deduced from the *primary* cadmium standard by measurements with an interferometer. In 1910, EVERSHEIM† confirmed a part of this series and extended it into the red region by giving a series of 58 wave-lengths from 4282·408 to 6945·223; and in 1911 he added a further series of 26 wave-lengths from 3370·787 to 4282·409. This confirmation was followed by the compilation of a series of international *secondary* standards of wave-length, in which 84 of the lines measured by these authors in the range from 3370·789 to 6750·163 were chosen as standards.‡ To these international standards can be added some 22 lines, measured by FABRY and BUISSON only, whereby the range is extended from 3370·789 to 2373·737. These readings have not been confirmed by the independent observations of any other worker, and have therefore not been included amongst the international standards, but it is evident from the agreement recorded in the region of longer wave-lengths that the uncertainty in the values is of the order of 0·001 A.U. only.

(ii) More recently KAYSER§ has derived from these secondary international standards a further list of wave-lengths, serving as *tertiary* standards for the visible spectrum, in

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* 'Comptes Rendus,' vol. 144, p. 1155 (1907); 'Jour. Physique,' vol. 7, p. 169 (1908).

† 'Astroph. J.,' vol. 31, p. 76 (1910); 'Ann. Physik,' vol. 36, p. 1071 (1911).

‡ 'Astroph. J.,' vol. 32, p. 215 (1910); vol. 33, p. 85 (1911); vol. 39, p. 94 (1914).

§ 'Z. f. wiss. Photogr.,' vol. 9, p. 173 (1911); 'Astroph. J.,' vol. 32, p. 217 (1910).

which values are given to three places of decimals for 371 lines in the iron spectrum from 4118·553 to 6494·994, whilst F. GOOS[*] has given the wave-lengths of a similar series of 351 lines from 4282·408 to 6494·992, so that accurate values are now available for nearly every important line in this region. PAPENFUS[†] extended these series in both directions by giving provisionally to 3 decimal places the wave-lengths of 71 lines, from 6065·493 to 6678·008, and of 111 lines, from 4096·641 to 4375·935. In the region of longer wave-lengths, GEIGER[‡] has given values to two decimal places for 216 lines, from 6703·86 to 9809·23 A.U.; but these were based on ROWLANDS' standards and wave-lengths deduced by the use of the interferometer do not appear as yet to be available in this part of the spectrum.

(iii) In the ultra-violet region, BURNS has deduced by direct measurements with the interferometer a new series of *secondary* standards, which also extend into the visible spectrum. His measurements include 125 lines, from 5434·529 to 8824·254,[§] a series of 402 lines, from 3233·056 to 6750·164,[||] and a series of 131 ultra-violet lines, from 2851·802 to 3701·082. The further ultra-violet region beyond 2373 A.U. has not yet been mapped out under this new scheme, but its completion is now merely a question of time and opportunity.

(iv) Attention must also be directed to the very great value, from the point of view of the present series of measurements, of a series of some 2300 *tertiary* wave-lengths from 2373·624 to 5434·527, interpolated by means of a grating from the international secondary standards by BURNS.[¶] It is noteworthy that the calculation of rotatory dispersions not only fails in the region beyond the international standards, where the rotations are more exact than the wave-lengths as at present determined, but that an even worse state of chaos prevails in the small range from 2413·310 to 2562·541, between two of the standard lines, in which the interpolated wave-lengths of BURNS were not completed through lack of time. Later readings intended to provide *tertiary* standards in the visible and ultra-violet regions include interpolated values deduced from grating spectra for 701 wave-lengths from 2990·385 to 4114·452,[**] for 127 lines, from 4383·542 to 4903·326[††] for 1,065 lines, from 2987·293 to 5658·836,[‡‡] and for 977 lines, from 3370·788 to 6494·993.[§§] SAINT-JOHN and BABCOCK have also made measurements with an interferometer for 407 lines, from 3370·788 to 6750·166, and these may be regarded as providing materials for a series of *secondary* standards over this range,

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[*] 'Z. f. wiss. Photogr.,' vol. 11, pp. 1 and 313 (1912).

[†] 'Z. f. wiss. Photogr.,' vol. 9, p. 332 (1911).

[‡] 'Ann. d. Physik,' vol. 39, p. 782 (1912).

[§] 'Comptes Rendus,' vol. 156, p. 1612 (1913); 'J. Physique,' vol. 3, p. 457 (1913).

[||] Bul. Bur. Stand.,' vol. 274, p. 245 (1916).

[¶] 'Z. f. wiss. Photogr.,' vol. 12, p. 207 (1913).

[**] VIEFHAUS, 'Z. f. wiss. Photogr.,' vol. 13, p. 209 (1914).

[††] JANICKI, *ibid*, p. 174.

[‡‡] HOELTZENBEIN, 'Z. f. wiss. Photogr.,' vol. 16, p. 225 (1917).

[§§] SAINT-JOHN and BABCOCK, 'Astroph. J.,' vol. 53, p. 360 (1921).

confirming the values given by BURNS for a similar number of lines over a similar range of wave-lengths (402 lines, from 3233·056 to 6750·164, as cited under (iii) above). Since, however, all these later determinations vary by only a few thousandths of an Ångström unit from one another, or from BURNS' original series of 2,300 tertiary standards, the latter have been retained without alteration in Table VI, since the calculations based on them would not be altered appreciably by varying the third decimal in the wave-lengths.

7. *Rotatory Power of Quartz in the Violet and Ultra-Violet Regions.*

(*a*) *Ultra-Violet Rotations of Short and Long Columns of Quartz.*—Attention has already been directed to the fact that, when light which has passed through a substantial column of quartz in a polarimeter is examined spectroscopically, several extinctions are seen simultaneously, which pass along the spectrum when the analyser is rotated, pursuing one another across the field of view like a series of ripples. With the very long columns used in the present experiments this effect begins to disappear, since the ripples are almost as abundant as the lines. The effect is, therefore, more like that of a series of narrow shadows falling on a widely-spaced railing, the rails of which would flicker with the light and shade, but without reproducing the regular wave-length of the shadows. This statement can be verified by looking at figs. 4 to 6 (Plates 17, 18), where the periodic character of the extinctions is almost completely masked, and the ripples can scarcely be distinguished from the lines.

This closing up of the ripples introduced a new and serious difficulty in determining the rotations, since it was much easier to find out the position of the extinction relatively to the zero of the analyser-circle, as described in § 6 (*b*) above, than to know how many revolutions had preceded the emergence of the plane of polarisation in this position. The method adopted for this purpose is illustrated in fig. 7 (Plate 17). The first step was to photograph 226·366 mm. of the "lævo" quartz in series with 181·438 mm. of the "dextro" quartz, giving rotations corresponding with an active column of only 44·926 mm. The number of complete revolutions was then small, and could be deduced easily from the known rotatory power of quartz in the visible spectrum. The extinctions on this exposure were wide apart, and therefore provided an open scale on which the number of half-revolutions ($n\pi$) could be read off easily. An exposure was next made with a column of 226·366 mm. of "lævo" quartz, giving rotations approximately five times as great as in the preceding case. This second exposure, therefore, contained five times as many extinctions as the previous one; but every fifth extinction was at almost exactly the same wave-length as on the previous exposure, and could therefore be identified as representing a multiple of 5π. In the same way, when two columns of 226·36 mm. were photographed in series, the number of extinctions was again multiplied by two, the even series coinciding with the extinctions on the preceding exposure, whilst the odd extinctions were intermediate between them. Those extinctions of the *third* series which coincided with extinctions of the *first* series evidently represented multiples of 10π, and the corresponding value of $n\pi$ could therefore be determined by multiplying by 10 the values already worked out for the widely-spaced extinctions of the first series. Even then very great difficulties were experienced in avoiding errors, especially in the part of the spectrum where a single Ångström unit increases the observed rotations by more than a right angle, and it was only when a concordant relation was established between rotation and wave-length (as set out in a long series of graphs) that the last errors from this source were discovered and eliminated. When, however, a still longer column of 496·474 mm. of quartz was used for the final series of measurements, this relation had been established so completely that the determination of the number of half-rotations for a given wave-length was a mere matter of arithmetic, based either upon the use of a formula, or on the rotations per millimetre which had already been deduced from the readings of the earlier series.

(*b*) *First Series of Measurements.*—Through the great kindness of Col. J. W. GIFFORD, the earliest complete series of photographs, A_1, A_2, A_3, were taken on his large spectrometer, with quartz lenses of 30 inches focus and a pair of quartz Cornu (30°) prisms, 3 inches in height, to produce the dispersion. The polarimeter was set up in a line at right angles to the collimator of the spectrometer. An achromatic lens, of quartz and fluorspar, of 6 inches focal length, was substituted for the telescope of the polarimeter, and (with the help of a reflecting mirror of speculum metal) served to cast a real image of the triple-field on the slit of the spectrometer. It was found that an exposure of 15 to 20 minutes was sufficient, with a current of 5 to 6 amperes in the iron arc. The two columns of quartz used in these experiments produced a rotation of 11561·52° for the green mercury line of wave-length 5460·742. A few photographs were also taken with one column of "lævo" quartz and a shorter column of "dextro" quartz, producing a total rotation of 1147·55°, in order to determine the number of half-revolutions corresponding to the extinctions of the main series.

Three complete sets of photographs were taken, one with an iron arc, and two with iron-nickel electrodes. In each case exposures were made at intervals of 10° over a range of 180°, making a total of 54 exposures in all. It was found that an arc of "invar" nickel-steel would carry a heavier current than the iron arc, and gave a spectrum extending rather farther into the ultra-violet; but when the time came to read off the rotations, the iron-nickel photographs were abandoned, for reasons which have already been explained. The photographs taken with the iron arc, however, gave readings for 258 lines from 2327·49 to 3100·305 A.U. Lines of longer wave-length could not be read, as they were not sufficiently separated to enable them to be seen clearly at the extinction-position. Although the exact position of the extinction had to be judged by interpolation from exposures at intervals of 10°, the error did not appear as a rule to be more than two or three degrees in each reading.

(*c*) *Second Series of Measurements.*—The second and longest series of measurements was made in London, with the apparatus shown in fig. 1 (p. 415). A set, B_1, of 60 photographs was first taken, with the analyser at positions 3° apart on the graduated circle from 0° to 177°. As some of the exposures were weak, a second set, B_2, of 60 photographs was taken with the analyser at intermediate positions from $1\frac{1}{2}°$ to $178\frac{1}{2}°$, and these were used to locate the extinctions. Two similar sets, B_3 and B_4, of 60 photographs were then taken with two glass prisms on the spectroscope, and Nicol prisms in the polarimeter, in order to secure a greater dispersion in that portion of the spectrum which is transmitted by glass. Wratten's " Drop-Shutter " plates were used, with an exposure of 45 minutes for the series with glass prisms, and 30 minutes for the series with quartz prisms.

The wave-lengths for which rotations were determined extended from 5383 to 2327 A.U. This corresponded with a range of over 72,000° in the observed rotation, so that, if a continuous spectrum had been photographed, each exposure would have included 400 consecutive extinctions in a range of 3000 A.U. In practice the portion of the spectrum which was photographed through glass prisms extended from 5383 to 3491 A.U., and included some 100 extinctions in a space of about 120 mm. on the plate : the portion that was photographed through quartz prisms extended from 3542 to 2327 A.U., and included over 300 extinctions in about the same length of spectrum ; for this reason the " quartz " series of plates was much more difficult to read than the " glass " series. An overlap from 3542 to 3491 A.U. provided a few lines for which the readings with glass and with quartz prisms could be compared.

In all some 700 lines were read. Although larger errors were to be expected when the position of the extinction had to be judged by interpolation, the error of reading appeared to be only about 1° for those lines which could be seen clearly at the extinction-position. Thus, for 99 lines of the " glass " series from 3555 to 3814 A.U., the average difference between the observed and calculated rotations was 0·002° mm., corresponding to an average error of only ± 1° in the observed rotations. In the quartz series the limits of error were probably similar for lines that could be seen with equal clearness. Thus, in the range from 2327 to 2424 A.U., 21 " full-type " readings of series B_1 and B_2 (not including the weak or interpolated readings which are printed in italics in Table VI) showed an average difference from the mean of rather less than ± 1° on the total rotation, or ± 0·002°/mm., just as in the " glass " series cited above. Again, at the overlap between glass and quartz the three pairs of " full-type " readings of series B_2 and B_4 differed by 0°, 1° and 1° only, thus confirming the preceding estimate of the normal error of reading. Since, however, the lines were much more crowded and a narrower slit-width had to be used to separate them, the conditions for maximum accuracy were fulfilled less frequently in the " quartz " series than when glass prisms were used in the spectrograph. Moreover, in a region where the rotations were increasing very rapidly with decreasing wave-length, the differences between the observed and calculated rotations were liable to be augmented by the presence of weak satellites which could not be separated by the relatively low dispersion of the quartz prisms. For these reasons the average difference between the observed and calculated rotations was about twice as great in the quartz series as in the glass series, namely, about ± 3° on the total rotation, or 0·006°/mm.

(*d*) *Third Series of Measurements.*—The last sets of photographs were taken at Cambridge, using the complete column of 496·474 mm. of quartz, after regrinding. Exposures of five minutes only were made at intervals of 2° in the setting of the analyser, both with quartz prisms in the spectrograph, series C_1, and with glass prisms, series C_2. The total number of lines read was 93 with quartz prisms and 100 with glass prisms, but this total includes nearly a score of "composite" readings, which are not reproduced in the table. The shorter exposure reduced the number of lines that could be seen on the plate, but increased the ease of reading them, since many of the weaker lines did not appear. For this reason the errors were generally smaller than in the preceding series, especially in the more difficult parts of the spectrum; but the hope that the rotations might be determined to a fraction of a degree was not realised, since the readings were still subject to casual errors of one or two degrees.

(*e*) *Tabulated Measurements.*—The observed and calculated rotations are set out in Table VI. Secondary standards of wave-length are printed in heavy type: the same type has also been used for the observed and calculated rotations for the long column of reground quartz, except in the case of interpolated or weak readings, which are printed throughout in italics. Wave-lengths deduced from early grating-readings, without any check from the interferometer, and rotations calculated from them, are also printed in italics. Since these wave-lengths are usually about 0·06 A.U. too high, the calculated rotations are too low, giving rise to an excessive proportion of positive differences.

In order to avoid the suggestion that only selected rotations have been published, the table includes *all* the recorded readings (nearly 1,000 in number) for individual spectrum lines, with the exception of half a dozen cases where the readings were obviously untrustworthy, *e.g.*, because two series of readings gave widely discordant values, or because the recorded rotations were not in the correct sequence. We have also omitted 15 composite readings of series C_1 and 2 of series C_2, where the components were so widely separated that the observed rotation could only be compared with a weighted mean of calculated rotations covering a range of 12° or more. In these cases, in spite of the excellent agreement which was generally found between the observed and calculated rotations, the readings have been omitted on the general ground that they were not made with monochromatic light, and that the observed rotations did not correspond with any single spectrum line.

In about 30 cases the wave-lengths corresponding to the recorded extinctions could not at first be identified with any known line in the spectrum of the iron arc, even when a liberal allowance was made for inaccuracy in the readings. This list of unidentified wave-lengths, which may include a small residue of actual mistakes in recording the rotations, was reduced to about one-half when it was realised that the spectrum of the iron arc might contain a few of the strongest lines of some of the principal impurities of metallic iron. In attempting to identify these unknown lines, however, we have limited ourselves strictly to those lines which have already been recorded in the spectrum of the iron arc, but have been attributed to foreign elements by the authors of the various tables of wave-lengths. We then discovered that our readings included 10 lines due to manganese, two ultra-violet copper lines, and one line each due to nickel and to magnesium. The fact that the list of unidentified extinctions was approximately halved by making use of a short list of known lines of known impurities, without bringing in the complete wave-length tables for Cu, Mg, Mn or Ni, is a remarkable vindication of the general correctness of the tabulated rotations, and suggests that some of the other outstanding cases may perhaps be capable of a similar simple interpretation.*

Duplicate readings of about 180 lines were available for the quartz before and after regrinding. The rotations of the two series are slightly divergent, since the rotatory power of the quartz was increased to the extent of about 1 part in 25,000 by regrinding. In order to render available the long series of rotatory powers which were measured before the quartz was reground, a smooth series of differences was deduced from the formulæ which express the two series of readings, and these differences can be applied to correct the rotations of the old series. Special attention is directed to the fact that the correction for regrinding must be applied both to the observed and to the calculated rotations of the older series in order to give correct values for the lines in question. The concordance of the old and new series can be judged by making use of the tabulated corrections for regrinding, or by comparing the *differences* between the observed rotations and those calculated from the corresponding formulæ for the two series of readings.

When this was done, it was found that the errors in the two series were predominantly parallel, *e.g.*, the two series would show three pairs of positive errors, followed by one pair of negative errors and a further pair of positive errors, with only one pair of errors of opposite sign. Various explanations might be given of this clearly-established parallelism. Thus, if the systematic errors were greater than the casual errors, both formulæ would show a run of predominantly positive or predominantly negative errors. But in the " quartz " series, where the casual errors were much larger than in the " glass " series, this explanation could not be maintained, in view of the fact that the sign of these concordant errors often showed an abrupt reversal. On further investigation, this reversal was traced in some instances to the presence of recorded satellites, positive errors being shown by lines with a satellite of shorter wave-length and conversely. This discovery affords a possible explanation of the very baffling fact that the differences between the observed and calculated rotations were often much larger than the probable error of the rotations, or than any conceivable error of the wave-lengths. Thus, in the range from 2413·310 to 2373·737, where the systematic error is only − 0·002°/mm.,

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* The last line to be identified gave (after correcting an error of calculation) a deviation of 0·086°/mm. between the observed rotation and that calculated for what was thought to be the nearest line. Further calculation showed that the difference from the value for a neighbouring line, which was obviously the one that had been read, was ±. The error was therefore not in the reading, but in its interpretation.

and the average casual error of all the readings, good and bad alike, is ± 0·006°/mm., the error at wave-length 2410·526 A.U. increases abruptly to + 0·014°/mm. The corresponding rotations, however, were completely concordant in three series of exposures at $428\pi + 2^\circ, 3^\circ, 4^\circ = 77043 \pm 1^\circ$, and these concordant rotations would have to be increased by about 6° in order to give the calculated value for the rotation in degrees per millimetre. In such a case as this it is much easier to imagine that the polarimetric readings included a satellite which increased the effective wave-length of the light by 0·07 A.U. than to postulate an error of this magnitude in the recorded wave-length of the main line, or of 6° in rotations which differed only by ± 1°. This explanation probably applies to a large number of other cases in which concordant errors are recorded in two series of readings, and it is even possible that some of the discordant readings may have been due to the fact that in one series a satellite was included in the readings, whilst in the other series it was possible to read the main line without the satellite.

(*f*) *Sub-Division of the Table.*—The number and accuracy of the readings, as well as of the available wave-lengths, vary greatly in different parts of the table. The table has, therefore, been broken up into a series of sections, and notes dealing with the special features of each section are set out below.

(i) *First Section.*—2327·49 to 2368·60 A.U.

In this region of the spectrum the rotations were very large, but the lines are so widely separated that they could be read with an accuracy that was not surpassed by any of the other photographic readings. The probable error of the readings was, indeed, of the order of only 1 or 2 parts in 100,000. Unfortunately, this part of the table lies beyond the last of the standard lines of the iron-arc spectrum. The wave-lengths, therefore, depend on measurements with a grating, and are not even interpolated from interferometer readings. Although, therefore, every line for which rotations were determined could be identified with ease and certainty, none of the wave-lengths was known with sufficient accuracy to provide a check upon the validity of our formulæ for the rotatory dispersion of quartz. On the other hand, since a single Ångström unit in this part of the table corresponds with a change of 100° in the observed rotations, which were usually concordant within 2° or 3°, it is possible to check the wave-lengths within a few hundredths of an Ångström unit from the rotations. Thus in the case of the seven least refrangible lines of this section, the wave-lengths of which have been given both by Exner and by Schumacher, the average difference is *decreased* from 0·015° to 0·008°/mm. by using the latter, the individual differences (× 1,000) being as follows :—

Schumacher .. — 4 — 8 — 4 — 3 [— 23]* — 8 — 5. Mean error ± 18 [or 5].
Exner .. .. + 14 + 8 + 31 + 20 [±]* + 15 +18. Mean error ± 15 [or 18].

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* The values shown in brackets are for a line for which Exner's wave-length gives a much closer agreement than Schumacher's. Since the rotations for this wave-length are particularly concordant, it may be taken that Exner's wave-length is substantially correct.

On the other hand, in the case of the seven most refrangible lines, the error in the rotations of Series A_1 and B_1 is *increased* from 0·005 to 0·019 by adopting SCHUMACHER'S wave-lengths, the individual differences (× 1000) being as follows :—

SCHUMACHER	− 23	− 19	− 12	− 26	− 20	− 18	− 16.	Mean diff. = 19.
EXNER—								
(Series A_1 and B_1) ..	+ 9	+ 3	+ 8	− 4	− 3	− 1	+ 3.	Mean diff. = 5.
(Series C_1)	±	+ 1	+ 3.					Mean diff. = 1.

EXNER'S values, therefore, appear to be more exact than SCHUMACHER'S for the seven shortest wave-lengths covered by our observations, and this conclusion becomes almost a certainty in view of the fact that EXNER'S values give an average error of only ± 0·001°/mm. in the rotations for the three shortest wave-lengths of Series C. It would, indeed, have been possible in this portion of the spectrum to give a new table of wave-lengths based upon our observations of rotatory dispersion, thus using the DRUDE equation as a means of extrapolation from the standard wave-lengths determined with the help of the interferometer ; but since these wave-lengths will presumably be measured in due course with the interferometer, we have preferred to limit ourselves to expressing a preference for one or other of the values already published, and are content to await the vindication by later direct measurements of the choice that we have made.

(ii) *Second Section.*—2373·737 to 2413·310 A.U.

In this section the rotations are in remarkably good agreement with the values calculated from wave-lengths interpolated by BURNS, with the help of a grating, from those of the last two standard lines of the iron-arc spectrum. The average differences* between the observed and calculated values were as follows :—

Series A and B. 16 lines.

$$\text{Casual errors} \quad \pm\frac{24+76}{16} \equiv \pm\, 0{\cdot}006^\circ/\text{mm.}$$

$$\text{Systematic error} \quad \frac{24-76}{16} \equiv -\, 0{\cdot}003_3{}^\circ/\text{mm.}$$

Series C. 6 lines.

$$\text{Casual errors} \quad \pm\frac{21+16}{6} \equiv \pm\, 0{\cdot}006^\circ/\text{mm.}$$

$$\text{Systematic error} \quad \frac{21-16}{6} \equiv +\, 0{\cdot}000_8{}^\circ/\text{mm.}$$

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* In the tables which follow, the sum and difference of the positive and negative errors, as recorded in Table VI *in thousandths of a degree per millimetre*, are divided by the total number of readings in order to give the average values of the casual and systematic errors ; but the latter are expressed throughout *in degrees per millimetre.*

From these averages it is clear that the formulæ which fit the data for the visible and infra-red regions are also valid in the farthest part of the ultra-violet region for which trustworthy wave-lengths are available.

(iii) *Third Section.*—2417·91 to 2551·32 A.U.

In this section, which lies between the next pair of standard iron lines, the published wave-lengths are most unsatisfactory, since Burns was only able to make one hurried series of unconfirmed readings, and these are so incomplete as to be entirely inadequate for the purpose of calculating the optical rotations.

The six selected lines of Series C are all included in Burns' table; but only 35, or rather less than one-half, of the 74 readings of Series A and B could be recognised as agreeing even approximately with wave-lengths measured by Burns, and of these 35 lines six were classed as "unidentified," since the deviations between the observed and calculated rotations were $> \pm 0\cdot04^\circ/\text{mm.}$, whilst in nine more cases the attempted identification gave deviations $> \pm 0\cdot02^\circ/\text{mm.}$ The average differences between the observed and calculated rotations for all these lines, except the six lines referred to above as "unidentified," were as follows:—

Series A and B. 29 readings (6 omitted).

Casual errors $\pm\frac{224+194}{29} \equiv \pm 0\cdot014^\circ/\text{mm.}$

Systematic error $\frac{224-194}{29} \equiv +0\cdot001_0{}^\circ/\text{mm.}$

Series C. 6 readings.

Casual errors $\pm\frac{24+13}{6} \equiv \pm 0\cdot006^\circ/\text{mm.}$

Systematic error $\frac{24-13}{6} \equiv +0\cdot001_8{}^\circ/\text{mm.}$

It is interesting to note that when the six "unidentified" lines were omitted, the remaining 29 lines of series A and B showed a systematic error which was only $+0\cdot001^\circ/\text{mm.}$, although the casual error was twice as great as in Section 2. Even in this very difficult portion of the spectrum, therefore, there is no indication of any failure of the formula to represent the recorded rotations correctly.

The other readings of Series A and B were easily identified with lines measured by Exner in 1897, and having an intensity of 4 or more. Of these remaining 38 lines, the only two which remained "unidentified" gave rotations corresponding with wave-lengths of 2511·58 A.U. and 2546·61 A.U., the latter being an unidentified satellite of a line at 2546·86 A.U., of which a satisfactory reading had already been taken. Exner's wave-lengths, however, like others based upon ROWLAND'S data, are uniformly too high, the average being about 0·06 A.U. Since, in this part of the table, 6 A.U. $\equiv 1°$/mm., an error of 0·06 A.U. in the wave-lengths would produce a systematic error in the rotations of about $+0·01°$/mm. This corresponds closely with the average difference actually found between the observed and calculated rotations for these 36 lines, which amounted to $+0·013°$/mm., after omitting one composite reading of a close doublet. The casual deviations were only slightly larger at $\pm 0·016°$/mm.

Since the published wave-lengths for these lines are so untrustworthy, we have ventured to add as a footnote to the table a number of wave-lengths calculated from the rotatory powers. We have, however, only done this in those cases in which the probability of our readings being correct was vouched for by concordant duplicates or by ease of reading. Calculated wave-lengths have thus been recorded for 21 of EXNER'S lines. We have also added calculated wave-lengths for six other lines, which could be identified with lines measured by BURNS only on the assumption that the observed rotations were subject to an error of about 20°. Calculated values have also been given for the two lines for which no identification at all was possible. No importance attaches to the rotations (about 32 out of 85 observations) which depend on a single weak or interpolated reading; but even in these cases the larger deviations are probably due to the difficulty of identifying correctly the simple or composite line on which the observations were made, rather than to mere errors in the observed rotations.

(iv) *Fourth Section.*—2562·541 to 3100·305 A.U.

In this section there are duplicate readings on the films and plates of Series A and B before the quartz was reground, and also a large number of readings of Series C with the reground quartz. A characteristic feature of this section is the occurrence of many small differences, interspersed with a few differences of much larger magnitude. Since these larger differences are often found in the case of lines for which concordant rotations were given by films and plates, or by readings taken before and after regrinding the quartz, we think that they may be due in part to deviations in the mass-centre of the light from the published wave-lengths, *e.g.*, owing to the presence of satellites of shorter or longer wave-length. In this section two lines were completely unidentified, and 10 others were classed with these because the nearest published wave-length gave a deviation $> 0·03°$/mm. The average differences between the observed and calculated rotations for the remaining lines were as follows:—

Series A and B. 140 readings (10 omitted).

$$\text{Casual errors} \qquad \pm \frac{657 + 572}{139} \equiv \pm 0·009°/\text{mm.}$$

$$\text{Systematic error} \quad .. \frac{657 - 572}{139} \equiv + 0·000_6°/\text{mm.}$$

Series C. 51 readings.

$$\text{Casual errors} \quad \pm \frac{224 + 64}{51} \equiv \pm\, 0{\cdot}005^\circ/\text{mm}.$$

$$\text{Systematic error} \quad ..\ \frac{224 - 64}{51} \equiv +\, 0{\cdot}003_1{}^\circ/\text{mm}.$$

(v) *Fifth Section.*—3116·632 to 3485·345 A.U.

In this section only one series of rotations was available, since the extinctions on the films of Series A could no longer be read; but the wave-lengths had been established by three or four independent observers, so that the intensities of the lines as well as their wave-lengths could readily be checked. Large deviations between the observed and calculated rotations could generally be traced to the fact that two or more lines were in such close contiguity that they could not be read separately. The average differences between the observed and calculated rotations in this section (which included three completely unidentified readings) were as follows:—

Series B. 66 lines.

$$\text{Casual errors} \quad \pm \frac{126 + 243}{66} \equiv \pm\, 0{\cdot}006^\circ/\text{mm}.$$

$$\text{Systematic error} \quad ..\ \frac{126 - 243}{66} \equiv -\, 0{\cdot}001_8{}^\circ/\text{mm}.$$

Series C. 18 lines.

$$\text{Casual errors} \quad \pm \frac{25 + 20}{18} \equiv \pm\, 0{\cdot}002_5{}^\circ/\text{mm}.$$

$$\text{Systematic error} \quad ..\ \frac{25 - 20}{18} \equiv +\, 0{\cdot}000_3{}^\circ/\text{mm}.$$

(vi) *Sixth Section.*—3490·577 to 3542·079 A.U.

This section includes the "overlap" between the "quartz" series B_2 and the "glass" series B_4. The differences between these readings, taken under widely contrasted conditions, were as follows:—

$$+\,5,\ \pm,\ -\,1,\ +\,1,\ -\,3^\circ.$$

The average differences between the observed and calculated rotations are as follows:—

Series B and C. 10 readings.

$$\text{Casual errors} \quad \pm \frac{28 + 10}{10} \equiv \pm\, 0{\cdot}004^\circ/\text{mm}.$$

$$\text{Systematic error} \quad ..\ \frac{28 - 10}{10} \equiv +\, 0{\cdot}001_8{}^\circ/\text{mm}.$$

In the case of the analogous series for the reground quartz, the overlap between the two series corresponding C_1 and C_2 occurred at a different wave-length, but the concordance was equally close, thus :—

Wave-length.	Observed rotations.		
	Quartz prisms. (Series C_1.)	Glass prisms. (Series C_2.)	Difference.
3887·053	+119°	+120°	−1°
4045·822	+ 11°	+ 10°	+1°

(vii) *Seventh Section.*—3554·924 to 3814·525 A.U.

This section includes the first lines of the "glass" series, taken prior to regrinding the quartz. On account of the longer exposures, this series extends to shorter wave-lengths than the "glass" series for the reground quartz. The high dispersion of the glass is very favourable for reading the rotations, and the wave-lengths are all determined with an ample margin of accuracy. Although, therefore, no duplicate series of readings were available, the concordance between the observed and calculated rotations was closer than in any other part of the table, the average differences being as follows :—

Series B. 99 readings.

$$\text{Casual errors} \qquad \pm \frac{119 + 81}{99} \equiv \pm\, 0{\cdot}002^\circ/\text{mm.}$$

$$\text{Systematic error} \;.. \qquad \frac{119 - 81}{99} \equiv +\, 0{\cdot}000_4{}^\circ/\text{mm.}$$

The three readings of Series C, made with the help of *quartz* prisms in this range, showed deviations of − 8, − 2, − 1, mean − 0·004°/mm. There were no unidentified readings.

(viii) *Eighth Section.*—3815·844 to 5383·366 A.U.

In this section readings were available for the quartz both before and after regrinding. Since the regrinding only increased the rotations by 0·001°/mm., the concordance of the two series is immediately obvious. On account of the relatively high dispersion, the rotations could be read with more accuracy than in the region in which quartz prisms had to be used. The wave-lengths were also accurately known from the measurements of four different observers ; but the influence on the rotations of small variations of wave-lengths was so insignificant that the values given by BURNS were employed throughout, except in the case of the international standards. Under these favourable conditions, in spite of the crowding of the lines in the region of longer wave-lengths, the observed and calculated rotations agreed nearly as closely as in the preceding section. Three lines in the section were completely unidentified, and three other readings were omitted from the averages because the published wave-length gave deviations $> 0{\cdot}016$. The average differences of the remaining lines were as follows :—

Series B. 256 readings.

$$\text{Casual errors} \qquad \pm \frac{249 + 415}{256} \equiv \pm 0{\cdot}002_6{}^\circ/\text{mm.}$$

$$\text{Systematic error} \qquad \frac{249 - 415}{256} \equiv - 0{\cdot}000_6{}^\circ/\text{mm.}$$

Series C. 105 readings.

$$\text{Casual errors} \qquad \pm \frac{37 + 205}{105} \equiv \pm 0{\cdot}002_3{}^\circ/\text{mm.}$$

$$\text{Systematic error} \qquad \frac{37 - 205}{105} \equiv - 0{\cdot}001_6{}^\circ/\text{mm.}$$

(ix) *Summary.*

The total number of readings, not counting duplicates on films and plates, or with quartz and glass prisms, was 736 before and 231 after the quartz had been reground, making a total of 967 rotations recorded. Six readings of the old series were omitted because the duplicate readings were discordant or the individual readings were out of correct sequence, etc., and 17 readings of the new series were omitted because they referred to groups of lines of which the components gave rotations more than 10° apart. The total number of lines in Table VI is therefore 944.

Of this long list of rotations, only 9 remained completely unidentified, since of the 22 readings which did not correspond with any known iron line, 13 were found to be due to known impurities in the iron arc ; but 15 other readings of the " quartz " series were classed with the " unidentified " lines because the nearest known wave-length gave errors $> 0{\cdot}03^\circ$ or $0{\cdot}04^\circ/\text{mm.}$, and in the same way 3 readings of the " glass " series were omitted from the subsequent calculations because the nearest known line gave errors $> 0{\cdot}016^\circ/\text{mm.}$ In addition, 51 readings of the old series and 5 readings of the new series were of lines for which no modern wave-lengths were available, so that it was impossible to deduce trustworthy values for the calculated rotations. Finally, 37 of the tabulated readings of the old series and 18 of the new series were found to correspond with close doublets, or with a line carrying a satellite, and these gave differences (enclosed in square brackets) which were also omitted from the subsequent calculations, in spite of the fact that the weighted mean of the calculated rotations was usually in excellent agreement with the observed rotation. Table VI therefore includes 804 cases in which the

[*Continued on p.* 457.

TABLE VI.—Rotatory Power of Quartz in the Violet and Ultra-Violet Regions.

K = KAYSER and RUNGE.
E = EXNER and HASCHEK (‘Sitz. Akad. Wiss. Wien,’ vol. 106 (1897)).
S = SCHUMACHER (‘Z. wiss. Photogr.,’ vol. 19, p. 149 (1919)).
F = FABRY and BUISSON (‘C. R.,’ vol. 144, p. 1155; ‘Jour. Phys.’ [iv], vol. 7, p. 169 (1908)).
B = BURNS (‘Z. wiss. Photogr.,’ vol. 12, pp. 207–236 (1913)).
V = VIEFHAUS (‘Z. wiss. Photogr.,’ vol. 13, p. 209 (1914)).
H = HOELTZENBEIN (‘Z. wiss. Photogr.,’ vol. 16, p. 225 (1917)).

(i) *First Section.* 2327·49 to 2368·60 A.U.

Wave-length.	Series C_1. Series A_1.	B_1.	B_2.	Total rotation.	Observed rotation per millimetre.	Correction* for regrinding.	Calculated rotations per millimetre.	Diff. O–C.
	°	°	°	°	°	°	°	
2327·49 (6) E	**516π + 83**			**=92963**	**187·247**	Correct	*187·247*	±
2327·49 (6) E	470π + 162	163	163	=84763	187·225	+0·030	*187·216*	+ *9*
2327·37 (6) S						+0·030	*or 187·248*	*–23*
2331·41 (7) E	**514π + 14**			**=92534**	**186·383**	Correct	*186·382*	+ *1*
2331·41 (7) E	468π + 124	126	126	=84366	186·3485	+0·029	*186·352*	– *3*
2331·29 (7) S						+0·029	*or 186·367*	*–19*
2332·88 (8) E	**513π + 35**			**=92375**	**186·062**	Correct	*186·059*	+ *3*
2332·88 (8) E	467π + 164	163	167	=84225	186·037	+0·029	*186·029*	+ *8*
2332·74 (6) S						+0·029	*or 186·049*	*–12*
2338·09 (8) E	464π + *10*	10	*9*	=83710	184·889	+0·029	*184·893*	– *4*
2337·99 (6) S						+0·029	*or 186·915*	*–26*
2343·58 (9) E	462π + *8*	9	10	=83169	183·705	+0·029	*183·708*	– *3*
2343·50 (7) S						+0·029	*or 183·725*	*–20*
2344·05 (3) E	461π + *145*	144	142	=83124	183·605	+0·029	*183·606*	– *1*
2343·97 (3) S						+0·029	*or 183·623*	*–18*
2344·40 (5) E	461π + *118*	112		=83092	183·534	+0·029	*183·531*	+ *3*
2344·31 (4) S						+0·029	*or 183·550*	*–16*
2348·23 (7) E	458π + *92*	97	97	=82717	182·705	+0·029	*182·714*	– *9*
2348·14 (5) S *2348·32 (5) S*						+0·029	*182·714*	– *9*
2348·40 (7) E	**503π + 179**			**=90709**	**182·726**	Correct	*182·708*	*+18*
2355·00 (5) E	454π + 176	180	*187*	=82080	181·301	+0·028	*181·283*	*+18*
2354·89 (6) S						+0·028	*or 181·306*	– *5*
2359·23 (7) E	**497π + 117**			**=89577**	**180·426**	Correct	*180·425*	+ *1*
2359·23 (7) E	453π + 136	139	139	=81678	180·411	+0·028	*180·396*	*+15*
2359·12 (6) S						+0·028	*180·419*	– *8*
2360·08 (5) E	453π + 50	51	52	=81591	180·219	+0·027	*180·219*	±
2359·97 (4) S						+0·027	*or 180·242*	*–23*
2360·42 (5) E	453π + 20	27	*27*	=81566	180·163	+0·027	*180·143*	*+20*
2360·31 (5) S						+0·027	*or 180·166*	– *3*
2362·23 (4) E	452π + *40*	*45*	*43*	=81403	179·804	+0·027	*179·773*	*+31*
2362·06 (8) S						+0·027	*or 179·808*	– *4*
2364·90 (7) E	450π + 142	142	142	=81142	179·228	+0·027	*179·220*	+ *8*
2364·82 (8) S						+0·027	*or 179·236*	– *8*
2368·69 (8) E	448π + 152	151	153	=80792	178·454	+0·027	*178·440*	*+14*
2368·60 (7) S						+0·027	*or 178·458*	– *4*

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* This correction applies both to the observed and to the calculated rotation.

Table VI (continued).

(ii) *Second Section.* 2373·737 to 2413·310 A.U.

Wave-length.	Series C₁ Series A₁.	B₁.	B₂.	Total rota-tion.	Observed rotation per milli-metre.	Correction* for regrinding.	Calcu-lated rotations per milli-metre.	Diff. O–C.
	°	°	°	°	°	°	°	
2373·737 (6) F	446π + 32	37	39	=80318	177·407	+0·027	177·411	− 4
2375·193 (4) B	**488π + 107**			=**87947**	**177·143**	—	**177·143**	±
2375·193 (4) B	445π + 80	*82*	82	=80182	177·107	+0·027	177·116	− 9
2379·276 (4) B	443π + 66	*74*	65	=79806	176·276	+0·026	176·292	−16
2380·763 (4) B	442π + 112	117	115	=79675	175·987	+0·026	175·994	− 7
2382·039 (8) B	**484π + 139**			=**87259**	**175·759**	—	**175·766**	− **7**
2382·039 (8) B	442π + 8	2	3	=79563	175·740	+0·026	175·738	+ 2
2383·253 (4) B	**484π + 24**			=**47144**	**175·526**	—	**175·523**	+ **3**
2383·253 (4) B	441π + 70	*70*		=79450	175·490	+0·026	175·496	− 6
2384·39 (2) B	440π + 148	*147*	*144*	=79347	175·263	+0·026	175·269	− 6
2388·631 (6) B	438π + 128	126	129	=78968	174·425	+0·026	174·428	− 3
2395·628 (8) B	**477π + 70**			=**85930**	**173·099**	—	**173·081**	+**18**
2395·628 (8) B	435π + 52	46	49	=78349	173·059	+0·025	173·054	+ 5
2399·244 (6) B	433π + 86	90	90	=78030	172·353	+0·025	172·351	+ 2
2404·435 (4) B	430π + 172	*174*	168	=77571	171·340	+0·025	171·350	−10
2404·888 (6) B	430π + 134	136	137	=77536	171·262	+0·025	171·263	− 1
2406·663 (6) B	**471π + 90**			=**84870**	**170·946**	—	**170·949**	− **3**
2406·663 (6) B	429π + 164	164	167	=77384	170·927	+0·024	170·923	+ 4
2410·526 (6) B	428π + 2	3	4	=77043	170·173	+0·024	170·187	−14
2411·071 (6) B	427π + 145	148	146	=77006	170·092	+0·024	170·083	+ 9
2413·310 (6) F	**468π + 1**			=**84241**	**169·678**	—	**169·684**	− **6**
2413·310 (6) F	426π + 130	*132*	131	=76810	169·659	+0·024	169·657	+ 2

* This correction applies both to the observed and to the calculated rotation.

(iii) *Third Section.* 2417·91 to 2563·541 A.U.

†*2417·91 (5) E*	423π + 106	102	103	=76424	168·806	+0·024	*168·794*	+*12*
†*2424·18 (7) E*	420π + 114	116	113	=76894	167·636	+0·023	*167·625*	+*11*
†*2430·18 (7) E*	417π + 156	157	*160*	=75396	166·535	+0·023	*166·518*	+*17*
†*2432·30 (6) E*	416π + 156	*159*	*161*	=75216	166·138	+0·023	*166·127*	+*11*
†*2439·35 (6) E*	414π + *108*	*120*	*120*	=74640	164·866	+0·023	*164·850*	+*16*
2439·746 (4) B	414π + *68*		73	=74593	164·762	+0·023	164·779	−17
2440·48 (4) E	414π	*8*		=74528	164·618	+0·023	*164·647*	−*29*
2442·574 (4) B	**453π** + *24*			=**81564**	**164·286**	—	**164·294**	− **8**
2442·574 (4) B	413π + *24*		*29*	=74367	164·262	+0·022	164·270	− 8
†*2444·57 (6) E*	412π + 54		56	=74215	163·927	+0·022	*163·910*	+*17*
†*2445·67 (4) E*	411π + *150*		*148*	=74129	163·737	+0·022	*163·710*	+*27*
2447·717 (4) B	410π + *150*		*152*	=73951	163·344	+0·022	163·351	− 7
2457·602 (6) B	**445π** + *145*			=**80245**	**161·630**	—	**161·631**	− **1**
2457·602 (6) B	406π + *92*			=73172	161·623	+0·022	161·608	+15
†*2458·80 (6) E*	405π + 174		*177*	=73076	161·411	+0·022	*161·400*	+*11*
2461·36 (5) E	404π + 152		*154*	=72872	160·960	+0·022	*160·954*	+ *6*
†*2461·90 (5) E*	404π +		115	=72835	160·879	+0·022	*160·860*	+*19*
2462·191 (6) B	404π + *94*			=72814	160·834	+0·022	160·809	+25
2465·155 (5) B	403π + *16*		*25*	=72563	160·277	+0·022	160·296	−19

† See Note † on p. 436.

Table VI (continued).

(iii) *Third Section* (continued).

Wave-length.	Series C_1 Series A_1.	B_1.	B_2.	Total rotation.	Observed rotation per millimetre.	Correction* for regrinding.	Calculated rotations per millimetre.	Diff. O–C.
	°	°	°	°	°	°	°	
2466·73 (4) E	402π + 88		*91*	=72450	160·028	+0·021	*160·025*	+ *3*
2466·87 (4) E						+0.021	*160·001*	[+*27*]
2468·885 (5) B	401π +		*104*	=72284	159·662	+0·021	159·655	+ 7
†*2470·73 (4) E*	400π + 148		146	=72147	159·359	+0·021	*159·337*	+*22*
2472·351 (5) B	400π + 6		*10*	=72008	159·052	+0·021	159·062	—10
2474·818 (5) B	**437π** + *111*			**=78771**	**158·660**	—	**158·664**	— **4**
2474·818 (5) B	399π + *10*		*16*	=71834	158·667	+0·021	158·642	+25
[*2476·43 calc.*]	398π + *62*		*61*	=71701	158·370	+0·021	—	[+41]
2476·67 (2) B						+0·021	158·329	
2479·782 (4) B	396π + *156*		162	=71442	157·802	+0·021	157·804	— 2
2483·83 (2) E	395π + *30*			=71130	157·113	+0·021	*157·124*	—*11*
2484·188 (6) B	395π + *6*		5	=71105	157·078	+0·021	157·065	+13
[*2485·82 calc.*]	394π + *94*			=71014	156·856	+0·021	—	—
2487·069 (4) B	393π + *146*		*154*	=70890	156·582	+0·021	156·585	—3
2488·148 (4) B						+0·021	156·405	—
2490·659 (4) B	392π + *50*			=70610	155·964	+0·021	155·990	—26
2490·91 (3) E							*155·948*	[+*16*]
2491·162 (4) B	392π + *10*		*18*	=70574	155·885	+0·021	155·907	—22
2491·47 (4) E							*155·856*	[+*29*]
2493·31 (8) E	391π + 52		55	=70434	155·576	+0·020	*155·554*	+*22*
2495·91 (3) E	390π + *6*		*22*	=70214	155·125	+0·020	*155·130*	— *5*
2496·539 (5) B	389π + *166*		*169*	=70188	155·032	+0·020	155·023	+ 9
2497·88 (5) E	389π +		*76*	=70096	154·829	+0·020	*154·803*	+*26*
†*2498·95 (7) E*	388π + 176		178	=70017	154·654	+0·020	*154·631*	+*23*
†*2501·00 (3) E*	388π + *22*		*19*	=69860	154·308	+0·020	*154·296*	+*12*
2501·135 (3) B	388π + *6*		*8*	=69847	154·279	+0·019	154·275	+ 4
†*2502·49 (4) E*	387π + *90*		97	=69757	154·080	+0·019	*154·054*	+*26*
2505·30 (2) E	386π		*56*	=69536	153·592	+0·019	*153·602*	—*10*
2507·904 (4) B	395π + *30*		*40*	=69337	153·152	+0·019	153·182	—30
2510·837 (6) B	384π + *8*			=69128	153·691	+0·019	152·713	—22
[*2511·58 calc.*]	383π + 138		137	=69077	152·578	+0·019	—	[+*43*]
2511·85 (7) E						+0·019	*152·535*	
2512·366 (4) B	**420π** + *113*			**=73713**	**152·499**	—	**152·490**	+ **9**
†*2514·49 (6) E*	382π + 122		123	=68883	152·149	+0·019	*152·131*	+*18*
2516·19 (2) E	4		*9*	=68765	151·889	+0·019	*151·863*	+*26*
2516·68 (1) E	381π		*120*	=68700	151·745	+0·019	*151·740*	+ *5*
2518·107 (6) B						+0·019	151·588	[—56]
[*2518·48 calc.*]	381π + *10*			=68590	151·502	+0·019	—	
2521·22 (5) E	380π + *6*			=68406	161·096	+0·019	*151·069*	+*27*
[*2523·33 calc.*]	379π + *24*			=68244	150·738	+0·019	—	[+52]
2523·661 (4) B						+0·019	150·686	
2525·03 (2) B						+0·019	150·472	[—41]
[*2525·30 calc.*]	378π +		*75*	=68105	150·431	+0·019	—	
2525·50 (7) E	378π + *52*		*60*	=68096	150·411	+0·019	*150·401*	+*10*
†*2526·40 (6) E*	378π + 2		*5*	=68042	150·292	+0·019	*150·259*	+*33*
2527·44 (4) B	**414π** + *15*			**=74535**	**150·126**	—	**150·116**	**+10**
2527·44 (4) B	377π + *102*			=67962	150·115	+0·019	150·098	+17
2529·137 (6) B	376π + 150			=67830	149·824	+0·019	149·834	—10

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* This correction applies both to the observed and to the calculated rotation.

† See Note † on p. 436.

Table VI (continued).

(iii) *Third Section* (continued).

Wave-length.	Series C_1 Series A_1.	B_1.	B_2.	Total rotation.	Observed rotation per millimetre.	Correction* for regrinding.	Calculated rotations per millimetre.	Diff. O–C.
	°	°	°	°	°	°	°	
2530·70 (2) B	**414π** + *121*			**=74641**	**149·616**	—	**149·611**	**+ 5**
2530·70 (2) B	376π + *44*			=67724	149·590	+0·018	149·592	− 2
[2533·64 calc.]								
2533·71 (7) E	375π + 18		24	=67521	149·141	+0·018	*149·129*	+*12*
2533·80 (2) B							*or* 149·115	+26
†*2534·50 (6) E*	374π + 152		154	=67473	149·035	+0·018	*149·008*	+*27*
2535·610 (6) B	374π + *80*		64	=67384	148·838	+0·018	148·837	+ 1
2536·84 (3) E	373π + 168		*172*	=67308	148·671	+0·018	*148·682*	[−*11*]
†*2536·95 (5) E*							*148·666*	[+ *5*]
2537·180 (6) B	373π + *146*			=67286	148·622	+0·018	148·596	+26
†*2538·95 (5) E*	373π + 14		18	=67154	148·330	+0·018	*148·326*	+ *4*
†2540·976 (6) B	372π + 62		60	=67021	148·037	+0·018	148·018	+19
[2541·83 calc.]								
2541·91 (5) E	371π + 176		172	=66954	147·889	+0·018	*147·875*	+*14*
2542·105 (5) B							*or* 147·847	[+42]
†*2543·49 (5) E*	371π + 64		*70*	=66844	147·646	+0·018	*147·637*	+ *9*
2543·927 (5) B	371π + 26			=66806	147·562	+0·018	147·570	− 8
2544·716 (4) B	370π + *152*			=66752	147·443	+0·018	147·451	− 8
2545·979 (3) B						+0·018	147·257	—
[2546·61 calc.]	370π + *26*			=66626	147·164	+0·018	—	—
2546·86 (2) B	370π + *16*			=66616	147·142	+0·018	147·127	+15
2548·17 (3) K	369π + *104*			=66524	146·939	+0·018	*146·932*	+ *7*
2548·42 (3) E						+0·018	*or 146·894*	
2549·20 (3) E	369π + *42*			=66462	146·802	+0·018	*146·777*	+*25*
2549·616 (6) B	369π + *12*			=66432	146·736	+0·018	146·714	+22
2550·20 (5) E	368π + *154*			=66394	146·652	+0·017	*146·627*	+*25*
2550·87 (5) E	368π + *108*			=66348	146·550	+0·017	*146·527*	+*23*
2551·32 (4) E	368π + *68*			=66308	146·462	+0·017	*146·460*	+ *2*

* This correction applies both to the observed and to the calculated rotation.

† The calculated wave-lengths are as follows :—

2417·85 2424·12 2430·09 2432·24 2439·26 2444·47 2445·51 2458·74
2461·79 2470·60 [2476·43] 2485·82 ? 2493·17 2498·81 2500·93 2502·33
[2511·58] 2514·38 [2518·48] [2523·33] [2525·30] 2526·20 [2533·64] 2534·32
2536·92 2538·92 2540·85 [2541·83] 2543·43 2546·61 ?

(i) The two numbers marked with a query do not appear to correspond with any recorded line. (ii) The numbers enclosed in brackets may perhaps be identified with lines measured by BURNS, but give deviations > 0·025°/mm. (iii) The remaining numbers have been identified with lines measured by EXNER, but show deviations up to ±0·03°/mm.; these can be attributed in part to errors in the wave-lengths recorded prior to the introduction of interferometer methods of measurement.

Table VI (continued).

(iv) *Fourth Section.* 2562·541 to 3100·305 A.U.

Wave-length.	Series C_1 Series A_1.	B_2.	Total rota-tion.	Observed rotation per milli-metre.	Correction† for regrinding.	Calcu-lated rotations per milli-metre.	Diff. O–C.
	°	°	°	°	°	°	
2562·541 (5) F	364π + *40*	44	=65563	146·816	+0·017	144·798	+18
[*2563·11 calc.*]	363π + 174	178	=65517	144·715	+0·017	—	[+55]
2563·485 (5) B					+0·017	144·660	
2566·921 (4) B	**397π + 121**		**=71581**	**144·179**	—	**144·176**	**+ 3**
2566·921 (4) B	362π + *112*	110	=65270	144·169	+0·017	144·158	+11
2570·536 (3) B	361π + *34*	43	=65021	143·619	+0·017	143·623	− 4
2570·860 (3) B					+0·017	143·586	
2574·374 (3) B	**394π + 121**		**=71041**	**143·091**	—	**143·097**	**− 6**
2574·374 (3) B	359π + 162	165	=64784	143·096	+0·017	143·079	+17
2575·755 (4) B	359π + 64	59	=64681	142·868	+0·017	142·880	−12
2576·699 (4) B	359π + *0*	*10*	=64625	142·745	+0·017	142·745	±
2576·869 (4) B					+0·017	142·720	—
2577·930 (4) B	**393π + 55**		**=70795**	**142·595**	—	**142·586**	**+ 9**
2577·930 (4) B	358π + 112	115	=64554	142·588	+0·017	142·568	+20
2582·590 (4) B	356π + 174	172	=64253	141·923	+0·016	141·904	+19
2584·544 (4) B					+0·016	141·627	[−49]
[*2584·89 calc.*]	356π + *10*	19	=64097	141·578	+0·016	—	
2585·886 (7) B	**390π + 32**		**=70232**	**141·461**	—	**141·455**	**+ 6**
2585·886 (7) B	355π + 138	141	=64040	141·452	+0·016	141·437	+15
2587·958 (3) B	**389π + 61**		**=70081**	**141·158**	—	**141·162**	[− **4**]
2588·016 (5) F						**141·154**	[+ **4**]
2587·958 (5) F	305π + 6	*180*	=63903	141·150	+0·016	141·145	[+ 5]
2588·016 (5) F						141·136	[+14]
2591·264 (2) B						140·680	[−27]
2591·554 (4) B	353π + 136	139	=63678	140·653	+0·016	140·639	+14
2591·554 (4) B	**387π + 176**		**=69836**	**140·663**	—	**140·657**	**+ 6**
[*2593·30 calc.*]	352π + *30*	20	=63562	140·396	+0·016	—	[+32]
2593·525 (2) B						140·364	
Mn2593·732 (6) B	352π + 6	1	=63541	140·350	+0·016	140·338	+12
2598·380 (7) B	352π + *66*	66	=63246	139·695	+0·016	139·689	+ 6
*[*2599·25 calc.*]	351π + 6	7	=63187	139·568	+0·016		
2599·405 (6) B	**384π + 171**		**=69291**	**139·567**	—	**139·564**	**+ 3**
2599·405 (6) B	351π +	178	=63179	139·548	+0·016	139·547	+ 1
2599·577 (3) B						139·523	
2606·839 (5) B	348π + 68	64	=62705	138·504	+0·016	138·526	[−22]
2607·099 (7) B						138·489	[+15]
2611·885 (8) B	**380π + 44**		**=68444**	**137·859**	—	**137·855**	**+ 4**
2611·885 (8) B	346π + 126	*130*	=62408	137·847	+0·016	137·837	+10
2613·835 (8) B	**379π + 94**		**=68314**	**137·598**	—	**137·590**	**+ 8**
2613·835 (8) B	346π + 10	9	=62289	137·584	+0·015	137·573	+11
2617·627 (6) B	344π + 134	138	=62057	137·072	+0·015	137·062	+10
2621·677 (6) B	**378π + 111**		**=68151**	**136·524**	—	**136·534**	**−10**
2621·677 (6) B	343π + 68	*70*	=61809	136·525	+0·015	136·518	+ 7

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* There is a satellite at 2599·577 (3) B = 139·523 on the other side of 2599·405 ; if this was a member of the doublet actually read, the differences would be +21 and +25.

† This correction applies to the observed and to the calculated rotation.

Table VI (continued).

(iv) *Fourth Section* (continued).

Wave-length.	Series C_1 Series A_1.	B_2.	Total rotation.	Observed rotation per millimetre.	Correction for regrinding.	Calculated rotations per millimetre.	Diff. O–C.
	°	°	°	°	°	°	
2623·378 (2) B 2623·544 (4) B	**375π + 167**		**=67667**	**136·293**	—	**136·310** **136·286**	[**−17**] [+ **7**]
2623·378 (4) B 2623·544 (4) B	342π + *140*		=61700	136·284	+0·015	136·292 136·269	[− 8] [+15]
2625·499 (4) B 2625·676 (8) B	**375π + 27**		**=67527**	**136·013**	—	**136·026** **136·003**	[**−13**] [**+10**]
2625·499 (8) B 2625·676 (8) B	342π + *12*	15	=61574	136·005	+0·015	136·010 135·987	[− 5] [+18]
2628·296 (6) F	**374π + 32**		**=67352**	**135·661**	—	**135·665**	**− 4**
2628·296 (6) F	341π + 32	36	=61415	135·654	+0·015	135·650	+ 4
2631·053 (6) B	340π + *40*	40	=61240	135·268	+0·015	135·276	− 8
2635·818 (4) B	338π + 122	*115*	=60958	134·646	+0·015	134·651	− 5
2641·654 (3) B	**369π + 60**		**=66480**	**133·904**	—	**133·907**	**− 3**
2641·654 (3) B	336π + *124*		=60604	133·863	+0·014	133·892	−29
2644·008 (4) B	**368π + 94**		**=66334**	**133·616**	—	**133·606**	**+10**
2644·008 (4) B	335π + *6*		=60486	133·602	+0·014	133·588	+14
2647·568 (3) B	334π + *154*		=60274	133·132	+0·014	133·130	+ 2
2656·154 (3) B	332π + *10*		=59770	132·021	+0·014	133·035	−14
2664·670 (3) B	329π + 72	75	=59294	130·969	+0·014	130·963	+ 6
2666·405 (3) B 2666·644 (3) B 2666·818 (4) B	328π + 148	143	=59185	130·729	+0·014	130·733 130·716 130·695	[− 4] [+13] [+34]
2679·065 (6) F	**356π + 64**		**=64144**	**129·199**	—	**129·187**	**+12**
2679·065 (6) F	324π + 170	174	=58493	129·200	+0·013	129·173	+27
2684·759 (3) B	323π + *34*	37	=58176	128·500	+0·013	128·492	+ 8
2689·220 (5) B	321π + 144	135	=57918	127·930	+0·013	127·949	−19
2692·612 (3) B	**351π + 148**		**=63328**	**127·555**	—	**127·556**	**− 1**
2692·612 (3) B	320π + 146	144	=57745	127·548	+0·013	127·542	+ 6
2695·669 (2) B 2695·998 (4) B 2696·290 (5) B	319π + *152*		=57572	127·166	+0·013	127·176 127·137 127·102	[+10] [−29] —
2699·114 (4) B	**349π + 127**		**=62947**	**126·787**	—	**126·779**	**+ 8**
2699·114 (4) B	318π + 148	*158*	=57393	126·770	+0·013	126·766	+ 4
2703·995 (3) B	317π + *72*	75	=57134	126·198	+0·013	126·188	+10
2706·020 (3) B	317π + *126*	*130*	=57009	125·922	+0·013	125·950	−28
2706·590 (5) B	317π + *114*	110	=56991	125·882	+0·013	125·883	− 1
2708·580 (4) B	316π + *8*	1	=56882	125·633	+0·013	125·650	−17
2711·662 (5) B	**345π + 116**		**=62216**	**125·316**	—	**125·303**	**+13**
2711·662 (5) B	315π + 22	19	=56721	125·286	+0·013	125·290	− 4
2714·419 (6) F	**344π + 134**		**=62054**	**124·989**	—	**124·982**	**+ 7**
2714·419 (6) F	314π + 62	62	=56582	124·979	+0·012	124·969	+10
2719·037 (7) B	313π +	*2*	=56342	124·449	+0·012	124·435	+14
2720·910 (7) B	**342π + 121**		**=61681**	**124·238**	—	**124·232**	**+ 6**
2720·910 (7) B	312π + *84*	*91*	=56249	124·243	+0·012	124·219	+24
2723·582 (6) B [*2723·97 calc.*]	311π + 96	*100*	=56079	123·868	+0·012 +0·012	123·912 —	[−44]

Table VI (continued).

(iv) *Fourth Section* (continued).

Wave-length.	Series C_1 Series A_1.	B_2.	Total rotation.	Observed rotation per millimetre.	Correction for regrinding.	Calculated rotations per millimetre.	Diff. O–C.
	°	°	°	°	°	°	
2724·892 (3) B	$311\pi + 54$	56	=56035	123·771	+0·012	123·764	[+ 7]
2724·958 (4) B						123·756	[+15]
2726·064 (4) B	**$340\pi + 2$**		**=61202**	**123·636**	—	**123·639**	**— 3**
2727·389 (3) B	$310\pi + 96$	100	=55899	123·470	+0·012	123·477	[— 7]
2727·542 (5) B						123·460	[+10]
2730·740 (4) B	**$339\pi + 98$**		**=61118**	**123·104**	—	**123·110**	**— 6**
2730·740 (4) B	$309\pi + 114$	115	=55735	123·108	+0·012	123·097	+11
2733·580 (9) B	$308\pi + 142$		—55582	122·770	+0·012	122·775	— 5
2735·480 (8) B	$308\pi + 44$		=55484	122·554	+0·012	122·561	— 7
2736·970 (4) B	$307\pi + 154$	152	=55413	122·397	+0·012	122·394	+ 3
2737·312 (6) B	**$337\pi + 92$**		**=60752**	**122·361**	—	**122·368**	**— 7**
2739·550 (9) F	**$336\pi + 151$**		**=60631**	**122·123**	—	**122·117**	**+ 6**
2739·550 (9) F	$307\pi + 26$	25	=55285	122·115	+0·012	122·104	+11
2742·408 (6) B					+0·012	121·785	[—35]
[2742·09 calc.]	$306\pi +$ *40*	*40*	=55120	121·750	+0·012	—	
2743·199 (6) B	**$335\pi + 132$**		**=60432**	**121·721**	—	**121·709**	**+12**
2743·199 (6) B	$306\pi + 18$	21	=55100	121·706	+0·011	121·697	+ 9
2746·486 (7) B	$305\pi +$ *30*	32	=54932	121·334	+0·011	121·332	+ 2
2749·324 (7) B	**$333\pi + 153$**		**=60093**	**121·039**	—	**121·031**	**+ 8**
2749·324 (7) B	$304\pi + 74$	76	=54795	121·032	+0·011	121·019	+13
[*2749·75 calc.*]	$304\pi +$ *48*		=54768	120·972	+0·011	—	[+44]
2750·145 (6) B					+0·011	120·928	
2753·290 (4) B	$303\pi + 56$	57	=54597	120·595	+0·012	120·582	+13
2755·736 (8) B	$302\pi + 114$	114	=54474	120·323	+0·012	120·315	+ 8
2757·316 (4) B	$302\pi +$ *22*		=54382	120·120	+0·012	120·142	—22
2759·816 (4) B	**$330\pi + 120$**		**=59520**	**119·885**	—	**119·882**	**+ 3**
2759·816 (4) B	$301\pi + 88$	*93*	=54270	119·873	—	119·870	+ 3
2761·788 (5) B	$300\pi + 174$	174	=54174	119·650	+0·010	119·653	— 3
2761·809 (4) B							
2764·327 (4) B	$300\pi +$ *44*		=54044	119·373	+0·010	119·381	— 8
2767·518 (7) B	$299\pi +$ *70*	80	=53898	119·051	+0·010	119·037	+14
2768·938 (2) B	$298\pi + 166$	*176*	=53811	118·885	+0·010	118·885	±
2772·112 (6) B	**$326\pi + 3$**		**=58683**	**118·561**	—	**118·556**	**+ 5**
2772·112 (6) B	$298\pi + 28$	18	=53661	118·527	+0·010	118·545	—18
2774·733 (4) B	$297\pi + 88$	90	=53549	118·280	+0·010	118·266	+14
2778·226 (6) F	$296\pi + 94$	90	=53371	117·886	+0·010	117·884	+ 2
2779·304 (3) B	$296\pi +$	48	=53328	117·791	+0·010	117·781	+10
2781·840 (4) B	$296\pi + 104$	*106*	=53205	117·520	+0·010	117·514	+ 6
2783·696 (3) B	$295\pi + 14$	18	=53117	117·325	+0·010	117·318	+ 7
2788·108 (6) B	**$322\pi + 65$**		**=58025**	**116·874**	—	**116·867**	**+ 7**
2788·108 (6) B	$293\pi + 168$	169	=52909	116·866	+0·010	116·856	+10
Mn 2794·819 (5) B	**$320\pi + 65$**		**=57665**	**116·149**	—	**116·170**	**[—21]**
Fe 2795·008 (2) B						**116·151**	[**— 2**]
Mn 2794·819 (5) B	$292\pi +$ *24*		=52584	116·148	+0·010	116·158	[—10]
Fe 2795·008 (2) B						116·140	[+ 8]
Mg 2795·542 (4) B	$291\pi +$ *176*		=52556	116·086	+0·010	116·084	+ 2
2797·777 (4) B	$291\pi +$ *64*		=52444	115·839	+0·010	115·854	—15
Mn 2798·268 (5) B	$291\pi +$ *54*		=52434	115·817	+0·010	115·804	+13

Table VI (continued).

(iv) *Fourth Section* (continued).

Wave-length.	Series C_1 Series A_1.	B_2.	Total rotation.	Observed rotation per millimetre.	Correction for regrinding.	Calculated rotations per millimetre.	Diff. O–C.
	°	°	°	°	°	°	
Mn 2801·082 (5) B	290π + *100*	*103*	=52302	115·525	+0·010	115·515	+10
2804·523 (7) B	**317π + 123**		**=57182**	**115·178**	—	**115·174**	**+ 4**
2804·523 (7) B	289π + 116	118	=52137	115·156	+0·010	115·163	− 7
2806·985 (7) B	**316π + 177**		**=57057**	**114·926**	—	**114·923**	**+ 3**
2806·985 (7) B	289π + 6	7	=52027	114·918	+0·010	114·912	+ 6
2813·290 (9) F	**315π + 40**		**=56740**	**114·286**	—	**114·283**	**+ 3**
2813·290 (9) F	287π + 72	79	=51737	114·277	+0·010	114·274	+ 3
2823·276 (7) B	**312π + 85**		**=56245**	**113·289**	—	**113·275**	**+14**
2823·276 (7) B	284π + *162*	166	=51285	113·274	+0·009	113·265	+ 9
2825·556 (6) B	**311π + 153**		**=56133**	**113·063**	—	**113·058**	**+ 5**
2825·556 (6) B	284π + *66*	62	=51183	113·054	+0·009	113·048	+ 6
2828·808 (4) B	**310π + 0**		**=55800**	**112·755**	—	**112·737**	**+18**
2828·808 (4) B	283π + 96	103	=51041	112·740	+0·009	112·727	+13
2831·559 (3) B	282π +	150	=50910	112·451	+0·009	111·456	− 5
2832·433 (6) B	287π +	103	=50863	112·347	+0·009	112·371	+24
2835·710 (3) B	281π + *154*	151	=50732	112·057	+0·009	112·050	+ 7
2838·118 (6) B	**308π + 80**		**=55520**	**111·829**	—	**111·825**	**+ 4**
2838·118 (6) B	281π + *40*	*43*	=50622	111·814	+0·009	111·815	− 1
2840·422 (4) B	**370π + 142**		**=55402**	**111·591**	—	**111·601**	**[−10]**
2840·648 (2) B						**111·578**	**[+13]**
2840·422 (2) B	280π + *116*	*115*	=50515	111·578	+0·009	111·591	[−13]
2840·648 (2) B						111·569	[+ 9]
2843·629 (5) B	**306π + 165**		**=55245**	**111·273**	—	**111·289**	**[−16]**
2843·974 (7) B						**111·257**	**[+16]**
2843·629 (7) B	279π + *152*	157	=50376	111·271	+0·009	111·280	[− 9]
2843·974 (7) B						111·247	[+24]
2845·596 (4) B	279π + *76*	78	=50298	111·099	+0·009	111·090	+ 9
2848·714 (4) B	278π + 116		=50156	110·785	+0·009	110·792	− 7
2851·800 (8) F	**304π + 146**		**=54866**	**110·511**	—	**110·504**	**+ 7**
2851·800 (8) F	277π + 166	168	=50027	110·500	+0·009	110·495	+ 5
2858·341 (3) B	276π + *66*	63	=49744	109·875	+0·009	110·877	− 2
2863·434 (4) B	275π + 12	*19*	=49515	109·371	+0·009	109·392	[−21]
2863·866 (5) B						109·352	[+19]
2866·629 (4) B	274π + *66*	65	=49385	109·082	+0·009	109·092	−10
2869·313 (6) B	273π + *130*	*143*	=49279	108·848	+0·009	108·841	+ 7
2872·338 (4) B	**299π + 83**		**=53903**	**108·572**	—	**108·569**	**+ 3**
2872·338 (4) B	272π + *170*	179	=49137	108·534	+0·009	108·560	−26
2873·403 (2) B	272π +	153	=49113	108·481	+0·009	108·461	+20
2874·176 (7) F						108·389	
2875·308 (3) B	272π +	63	=49023	108·283	+0·009	108·284	− 1
2877·303 (5) B	271π + 162	*162*	=48942	108·104	+0·009	108·100	+ 4
2880·757 (3) B	271π + *4*	10	=48789	107·766	+0·009	107·782	−16
[*2881·521 calc.*]	270π + 166	165	=48765	107·713	+0·009	—	—
2887·808 (4) B	**295π + 94**		**=53194**	**107·143**	—	**107·146**	**− 3**
2887·808 (4) B	269π + *86*	84	=48504	107·134	+0·009	107·137	− 3
2894·506 (4) B	267π + 172	*169*	=48230	106·532	+0·009	106·530	+ 2
2895·036 (4) B	267π +	*153*	=48213	106·493	+0·009	106·482	+11

Table VI (continued).

(iv) *Fourth Section* (continued).

Wave-length.	Series C_1 Series A_1.	B_2.	Total rota-tion.	Observed rotation per milli-metre.	Correction for regrinding.	Calcu-lated rotations per milli-metre.	Diff. O–C.
	°	°	°	°	°	°	
2899·418 (4) B	**292π + 117**		**=52677**	**106·103**	—	**106·098**	**+ 5**
2899·418 (4) B	266π + 150	152	=48031	106·091	+0·009	106·089	+ 2
2901·382 (4) B	266π + 64	62	=47943	105·897	+0·009	105·912	−15
2901·919 (4) B	266π + *44*	45	=47925	105·857	+0·009	105·865	− 8
2907·518 (3) B	264π + *176*	177	=47697	105·354	+0·009	105·367	+13
2912·157 (8) F	**289π + 93**		**=52113**	**104·967**	—	**104·967**	±
2912·157 (8) F	263π + *174*	179	=47518	104·955	+0·008	104·957	− 2
2918·027 (5) B	262π + 122	124	=47283	104·439	+0·008	104·441	− 2
2920·693 (4) B	262π + *16*	*25*	=47183	104·216	+0·008	104·209	+ 7
2923·289 (4) B	261π + *94*	88	=47069	103·966	+0·008	103·983	[−17]
2923·441 (2) B						103·970	[− 4]
2923·852 (4) B						103·934	[+32]
2926·584 (5) B	260π + 148	150	=46949	103·701	+0·008	103·698	+ 3
2929·006 (7) B	**285π + 83**		**=51383**	**103·496**	—	**103·496**	±
2929·006 (7) B	260π + 54	53	=46853	103·489	+0·008	103·488	+ 1
2936·903 (7) B	253π + 112	*103*	=46547	102·814	+0·008	102·811	+ 3
2941·347 (8) F	257π + 116	115	=46375	102·434	+0·008	102·434	±
2944·400 (4) B	256π + *180*	179	=46259	102·177	+0·008	102·175	+ 2
2947·876 (5) B	256π + 52	55	=46134	101·901	+0·008	101·882	+19
2950·250 (6) B	255π + 126		=46026	101·663	+0·008	101·683	−20
2953·943 (5) B	**279π + 114**		**=50334**	**101·382**	—	**101·382**	±
2953·943 (5) B	254π + 170	178	=45895	101·373	+0·008	101·374	− 1
2957·370 (5) B	**278π + 155**		**=50195**	**101·103**	—	**101·097**	**+ 6**
2957·370 (5) B	254π + *48*	46	=45766	101·089	+0·008	101·089	±
2959·996 (4) B	253π + 124	127	=45666	100·868	+0·008	100·871	− 3
2964·632 (2) B	252π + 124	128	=45487	100·472	+0·008	100·489	[−17]
2965·040 (3) B						100·455	[+17]
2965·258 (5) B						100·437	[+35]
2966·902 (6) B	**276π + 122**		**=49802**	**100·311**	—	**100·310**	**+ 1**
2966·902 (6) B	252π + 56	50	=45412	100·306	+0·008	100·302	+ 4
2970·518 (4) B	251π + 100	99	=45279	100·012	+0·008	100·006	+ 6
2973·137 (4) B	250π + *180*	178	=45178	99·790	+0·007	99·794	[− 4]
2973·236 (4) B						99·786	[+ 4]
2981·448 (4) B	249π + 48	50	=44869	99·107	+0·007	99·121	[−14]
2981·856 (4) B						99·087	[+20]
2983·571 (4) B	**272π + 175**		**=49135**	**98·969**	—	**98·957**	**+12**
2983·571 (4) B	248π + 142	145	=44784	98·919	+0·008	98·949	−30
2984·834 (4) B	248π + 104	103	=44743	98·829	+0·008	98·848	−19
2987·293 (5) F	248π + 24	22	=44663	98·652	+0·008	98·651	+ 1
2990·394 (4) B	247π + 86	90	=44549	98·400	+0·008	98·403	+ 3
2991·648 (4) B	247π + *34*	*42*	=44499	98·290	+0·008	98·304	−14
2994·434 (6) B	**270π + 101**		**=48701**	**98·094**	—	**98·091**	**+ 3**
2994·434 (6) B	246π + 122	126	=44405	98·082	+0·008	98·083	− 1
2996·391 (4) B	246π + *50*	48	=44329	98·914	+0·008	97·928	−14
2999·516 (5) B	245π + 114	121	=44219	97·671	+0·008	97·681	−10
3000·453 (4) B	245π + *74*	79	=44178	97·581	+0·008	97·608	[−27]
3000·951 (5) B						97·569	[+12]

Table VI (continued).

(iv) *Fourth Section* (continued).

Wave-length.	Series C_1 Series A_1.	B_2.	Total rotation.	Observed rotation per millimetre.	Correction for regrinding.	Calculated rotations per millimetre.	Diff. O–C.
	°	°	°	°	°	°	
3002·651 (2) B	**268π + 133**		**=48373**	**97·433**	—	**97·440**	— **7**
3002·651 (2) B	245π + 8	10	=44109	97·428	+0·007	97·432	— 4
3007·284 (4) B	244π + 26	25	=43945	97·066	+0·007	97·073	— 7
3008·142 (5) B						97·006	[—36]
[*3008·60 calc.*]	243π + 166	*157*	=43901	96·970	+0·007	—	
3009·575 (5) B	243π + 124	128	=43867	96·894	+0·007	96·895	— 1
3011·484 (4) B	243π + 64	58	=43800	96·746	+0·007	96·747	— 1
3016·200 (2) B	242π + 68	79	=43635	96·381	+0·007	96·382	— 1
[*3017·07 calc.*]	242π +	6	=43566	96·229	+0·007	96·272	[—43]
3017·630 (5) B							
3020·495 (5) B						96·052	
3020·643 (6) B	241π + 102	99	=43480	96·039	+0·007	96·041	— 2
3025·846 (5) B	240π + 102	98	=43299	95·639	+0·007	95·644	— 5
3030·152 (4) F	239π + *130*	127	=43148	95·306	+0·007	95·316	—10
3031·641 (5) B	239π + 84	89	=43107	95·215	+0·007	95·204	+11
3037·392 (5) B	**261π + 75**		**=47055**	**94·777**	—	**94·778**	— **1**
3037·392 (5) B	239π + *68*	64	=42905	94·769	+0·007	94·771	— 2
3040·430 (4) B	237π +	127	=42787	94·508	+0·007	94·538	—30
3041·745 (4) B	237π + 96	88	=42751	94·429	+0·007	94·425	+ 4
3045·082 (4) B	236π +	*172*	=42652	94·210	+0·007	94·197	+13
3047·608 (6) B	**259π + 55**		**=46675**	**94·015**	—	**94·016**	— **1**
3047·608 (6) B	236π + 82	82	=42562	94·011	+0·007	94·009	+ 2
3053·070 (4) B	235π + 64	76	=42372	93·592	+0·007	93·608	—16
3055·268 (4) B	**257π + 133**		**=46393**	**93·445**	—	**93·453**	— **8**
3055·268 (4) B	235π + 0	4	=42302	93·437	+0·007	93·444	— 7
3057·451 (5) B	234π + 106	112	=42230	93·278	+0·007	93·284	— 6
3059·090 (5) B	234π + 54	60	=42178	93·163	+0·007	93·164	— 1
3060·990 (3) B						93·026	[—53]
[*3061·70 calc.*]	233π + *154*	*151*	=42092	92·973	+0·007	—	
3067·250 (5) B	232π + 152	145	=41907	92·565	+0·007	92·571	— 6
3075·725 (5) F	**253π + 120**		**=45660**	**91·968**	—	**91·969**	— **1**
3075·725 (5) F	231π + *60*	55	=41636	91·966	+0·007	91·961	+ 5
3083·745 (4) B	**252π + 16**		**=45376**	**91·394**	—	**91·397**	— **3**
3083·745 (4) B	229π + 156	154	=41375	91·390	+0·007	91·390	±
3091·581 (4) B	228π + 88	87	=41127	90·842	+0·007	90·836	+ 6
3093·806 (2) B	228π + *10*	*10*	=41050	90·672	+0·007	90·681	[— 9]
3093·888 (2) B						90·675	[— 3]
3098·191 (3) B					+0·007	90·375	[—35]
[*3098·69 calc.*]	227π + *40*	*40*	=40900	90·340	+0·007	—	
3100·305 (4) B	226π + 174	169	=40851	90·232	+0·007	90·229	+ 3

Table VI (continued).

(v) *Fifth Section.* 3116·632 to 3485·345 A.U.

Wave-length.	Series C_1 Series B_2.	Total rota-tion.	Observed rotation per milli-metre.	Correction‡ for regrinding.	Calcu-lated rotations per milli metre.	Diff. O–C.
	°	°	°	°	°	
3116·632 (5) B	**245π + 143**	**=44243**	**89·114**	—	**89·110**	**+ 4**
3116·632 (5) B	224π + 21	=40341	89·106	+0·006	89·104	+ 2
3119·495 (4) B	223π + 106	=40246	88·896	+0·006	88·910	–14
3120·435 (4) B	223π + 79	=40219	88·836	+0·006	88·845	– 9
3125·661 (6) F	222π + 99	=40059	88·483	+0·006	88·493	–10
3129·334 (4) B	**243π + 78**	**=43818**	**88·258**	—	**88·253**	**+ 5**
3129·334 (4) B	221π + *175*	=39955	88·253	+0·006	88·246	+ 7
3132·514 (2) B	221π + *46*	=39826	88·012	+0·006	88·033	–21
3134·109 (5) B	**242π + 96**	**=43656**	**87·930**	—	**87·932**	**– 2**
3134·109 (5) B	221π + 19	=39799	87·908	+0·006	87·926	+18
3142·445 (4) B	218π + *130*	=39550	87·359	—	87·343	[+16]
3142·888 (4) B					87·374	[–15]
3144·488 (4) B	218π + 77	=39497	87·241	—	87·238	+ 3
3151·341 (6) B	218π + 56	=39296	86·797	+0·006	86·788	+ 9
3175·446 (6) F	214π + 65	=38585	85·227	+0·006	85·234	– 7
3178·014 (6) B	**234π + 119**	**=42239**	**85·078**	—	**85·081**	**– 3**
3178·014 (6) B	213π + *177*	=38517	85·077	+0·006	85·075	+ 2
3180·220 (8) B	213π + 115	=38455	84·940	+0·006	84·932	+ 8
3184·903 (4) B	**233π + 82**	**=42022**	**84·641**	—	**84·642**	**– 1**
3184·903 (4) B	212π + *159*	=38319	84·639	—	84·637	+ 2
3188·837 (5) B	**232π + 143**	**=41903**	**84·401**	—	**84·395**	**+ 6**
3188·837 (5) B	212π + 48	=38208	84·394	+0·006	84·390	+ 4
3193·264 (4+4)B*	211π + 100	=38080	84·111	+0·006	84·113	– 2
3196·937 (4) B	211π + 1	=37981	83·893	+0·006	83·885	+ 8
3199·526 (6) B	210π + 99	=37899	83·712	+0·006	83·725	–13
3200·484 (6) B	210π + 79	=37879	83·667	+0·006	83·666	+ 1
3205·396 (7) B	**229π + 172**	**=41392**	**83·372**	—	**83·369**	**+ 3**
3205·396 (7) B	209π + *118*†	=37738	83·356	—	83·363	– 7
3214·044 (8) B	208π + 62	=37502	82·835	+0·006	82·835	±
3217·389 (4) B	207π + *142*	=37402	82·614	+0·006	82·632	–18
3219·582 (5) B	207π + 88	=37348	82·495	+0·006	82·500	– 5
3222·070 (6) B	207π + 24	=37284	82·353	+0·006	82·348	+ 5
3225·790 (8) F	**226π + 95**	**=40775**	**82·129**	—	**82·131**	**– 2**
3225·790 (8) F	206π + 103	=37183	82·130	+0·005	82·126	+ 4
3227·814 (4) B	206π + 46	=37126	82·004	+0·005	82·007	[– 3]
3228·003 (2) B					81·996	[+ 8]
Mn 3228·099 (2) B					81·990	[+14]
3228·262 (4) B					81·980	[+24]
3230·210 (4) B	205π + 151	=37061	81·861	+0·005	81·862	– 1
3233·061 (5) B	205π + *82*	=36982	81·686	+0·005	81·691	– 5
3233·976 (6) B	205π + 56	=36956	81·628	+0·005	81·638	–10
Mn 3236·785 (4) B	204π + 168	=36888	81·479	+0·005	81·471	+ 8
3239·449 (8) B	**224π + 52**	**=40372**	**81·317**	—	**81·319**	**– 2**
3239·449 (8) B	204π + 94	=36814	81·315	+0·005	81·313	+ 2

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* 3193·214 and 3193·314 were seen by BURNS as a single line on most of his plates.

† Another weak line at *157°*.

‡ This correction applies both to the observed and to the calculated rotation.

Table VI (continued).

(v) *Fifth Section* (continued).

Wave-length.	Series C_1 Series B_2.	Total rota-tion.	Observed rotation per milli-metre.	Correction for regrinding.	Calcu-lated rotations per milli-metre.	Diff. O–C.
	°	°	°	°	°	
3244·186 (8) B	203π + 148	=36688	81·037	+0·004	81·031	+ 6
3246·015 (3) B	203π + *85*	=36625	80·898	0·004	80·925	[−27]
3246·492 (2) B					80·898	[±]
3246·973 (4) B					80·871	[+27]
Cu 3247·554 (7) B	203π + 52	=36592	80·825	+0·004	80·838	−13
3254·372 (4) B	202π + 56	=36416	80·436	+0·004	80·439	− 3
3265·629 (6) B	200π + 123	=36123	79·789	+0·004	79·790	− 1
3271·003 (6) F	**219π + 42**	**=39462**	**79·485**	—	**79·488**	− **3**
3271·003 (6) F	199π + 166	=35986	79·486	+0·004	79·483	+ 3
[*3273·44 calc.*]	199π + 102	=35922	79·345	+0·004	—	—
Cu 3273·965 (7) B	**218π + 138**	**=39378**	**79·315**	—	**79·319**	− **4**
3280·268 (5) B	**217π + 143**	**=39203**	**78·962**	—	**78·963**	− **1**
3280·268 (5) B	198π + 104	=35744	78·952	+0·004	78·958	− 6
3286·763 (8) B	**216π + 141**	**=39021**	**78·598**	—	**78·599**	− **1**
3286·763 (8) B	197π + 121	=35581	78·592	+0·004	78·593	− 1
3292·029 (5) B	196π + 162	=35442	78·285	+0·004	78·300	[−15]
3292·599 (5) B					78·267	[+18]
3298·137 (5) B	**215π + 6**	**=38706**	**77·964**	—	**77·964**	±
3298·137 (5) B	196π + 15	=35295	77·960	+0·004	77·960	±
3305·980 (8) B	194π + 174	=35094	77·516	+0·004	77·529	[−13]
3306·357 (8) B					77·508	[+ 8]
3314·746 (6) B	**212π + 96**	**=38256**	**77·055**	—	**77·054**	+ **1**
3314·746 (6) B	193π + 142	=34882	77·048	+0·004	77·050	− 2
3323·739 (4) F	192π + *97*	=34657	76·551	+0·004	76·560	− 9
3328·871 (4) B	191π + 160	=34540	76·292	+0·004	76·290	+ 2
3341·912 (4) B	190π + *22*	=34222	75·590	+0·004	75·597	− 7
3355·235 (4) B	188π + 69	=33909	74·899	+0·004	74·900	− 1
3366·790 (3) B	186π + 160	=33640	74·304	+0·004	74·300	+ 4
3366·870 (3) B						
Ni 3369·555 (5) B	186π + 92	=33572	74·154	+0·004	74·162	− 8
Ni 3369·555 (5) B	**204π + 85**	**=36805**	**74·133**	—	**74·165**	[−**32**]
3370·789 (6) I					**74·102**	[+**31**]
3370·789 (6) I	186π + 64	=33544	74·088	+0·004	74·098	−10
3372·081 (3) B					74·033	
3379·024 (4) B	185π + 61	=33361	73·688	+0·004	73·680	+ 8
3380·115 (5) B	185π + 34	=33334	73·628	+0·004	73·626	+ 2
3383·985 (5) B	**202π + 98**	**=36458**	**73·434**	—	**73·434**	±
3383·985 (5) B	184π + 123	=33243	73·427	+0·004	73·430	− 3
Ni 3392·992 (3) B	183π + 109	=33049	72·979	+0·004	72·978	+ 1
3392·658 (5) B					72·995	
3394·590 (4) B	183π + 64	=33004	72·900	+0·004	72·899	+ 1
3399·337 (6) I	182π + 136	=32896	72·661	+0·004	72·663	− 2
3404·356 (6) B	182π + 25	=32785	72·414	+0·004	72·415	− 1
3413·140 (7) B	181π + 7	=32587	71·979	+0·004	71·984	− 5
3417·847 (6) B	**197π + 157**	**=35617**	**71·740**	—	‡ 71·755	[−15]
3418·179 (2) B	180π + 79	=32479	71·740	+0·003	71·739	[+ 1]
3418·514 (5) B					71·722	[+17]
3422·655 (4) B	179π + 160	=32380	71·521	+0·003	71·521	±

See Note ‡ on next page.

Table VI (continued).

(v) *Fifth Section* (continued).

Wave-length.	Series C_1 Series B_2.	Total rotation.	Observed rotation per millimetre.	Correction for regrinding.	Calculated rotations per millimetre.	Diff. O–C.
	°	°	°	°	°	
3424·290 (6) B	$179\pi + 120$	=32340	71·433	+0·003	71·443	–10
3426·646 (6) B	**$196\pi + 117$**	**=35397**	**71·337**	—	**71·331**	**+ 6**
3427·127 (6) B	$179\pi +$ 63	=32283	71·307	+0·003	71·306	+ 1
3428·200 (6) B	$179\pi +$ *43*	=32263	71·263	+0·003	71·254	+ 9
3440·614 (7) B	$177\pi + 129$	=31989	70·658	+0·003	70·662	– 4
3443·883 (6) B	$177\pi +$ *58*	=31918	70·501	+0·003	70·507	– 6
345·1544 (4) I	$177\pi +$ *37*	=31897	70·454	+0·003	70·448	+ 6
†[*3446·71 calc.*]	$177\pi +$ 0	=31860	70·372	+0·003		
†[*3452·67 calc.*]	$176\pi +$ 54	=31734	70·094	+0·003		
3465·864 (6) B	**$191\pi + 116$**	**=34496**	**69·481**	—	**69·482**	**– 1**
3465·864 (6) B	$174\pi + 134$	=31454	69·475	+0·003	69·480	– 5
*3468·849 (4) B	$174\pi +$ 66	=31386	69·326	+0·003	69·342	–16
3471·34 (3) B	$174\pi +$ 21	=31341	69·226	+0·003	69·227	– 1
3476·336 (2) B	$173\pi +$ *97*	=31237	68·997	+0·003	68·998	– 1
3476·705 (5) B	$173\pi +$ 88	=31228	68·977	+0·003	68·981	– 4
3485·345 (6) I	$172\pi +$ *91*	=31051	68·586	+0·003	68·588	– 2

* The observed rotation has probably been diminished by the presence of 4 adjacent weak lines of longer wave-length.

† These are, perhaps, composite readings of iron and nickel lines—

Ni 3446·263 (3) B = 70·396 (–24). Fe 3447·283 (6) B = 70·346 (+26).

Fe 3452·279 (4) B = 70·112 (–18). Ni 3452·891 = 70·083 (+11).

‡ The calculated values are for the unground quartz; for the reground quartz they should be 0·003 higher.

(vi) *Sixth Section.* 3490·577 to 3542·079 A.U.

Wave-length.	Series C_1 Series B_2.	B_4.	Total rotation.	Observed rotation per millimetre.	Correction* for regrinding.	Calculated rotation per millimetre.	Diff.
	°	°	°	°	°	°	
3490·577 (6) B	**$188\pi +$ 99**		**=33939**	**68·360**	—	**68·355**	**+ 5**
3490·577 (6) B	$171\pi + 165$	*170*	=30946	68·354	+0·003	68·3520	+ 2
3497·842 (5) B	$171\pi +$ *21*		=30801	68·034	+0·003	68·0259	+ 8
3513·821 (5) I	$169\pi +$ 55		=30475	67·313	+0·003	67·3171	– 4
3521·264 (4) B	$168\pi +$ *90*		=30330	66·993	+0·003	66·9910	+ 2
3526·167 (5) B	$167\pi + 170$	170	=30230	66·772	+0·003	66·776	– 4
3526·672 (5) B					+0·003	66·7554	
3533·196 (5) B	$167\pi +$ 37	36	=30096	66·477	+0·003	66·4734	+ 4
3536·552 (6) B	$166\pi + 150$	151	=30030	66·332	+0·003	66·3285	+ 3
3541·090 (6) B	$166\pi +$ 63		=29943	66·138	+0·002	66·1338	+ 4
3542·079 (6) B	$166\pi +$ *43*	40	=29920	66·089	+0·002	66·0914	– 2

* This correction applies both to the observed and to the calculated rotation.

Table VI (continued).

(vii) *Seventh Section.* 3554·924 to 3814·525 A.U.

Wave-length.	Series C_1 Series B_4.	Total rota-tion.	Observed rotation per milli-metre.	Correction* for regrinding.	Calcu-lated rotations per milli-metre.	Diff.
	°	°	°	°	°	
3554·924 (8) B	164π + 155	=29675	65·546	+0·002	65·5457	±
3556·881 (6) I	164π + 118	=29638	65·465	+0·002	65·4632	+ 2
3558·522 (5) B	164π + 87	=29607	65·396	+0·002	65·3944	+ 2
3565·383 (6) B	163π + 137	=29477	65·109	+0·002	65·1061	+ 3
3565·383 (6) B 3565·584 (4) B	**179π + 102**	**=32322**	**65·103**		**65·108** **65·100**	[− **5**] [+ **3**]
3570·102 (7) B 3570·243 (7) B	163π + 46	=29386	64·908	+0·002	64·9098 64·9040	[− 2] [+ 4]
3571·998 (7) B	163π + 11	=29351	64·831	+0·002	64·8311	±
3573·842 (3) B 3573·894 (4) B	162π + 158	=29318	64·758	+0·002	64·7546 64·7524	[+ 3] [+ 6]
3575·375 (4) B	162π + 130	=29290	64·696	+0·002	64·6913	+ 5
3581·197 (8) B	**177π + 135**	**=31995**	**64·445**	—	**64·453**	− **8**
3581·197 (8) B	162π + 19	=29179	64·451	+0·002	64·4511	±
3584·662 (5) B	161π + 137	=29117	64·314	+0·002	64·3086	+ 5
3586·989 (6) B	161π + 91	=29071	64·212	+0·002	64·2135	− 1
3589·105 (4) B	161π + 53	=29033	64·128	+0·002	64·1271	+ 1
3594·627 (5) B	160π + 131	=28931	63·903	+0·002	63·9024	+ 1
3603·203 (5) B	160π + 154	=28774	63·556	+0·002	63·5538	+ 2
3605·454 (5) B	159π + 114	=28734	63·468	+0·002	63·4653	+ 3
3606·682 (5) I	159π + 91	=28711	63·417	+0·002	63·4157	+ 1
3608·860 (6) B	159π + 52	=28672	63·331	+0·002	63·3288	+ 2
3610·151 (5) B	159π + 28	=28648	63·278	+0·002	63·2772	+ 1
3617·789 (6) B	158π + 71	=28511	62·975	+0·002	62·9716	+ 3
3618·769 (6) B	158π + 53	=28493	62·936	+0·002	62·9341	+ 2
3621·463 (6) B	158π + 6	=28446	62·832	+0·002	62·8275	+ 4
3622·005 (6) B	157π + 172	=28432	62·801	+0·002	62·8061	− 5
3623·186 (5) B	157π + 155	=28415	62·763	+0·002	62·7595	+ 3
3625·148 (6) B	157π + 118	=28378	62·682	+0·002	62·6821	±
3631·464 (6) B	157π + 7	=28267	62·436	+0·002	62·4341	+ 2
3634·336 (5) B	156π + *136*	=28216	62·324	+0·002	62·3218	+ 2
3638·299 (6) B	156π + 66	=28146	62·169	+0·002	62·1674	+ 2
3640·392 (6) I	156π + 28	=28108	62·085	+0·002	62·0881	− 3
3643·624 (2) B 3643·716 (2) B	155π + 151	=28051	61·959	+0·002	61·9611 61·9574	− 2 + 2
3645·825 (4) B	155π + 123	=28023	61·897	+0·002	61·8979	− 1
3647·845 (6) B	155π + 78	=27978	61·798	+0·002	61·7979	±
3649·509 (6) B	155π + 49	=27949	61·734	+0·002	61·7338	±
3650·026 (3) B 3650·282 (4) B	155π + 41	=27941	61·716	+0·002	61·714 61·7041	[+ 2] [+12]
3651·473 (6) B	155π + 15	=27915	61·659	+0·002	61·6583	+ 1
3655·470 (4) B	154π + 126	=27846	61·507	+0·002	61·5053	+ 2
3659·521 (5) B	154π + 56	=27776	61·352	+0·002	61·3505	+ 1
3664·555 (2) B	153π + 147	=27687	61·155	+0·002	61·1592	− 4
3667·280 (4) B	153π + 100	=27640	61·052	+0·002	61·0560	− 4
3669·525 (6) B	153π + 64	=27604	60·973	+0·002	60·9713	+ 2
3670·035 (2) B 3670·085 (3) B	153π + 52	=27592	60·947	+0·002	60·9544 60·9525	[− 7] [− 5]

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* This correction applies both to the observed and to the calculated rotation.

Table VI (continued).

(vii) *Seventh Section* (continued).

Wave-length.	Series C_1. Series B_4.	Total rota-tion.	Observed rotation per milli-metre.	Correction for regrinding.	Calcu-lated rotations per milli-metre.	Diff.
	°	°	°	°	°	
3676·313 (4) I	$152\pi + 129$	=27489	60·718	+0·002	60·7159	+ 2
3677·629 (6) I	$152\pi + 106$	=27466	60·667	+0·002	60·6615	+ 5
3679·915 (5) B	$152\pi + 67$	=27427	60·581	+0·002	60·5810	±
3682·235 (6) B	$152\pi + 29$	=27389	60·497	+0·002	60·4944	+ 3
3683·056 (4) B	$152\pi + 14$	=27374	60·464	+0·002	60·4638	±
3684·110 (5) B	$151\pi + 176$	=27356	60·424	+0·002	60·4246	− 1
3685·995 (5) B	$151\pi + 145$	=27325	60·356	+0·002	60·3544	+ 2
3687·458 (6) B	$151\pi + 120$	=27300	60·301	+0·002	60·3003	+ 1
3689·456 (6) B	$151\pi + 87$	=27267	60·228	+0·002	60·2266	+ 1
3690·728 (2) B	$151\pi + 64$	=27244	60·177	+0·002	60·1792	− 2
3693·999 (6) B	$\mathbf{165\pi + 117}$	**=29817**	**60·058**	—	**60·060**	− 2
3693·999 (6) B	$151\pi + 11$	=27191	60·060	+0·002	60·0584	+ 2
3695·054 (3) B	$150\pi + 169$	=27169	60·011	+0·002	60·0195	− 8
3697·436 (2) B	$150\pi + 134$	=27134	59·934	+0·002	59·932	[+ 2]
3697·510 (1) B					59·931	[+ 3]
3701·083 (6) B	$150\pi + 74$	=27074	59·801	+0·002	59·7981	+ 3
3703·556 (1) B	$150\pi + 30$	=27030	59·704	+0·002	59·7075	− 3
3704·462 (5) B	$150\pi + 17$	=27017	59·675	+0·002	59·6746	±
3705·567 (6) B	$149\pi + 178$	=26998	59·633	+0·002	59·6343	− 1
3707·048 (3) B	$149\pi + 156$	=26976	59·585	+0·002	59·5803	+ 5
3707·828 (3) B	$149\pi + 140$	=26960	59·550	+0·002	59·553	[− 3]
3707·923 (5) B					59·549	[+ 1]
3709·250 (6) B	$149\pi + 118$*	=26938	59·501	+0·002	59·5002	+ 1
3716·450 (6) B	$149\pi + 0$*	=26820	59·240	+0·002	59·2391	+ 1
3718·410 (2) B	$148\pi + 147$	=26787	59·167	+0·002	59·1688	− 2
3719·938 (8) B	$148\pi + 123$	=26763	59·114	+0·002	59·1138	±
3722·565 (6) B	$148\pi + 80$	=26720	59·019	+0·002	59·0193	±
3724·380 (6) I	$148\pi + 51$	=26691	58·955	+0·002	58·9527	+ 2
3726·922 (3) B	$148\pi + 12$	=26652	58·869	+0·002	58·8631	+ 6
3727·622 (6) B	$\mathbf{162\pi + 52}$	**=29212**	**58·838**	—	**58·839**	− **1**
3727·622 (6) B	$147\pi + 179$	=26639	58·840	+0·001	58·8384	+ 2
3730·390 (3) B	$147\pi + 131$	=26591	58·734	+0·001	58·7395	− 5
3732·398 (6) B	$147\pi + 102$	=26562	58·670	+0·001	58·6665	+ 3
3734·869 (9) B	$147\pi + 86$	=25546	58·635	+0·001	58·6355	±
3735·329 (3) B	$147\pi + 60$	=26520	58·578	+0·001	58·5704	+ 8
3737·135 (7) B	$147\pi + 24$	=26484	58·498	+0·002	58·5001	− 2
3738·310 (4) B	$147\pi + 5$	=26465	58·456	+0·002	58·4584	− 2
3743·471 (4) B	$148\pi + 104$	=26384	58·277	+0·002	58·2766	±
3745·563 (7) B	$146\pi + 69$	=26349	58·200	+0·002	58·2029	− 3
3746·927 (2) B	$146\pi + 49$	=26329	58·156	+0·002	58·1553	+ 1
3748·264 (6) B	$146\pi + 28$	=26308	58·109	+0·002	58·1082	+ 1
3749·487 (8) B	$146\pi + 9$	=26289	58·067	+0·002	58·0654	+ 2
3753·615 (5) I	$145\pi + 123$	=26223	57·922	+0·002	57·9212	+ 1

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* An extinction at 152° between these two readings has been omitted, as it is obviously not in the correct sequence. It was perhaps a repetition of the adjacent reading of 147° below.

Table VI (continued).

(vii) *Seventh Section* (continued).

Wave-length.	Series C_1 Series B_4.	Total rotation.	Observed rotation per millimetre.	Correction for regrinding.	Calculated rotations per millimetre.	Diff.
	°	°	°	°	°	
3758·234 (7) B	145π + 49*	=26149	57·758	+0·002	57·7607	− 3
3760·051 (5) B	145π + 20*	=26120	57·694	+0·002	57·6979	− 4
3763·792 (6) B	144π + 143	=26063	57·568	+0·002	57·5682	±
3765·541 (6) B	144π + 116	=26036	57·509	+0·002	57·5079	+ 1
3767·194 (6) B	144π + 90	=26010	57·451	+0·002	57·4509	±
3770·305 (1) B	144π + 43	=25963	57·347	+0·002	57·344	+ 3
3774·826 (2) B	143π + 151	=25891	57·188	+0·002	57·1875	±
3776·456 (2) B	143π + 125	=25865	57·131	+0·002	57·1333	− 2
3778·515 (1) B	143π + 95	=25835	57·065	+0·002	57·0633	+ 2
3779·444 (2) B	143π + 79	=25819	57·029	+0·002	57·0317	− 3
3785·948 (5) B	142π + 161	=25721	56·813	+0·002	56·8110	+ 2
3787·880 (6) B	142π + 130	=25690	56·744	+0·002	56·7457	− 2
3790·094 (4) B	142π + 98	=25658	56·674	+0·002	56·6716	+ 2
3795·004 (6) B	142π + 22	=25582	56·506	+0·002	56·5058	±
3797·516 (5) B	141π + 164	=25544	56·422	+0·002	56·4216	±
3798·512 (6) B	141π + 149	=25529	56·389	+0·002	56·3884	+ 1
3799·548 (6) B	141π + 132	=25512	56·351	+0·002	56·3538	− 3
3801·681 (2) B	141π + 100	=25480	56·280	+0·002	56·2825	− 2
3805·346 (6) I	141π + 47	=25427	56·163	+0·002	56·1607	+ 2
3806·702 (6) B	141π + 25	=25405	56·115	+0·002	56·1154	±
3807·541 (4) B	141π + 13	=25393	56·088	+0·002	56·0868	+ 1
3808·732 (2) B	140π + 172	=25372	56·042	+0·002	56·0482	− 6
3810·759 (2) B	140π + 144	=25344	55·980	+0·002	55·9810	− 1
3812·966 (6) B	140π + 110	=25310	55·905	+0·002	55·9083	− 3
3814·525 (2) B	140π + 88	=25288	55·856	+0·002	55·8568	− 1

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* An extinction at 83° between these two readings has been omitted, as it is obviously not in the correct sequence.

Table VI (continued).

(viii) *Eighth Section.* 3815·844 to 5383·366 A.U.

Wave-length.	Series C_2 Series B_4.	Total rota-tion.	Observed rotation per milli-metre.	Correction† for regrinding.	Calcu-lated rotations per milli-metre.	Diff.
	°	°	°	°	°	
3815·844 (7) B	**153π + 173**	**=27713**	**55·819**	—	**55·814**	+ **5**
3815·844 (7) B	140π + 68	=25268	55·812	+0·002	55·8135	+ 1
3820·430 (8) B	140π + 0	=25200	55·662	+0·002	55·6630	− 1
3824·444 (6) B	**153π + 29**	**=27569**	**55·530**	—	**55·533**	− **3**
3824·444 (6) B	139π + 120	=25140	55·529	+0·002	55·5315	− 2
3825·886 (8) B	**153π + 7**	**=27547**	**55·485**	—	**55·485**	±
3825·886 (8) B	139π + 100	=25120	55·485	+0·002	55·4843	+ 1
[*3827·18 calc.*]	139π + 81	=25101	55·443	+0·002	55·4207	[+22]
3827·826 (6) B	**152π + 153**	**=27513**	**55·417**	—	**55·422**	− **5**
3830·761 (1) B 3830·866 (1) B	139π + 30	=25050	55·331	+0·002	55·322 55·326	[+ 9] [+ 5]
3833·312 (4) B	138π + 171	=25011	55·245	+0·002	55·2429	+ 2
3834·277 (7) B	**152π + 49**	**=27409**	**55·207**	—	**55·214**	− **7**
3834·277 (7) B	138π + 156	=24996	55·211	+0·002	55·2133	− 2
3836·339 (3) B	138π + 126	=24966	55·145	+0·002	55·1450	±
3838·259 (5) B	138π + 83	=24923	55·050	+0·002	55·0506	− 1
3840·443 (6) B	138π + 67	=24907	55·015	+0·002	55·0127	+ 2
	151π + 126	**=27306**	**55·000**	—	**55·014** **54·995**	[−**14**] [+ **5**]
3841·052 (6) B	138π + 54	=24894	54·986	+0·002	54·9933	− 7
3843·261 (5) I	139π + 25	=24865	54·922	+0·002	54·9243	− 2
*3845·178 (3) VH	138π + 0	=24840	54·867	—	54·862	+ 5
3846·806 (5) B	137π + 154	=24814	54·809	+0·002	54·8084	+ 1
3849·970 (6) B	137π + 109	=24769	54·710	+0·002	54·7072	+ 3
3850·820 (5) I	137π + 95	=24755	54·679	+0·002	54·6802	− 1
3852·577 (3) B	137π + 70	=24730	54·624	+0·002	54·6242	±
3856·373 (6) B	**150π + 58**	**=27058**	**54·507**	—	**54·504**	+ **3**
3856·373 (6) B	137π + 15	=24675	54·502	+0·002	54·5036	− 2
3859·215 (5) B	136π + 156	=24636	54·416	+0·002	54·4135	+ 2
3859·913 (7) B	**149π + 4**	**=26824**	**54·391**	—	**54·393**	− **2**
3859·913 (7) B	136π + 140	=24620	54·381	+0·002	54·3814	±
3863·745 (1) B	136π + 90	=24570	54·270	+0·002	54·2703	±
3865·527 (6) I	**149π + 95**	**=26915**	**54·212**	—	**54·215**	− **3**
3865·527 (6) I	136π + 64	=24544	54·213	+0·002	54·2143	− 1
3867·221 (3) B	136π + 41	=24521	54·162	+0·002	54·1596	+ 2
3869·563 (2) B	136π + 7	=24487	54·087	+0·002	54·0875	±
3871·752 (2) B	135π + 158	=24458	54·023	+0·002	54·0187	+ 4
3872·506 (6) B	**148π + 168**	**=26808**	**53·996**	—	**53·995**	+ **1**
3872·506 (6) B	135π + 144	=24444	53·992	+0·002	53·9943	− 2
[*3873·08 calc.*]	135π + 137	=24437	53·977	+0·002	—	[+21]
3873·766 (4) B				+0·002	53·9558	
3876·044 (1) B	135π + 96	=24396	53·886	+0·002	53·8848	+ 1
3878·024 (6) B	135π + 67	=24367	53·822	+0·002	53·8231	− 1
	148π + 76	**=26716**	**53·811**	—	**53·824** **53·809**	[−**13**] [+ **2**]
3878·578 (6) B	135π + 56	=24356	53·798	+0·002	53·8059	8

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* This line is not included in BURNS' list, but is given by VIEFHAUS, 3845·177 (3) and by HOLTZENBEIN 3845·179 (3).

† This correction applies both to the observed and to the calculated rotation.

Table VI (continued).

(viii) *Eighth Section* (continued).

Wave-length.	Series C_2 Series B_4.	Total rota-tion.	Observed rotation per milli-metre.	Correction for regrinding.	Calcu-lated rotations per milli-metre.	Diff.
	°	°	°	°	°	
3883·288 (2) B	134π + 169	=24289	53·650	+0·002	53·6597	—10
3884·365 (2) B	134π + 159	=24279	53·627	+0·002	53·6263	+ 1
3886·287 (7) B	**147π + 135**	**=26595**	**53·568**	—	**53·568**	±
3887·053 (6) B	**147π + 120**	**=26580**	**53·537**	—	**53·544**	— **7**
3888·520 (7) B	**147π + 100**	**=26560**	**53·497**	—	**53·499**	— **2**
3888·520 (7) B	134π + 100	=24220	53·497	+0·002	53·4980	— 1
3890·844 (2) B	134π + 69	=24189	53·429	+0·002	53·4265	+ 3
3891·933 (4) B	134π + 52	=24172	53·391	+0·002	53·3929	— 2
3893·395 (4) B	134π + 33	=24153	53·349	+0·002	53·3479	+ 1
3895·659 (5) B	**146π + 172**	**=26452**	**53·279**	—	**53·279**	±
3895·659 (5) B	134π + 1	=24121	53·279	+0·002	53·2785	±
3897·892 (4) B	**146π + 135**	**=26415**	**53·205**	—	**53·211**	[— **6**]
3898·013 (4) B					**53·207**	[— **2**]
3897·892 (4) B	133π + 151	=24091	53·212	+0·002	53·2103	[+ 2]
3898·013 (4) B					53·2066	[+ 5]
3899·711 (6) B	**146π + 108**	**=26388**	**53·151**	—	**53·156**	— **5**
3899·711 (6) B	133π + 125	=24065	53·155	+0·002	53·1546	±
3902·950 (7) B	**146π + 60**	**=26340**	**53·055**	—	**53·057**	— **2**
3902·950 (7) B	133π + 80	=24020	53·056	+0·002	53·0559	±
3903·903 (3) B	133π + 65	=24005	53·022	+0·002	53·0269	— 5
3906·482 (5) I	**146π + 6**	**=26286**	**52·946**	—	**52·949**	— **3**
3906·482 (5) I	133π + 31	=23971	52·947	+0·001	52·9486	— 2
3907·937 (3) I	133π + 11	=23951	52·903	+0·001	52·9044	— 1
3909·834 (2) B	132π + 166	=23926	52·848	+0·001	52·8470	+ 1
3910·847 (2) B	132π + 151	=23911	52·815	+0·001	52·8165	— 1
3913·635 (2) B	132π + 115	=23875	52·735	+0·001	52·7322	+ 3
3917·185 (5) B	132π + 68	=23828	52·632	+0·001	52·6252	+ 7
3918·645 (4) B	132π + 45	=23805	52·581	+0·001	52·5815	±
3920·261 (6) B	**144π + 161**	**=26081**	**52·533**	—	**52·534**	— **1**
3920·261 (6) B	132π + 23	=23783	52·532	+0·001	52·5329	— 1
3922·917 (6) B	**144π + 120**	**=26040**	**52·450**	—	**52·453**	— **3**
3922·917 (6) B	131π + 167	=23747	52·453	+0·001	52·4521	+ 1
3925·945 (3) B	**144π + 80**	**=26000**	**52·369**	—	**52·364**	+ **5**
3925·945 (3) B	131π + 127	=23707	52·364	+0·001	52·3630	+ 1
3927·925 (6) B	**144π + 47**	**=25967**	**52·303**	—	**52·305**	— **2**
3927·925 (6) B	131π + 98	=23678	52·300	+0·001	52·3040	— 4
3930·304 (7) B	**144π + 13**	**=25933**	**52·234**	—	**52·234**	±
3930·304 (7) B	131π + 68	=23648	52·234	+0·001	52·2331	+ 1
3932·635 (3) B	131π + 35	=23615	52·161	+0·001	52·1641	— 3
3933·607 (2) B	**143π + 144**	**=25884**	**52·136**	—	**52·136**	±
3933·607 (2) B	131π + 23	=23603	52·135	+0·001	52·1351	±
3935·818 (4) I	**143π + 110**	**=25850**	**52·068**	—	**52·070**	— **2**
3935·818 (4) I	130π + 172	=23572	52·066	+0·001	52·0698	— 4
3937·334 (2) B	130π + 154	=23554	52·026	+0·001	52·0250	+ 1
3940·885 (4) B	130π + 105	=23505	51–918	+0·001	51·9202	— 2
3942·446 (3) B	130π + 85	=23485	51·874	+0·001	51·8742	±
*3945·116 (2) VH	130π + 50	=23450	51·797	+0·001	51·7967	±

* Recorded by BURNS as 3945·123 (1).

Table VI (continued).

(viii) *Eighth Section* (continued).

Wave-length.	Series C_2 Series B_4.	Total rotation.	Observed rotation per millimetre.	Correction for regrinding.	Calculated rotations per millimetre.	Diff.
	°	°	°	°	°	
3948·779 (4) B	$129\pi + 179$	=23399	51·684	+0·001	51·6886	− 5
3949·956 (4) B	$129\pi + 165$	=23385	51·653	+0·001	51·6542	− 1
3951·165 (4) B	$129\pi + 148$	=23368	51·615	+0·001	51·6189	− 4
3952·606 (4) B	$129\pi + 127$	=23347	51·569	+0·001	51·5768	− 8
3956·682 (6) B	**$141\pi + 168^*$**	**=25548**	**51·458**	—	**51·460**	**− 2**
3956·682 (6) B	$129\pi + 77$	=23297	51·459	+0·001	51·4584	+ 1
[3960·74 calc.]	$129\pi + \mathit{23}$	=23243	51·339			
3963·119 (2) B	$128\pi + 171$	=23211	51·269	+0·001	51·2722	− 3
3964·524 (2) B	$128\pi + 156$	=23196	51·236	+0·001	51·2314	+ 5
3966·069 (5) B	$128\pi + 137$	=23177	51·194	+0·001	51·1868	+ 7
3967·426 (4) B	$128\pi + 117$	=23157	51·149	+0·001	51·1478	+ 1
3969·263 (7) B	**$140\pi + 166$**	**=25366**	**51·093**	—	**51·096**	**− 3**
3969·263 (7) B	$128\pi + 92$	=23132	51·094	+0·001	51·0950	− 1
3971·328 (4) B	**$140\pi + 136$**	**=25336**	**51·032**	—	**51·037**	**− 5**
3971·328 (4) B	$128\pi + 64$	=23104	51·032	+0·001	51·0226	+ 9
3973·656 (1) B	$128\pi + 36$	=23076	50·971	+0·001	50·9691	+ 2
3976·622 (2) B	$127\pi + 177$	=23037	50·884	+0·001	50·8843	±
3977·746 (5) I	**$140\pi + 46$**	**=25246**	**50·850**	—	**50·853**	**− 3**
3977·746 (5) I	$127\pi + 162$	=23022	50·851	+0·001	50·8524	− 1
3981·776 (3) B	**$139\pi + 169$**	**=25189**	**50·736**	—	**50·738**	**− 2**
3981·776 (3) B	$127\pi + 110$	=22970	50·736	+0·001	50·7376	− 2
3983·964 (5) B	**$139\pi + 137$**	**=25159**	**50·671**	—	**50·676**	**− 5**
3983·964 (5) B	$127\pi + 82$	=22942	50·675	+0·001	50·6754	±
3985·394 (1) B	$127\pi + 63$	=22923	50·633	+0·001	50·6350	− 2
3986·178 (3) B	$127\pi + 54$	=22914	50·613	+0·001	50·6124	+ 1
3990·380 (1) B	$127\pi + 2$	=22862	50·498	+0·001	50·4940	+ 4
3994·120 (1) B	$126\pi + 131$	=22811	50·385	+0·001	50·3915	− 6
3995·989 (1) B	$126\pi + 109$	=22789	50·337	+0·001	50·3361	+ 1
3997·398 (6) B	**$138\pi + 130$**	**=24970**	**50·294**	—	**50·297**	**− 3**
3997·398 (6) B	$126\pi + 90$	=22770	50·295	+0·001	50·2965	− 1
3998·059 (5) B	**$138\pi + 119$**	**=24959**	**50·272**	—	**50·279**	**− 7**
3998·059 (5) B	$126\pi + 81$	=22761	50·275	+0·001	50·2780	− 3
4000·464 (1) B	$126\pi + 52$	=22732	50·211	+0·001	50·2108	±
4001·667 (3) B	$126\pi + 37$	=22717	50·178	+0·001	50·1781	±
4005·250 (7) B	**$138\pi + 22$**	**=24062**	**50·077**	—	**50·078**	**− 1**
4005·250 (7) B	$125\pi + 169$	=22669	50·072	+0·001	50·0772	− 5
4007·274 (3) B	$125\pi + 144$	=22644	50·016	+0·001	50·0212	− 5
4009·718 (5) B	$125\pi + 115$	=22615	40·952	+0·001	49·9533	− 1
4014·536 (4) B	**$137\pi + 76$**	**=24736**	**49·824**	—	**49·821**	**+ 3**
4014·536 (4) B	$125\pi + 53$	=22553	49·815	+0·001	49·8196	− 5
4017·154 (3) B	$125\pi + 22$	=22522	49·747	+0·001	40·7474	±
4021·872 (5) I	**$136\pi + 153$**	**=24633**	**49·616**	—	**49·618**	**− 2**
4021·872 (5) I	$124\pi + 143$	=22463	49·617	+0·001	49·6174	±
4024·745 (2) B	**$135\pi + 112$**	**=24412**	**49·534**	—	**49·541**	**− 7**
4026·441 (1) B	$124\pi + 107$	=22407	49·493	+0·001	49·4924	+ 1

* Composite reading, including 3956·461 (4) B (Calc. 51·462°/mm.).

Table VI (continued).

(viii) *Eighth Section* (continued).

Wave-length.	Series C_2 Series B_4.	Total rotation.	Observed rotation per millimetre.	Correction for regrinding.	Calculated rotations per millimetre.	Diff.
	°	°	°	°	°	
Mn 4030·759 (8) B	124π + 33	=22353	49·374	+0·001	49·375	− 1
Mn 4033·072 (7) B	124π + 4	=22324	49·309	+0·001	49·311	− 2
Mn 4034·489 (7) B	123π + 167	=22307	49·272	+0·001	49·273	− 1
Mn 4041·366 (4) B	**135π + 70**	**=24370**	**49·087**	—	**49·088**	− **1**
Mn 4041·366 (4) B	123π + 81	=22221	49·082	+0·001	49·087	− 5
4045·822 (8) B	**135π + 10**	**=24310**	**48·967**	—	**48·968**	− **1**
4045·822 (8) B	123π + 27	=22167	48·963	+0·001	48·9667	− 4
4055·046 (1) B	**134π + 68**	**=24188**	**48·720**	—	**48·721**	− **1**
4055·046 (1) B	123π + 95	=22055	48·715	+0·001	48·720	− 5
Mn 4055·555 (2) B	—	—	—	—	48·707	—
Mn 4055·555 (2) B	—	—	—	—	48·706	—
4058·230 (2) B	122π + *52*	=22012	48·620	+0·001	48·6345	[−14]
4058·766 (1) B					48·6203	[±]
4059·726 (1) B	122π + *41*	=22001	48·596	+0·001	48·5948	+ 1
4062·451 (4) B	**133π + 151**	**=24091**	**48·520**	—	**48·523**	− **3**
4062·451 (4) B	122π + 9	=21969	48·525	+0·001	48·5223	+ 3
4063·604 (8) B	**133π + 134**	**=24074**	**48·490**	—	**48·493**	− **3**
4063·604 (8) B	121π + 169	=21949	48·481	+0·001	48·4919	−11
4066·983 (4) B	121π + 135	=21915	48·406	+0·001	48·4030	+ 3
4067·987 (5) B	**133π + 82**	**=24022**	**48·385**	—	**48·377**	+ **8**
4067·987 (5) B	121π + 118	=21898	48·369	+0·001	48·3759	− 7
4070·780 (2) B	121π + 80	=21860	48·285	+0·001	48·3021	[−17]
4071·748 (7) B	**133π + 28**	**=23968**	**48·277**	—	**48·278**	− **1**
4071·748 (7) B	121π + 75	=21855	48·274	+0·001	48·2767	− 3
4073·778 (3) H	121π + 51	=21831	48·221	+0·001	48·224	− 3
4074·793 (3) B	**132π + 169**	**=23929**	**48·197**	—	**48·198**	− **1**
4074·793 (3) B	121π + 39	=21819	48·194	+0·001	48·1973	− 3
4076·642 (5) I	**132π + 142**	**=23902**	**48·144**	—	**48·149**	− **5**
4076·642 (5) I	121π + 17	=21797	48·145	+0·001	48·1482	− 3
4078·362 (3) B	120π + 177	=21777	48·101	+0·001	48·1032	− 2
4079·847 (2) B	120π + 161	=21761	48·066	+0·001	48·0642	+ 2
4084·508 (4) B	**132π + 36**	**=23796**	**47·930**	—	**47·943**	[−**13**]
4085·012 (2) B					**47·930**	[±]
4085·314 (3) B					**47·921**	[+ **9**]
4085·314 (3) B	120π + 94	=21694	47·918	+0·001	47·9217	− 4
4087·102 (1) B	120π + 73	=21673	47·872	+0·001	47·8744	− 2
4095·980 (3) B	**131π + 75**	**=23655**	**47·646**	—	**47·646**	±
4095·980 (3) B	119π + 149	=21569	47·642	+0·001	47·6454	− 3
4098·189 (3) B	119π + 124	=21544	47·587	+0·001	47·5884	− 1
4100·745 (2) B	119π + 94	=21514	47·520	+0·001	47·5227	− 3
4104·135 (2) B	**130π + 149**	**=23549**	**47·433**	—	**47·437**	− **4**
4104·135 (2) B	119π + 56	=21476	47·436	+0·001	46·4357	±
4107·499 (5) B	**130π + 108**	**=23508**	**47·350**	—	**47·351**	− **1**
4107·499 (5) B	119π + 15	=21435	47·346	+0·001	47·3496	− 4
4109·810 (4) B	**130π + 77**	**=23477**	**47·288**	—	**47·291**	− **3**
4109·810 (4) B	118π + 168	=21408	47·286	+0·001	47·2907	− 5
4112·980 (2) B	118π + 135	=21375	47·213	+0·001	47·2100	+ 3
4114·454 (4) B	118π + 115	=21355	47·169	+0·001	47·1724	− 3

Table VI (continued).

(viii) *Eighth Section* (continued).

Wave-length.	Series C_2 Series B_4.	Total rota-tion.	Observed rotation per milli-metre.	Correction for regrinding.	Calcu-lated rotations per milli-metre.	Diff.
	°	°	°	°	°	
4118·552 (6) I	**129π + 148**	**=23368**	**47·068**	—	**47·069**	− **1**
4118·552 (6) I	118π + 69	=21309	47·068	+0·001	47·0685	±
4120·213 (2) B	**129π + 128**	**=23348**	**47·028**	—	**47·028**	±
4120·213 (2) B	118π + 48	=21288	47·021	+0·001	47·0266	− 5
4121·809 (2) B	118π + 31	=21271	46·984	+0·001	46·9861	− 2
4126·186 (2) B	117π + 165	=21225	46·882	+0·001	46·8759	+ 6
[4130·29 calc.]	117π + 115	=21175	46·772	+0·001	—	—
4132·064 (7) B	**128π + 160**	**=23200**	**46·727**	—	**46·729**	− **2**
4132·064 (7) B	117π + 94	=21154	46·725	+0·001	46·7284	− 3
4134·685 (5) I	**128π + 126**	**=23166**	**46·661**	—	**46·664**	− **3**
4134·685 (5) I	117π + 64	=21124	46·659	+0·001	46·6628	− 4
4137·002 (3) B	**128π + 101**	**=23141**	**46·611**	—	**46·608**	+ **3**
4137·002 (3) B	117π + 37	=21097	46·599	+0·001	46·6070	− 8
4143·420 (5) B 4143·874 (7) B	**128π + 14**	**=23054**	**46·436**	—	**46·447** **46·435**	[−**11**] [+ **1**]
4143·874 (7) B	116π + 143	=21023	46·436	+0·001	46·4342	+ 2]
4147·676 (4) I	**127π + 147**	**=23007**	**46·340**	—	**46·341**	− **1**
4147·676 (4) I	116π + 100	=20980	46·341	+0·001	46·3400	+ 1
4149·368 (2) B	116π + 81	=20961	46·299	+0·001	46·2980	+ 1
4152·176 (2) B	116π + 49	=20929	46·228	+0·001	46·2290	− 1
4154·504 (4) B	**127π + 64**	**=22924**	**46·174**	—	**46·173**	+ **1**
4154·504 (4) B	116π + 24	=20904	46·173	+0·001	46·1717	+ 1
4156·805 (4) B	115π + 178	=20878	46·116	+0·001	46·1152	+ 1
4157·805 (3) B	115π + 167	=20867	46·091	+0·001	46·0879	+ 3
4158·810 (2) B	115π + 156	=20856	46·067	+0·001	46·0661	+ 1
4170·906 (2) B	115π + 22	=20722	45·771	+0·001	45·7723	− 1
4172·128 (3) B	115π + 7	=20707	45·738	+0·001	45·742	− 4
4175·640 (4) B	**125π + 167**	**=22667**	**45·656**	—	**45·658**	− **2**
4175·640 (4) B	114π + 150	=20670	45·656	+0·001	45·6567	− 1
4178·048 (1) B	114π + *125*	=20645	45·601	+0·001	45·5988	+ 2
4181·759 (6) B	**125π + 94**	**=22594**	**45·509**	—	**45·510**	− **1**
4181·759 (6) B	114π + 83	=20603	45·508	+0·001	45·5094	− 1
4184·894 (4) B	**125π + 56**	**=22556**	**45·432**	—	**45·435**	− **3**
4184·894 (4) B	114π + 49	=20569	45·433	+0·001	45·4339	− 1
4187·052 (6) B	**125π + 30**	**=22530**	**45·380**	—	**45·383**	− **3**
4187·052 (6) B	114π + 24	=20544	45·378	+0·001	45·3821	− 4
4187·812 (6) B	**125π + 21**	**=22521**	**45·362**	—	**45·365**	− **3**
4187·812 (6) B	114π + 16	=20536	45·360	+0·001	45·3642	− 4
4191·443 (6) 1	**124π + 158**	**=22478**	**45·275**	—	**45·278**	− **3**
4191·443 (6) I	113π + 159	=20499	45·278	+0·001	45·2774	+ 1
4195·342 (3) B	113π + 116	=20456	45·183	+0·001	45·1877	− 5
4195·342 (3) B 4195·622 (2) B	**124π + 110**	**=22430**	**45·178**		**45·188** **45·182**	[−**10**] [− **4**]
4198·314 (6) B	**124π + 78**	**=22398**	**45·114**	—	**45·115**	− **1**
4199·098 (6) B	**124π + 68**	**=22388**	**45·094**	—	**45·096**	− **2**
4199·098 (6) B	113π + 78	=20418	45·099	+0·001	45·0953	+ 4
4202·032 (7) B	**124π + 34**	**=22354**	**45·026**	—	**45·027**	− **1**
4202·032 (7) B	113π + 45	=20385	45·027	+0·001	45·0258	+ 1

Table VI (continued).

(viii) *Eighth Section* (continued).

Wave-length.	Series C_2 Series B_4.	Total rota- tion.	Observed rotation per milli- metre.	Correction for regrinding.	Calcu- lated rotations per milli- metre.	Diff.
	°	°	°	°	°	
4203·985 (3) B	**124π + 12**	**=22332**	**44·980**	—	**44·981**	**— 1**
4203·985 (3) B	113π + 22	=20362	44·976	+0·001	44·9803	— 4
4207·127 (2) B	112π + 171	=20331	44·907	+0·001	44·9057	+ 1
4208·605 (2) B	112π + 156	=20316	44·874	+0·001	44·8708	+ 3
4210·362 (6) B	**123π + 116**	**=22256**	**44·829**	—	**44·830**	**— 1**
4210·362 (6) B	112π + 134	=20294	44·826	+0·001	44·8295	— 3
4213·649 (2) B	**123π + 80**	**=22220**	**44·755**	—	**44·756**	**— 1**
4213·649 (2) B	112π + 100	=20260	44·750	+0·001	44·7554	— 5
4216·185 (4) B	**123π + 49**	**=22189**	**44·693**	—	**44·694**	**— 1**
4216·185 (4) B	112π + 75	=20235	44·695	+0·001	44·6931	+ 2
4217·559 (2) B	112π + 58	=20218	44·658	+0·001	44·6609	— 3
4219·364 (5) B	**123π + 11**	**=22151**	**44·617**	—	**44·616**	**+ 1**
4219·364 (5) B	112π + 40	=20200	44·618	+0·001	44·6153	+ 3
4222·225 (5) B	**122π + 158**	**=22118**	**44·550**	—	**44·553**	**— 3**
4222·225 (5) B	112π + 10	=20170	44·552	+0·001	44·5522	±
4224·172 (3) B	**122π + 137**	**=22097**	**44·508**	—	**44·509**	**— 1**
4224·172 (3) B	111π + *169*	=20149	44·505	+0·001	44·5076	— 3
4225·464 (4) B	**122π + 120**	**=22080**	**44·474**	—	**44·478**	**— 4**
4225·464 (4) B	111π + 155	=20135	44·474	+0·001	44·4767	— 3
4227·445 (7) B	**122π + 98**	**=22058**	**44·429**	—	**44·432**	**— 3**
4227·445 (7) B	111π + 135	=20115	44·430	+0·001	44·4310	— 1
4233·615 (6) I	**122π + 28**	**=21988**	**44·288**	—	**44·289**	**— 1**
4233·615 (6) I	111π + 71	=20051	44·289	+0·001	44·2884	— 1
4235·953 (8) B	**122π + 1**	**=21961**	**44·234**	—	**44·235**	**— 1**
4235·953 (8) B	111π + 46	=20026	44·234	+0·001	44·2345	±
4238·828 (4) B	**121π + 146**	**=21926**	**44·163**	—	**44·169**	**— 6**
4238·828 (4) B	111π + 16	=19996	44·167	+0·001	44·1685	— 1
4245·258 (2) B	110π + 128	=19928	44·017	+0·001	44·0210	— 4
4247·440 (5) B	**121π + 51**	**=21831**	**43·971**	—	**43·972**	**— 1**
4247·440 (5) B	110π + 106	=19906	43·969	+0·001	43·9713	— 2
4250·791 (8) B	**121π + 14**	**=21794**	**43·898**	—	* 43·8950	[+ 5]
4250·134 (7) B	110π + 75	=19875	43·900	+0·001	43·9102	[—10]
4254·338 (2) B	110π + 37	=19837	43·816	+0·001	43·8126	+ 3
4260·489 (10)B	**120π + 84**	**=21684**	**43·676**	—	**43·677**	**— 1**
[4263·44 calc.]	109π + 123	=19743	43·609	+0·001	—	—
4271·171 (7) B	**119π + 139**	**=21559**	**43·425**	—	* 43·435	[—10]
4271·764 (8) B	109π + 40	=19660	43·425	+0·001	43·423	[— 2]
4274·801 (2) B	109π + 7	=19627	43·352	+0·001	43·3545	— 2
4282·408 (6) I	**119π + 20**	**=21440**	**43·185**	—	**43·186**	**— 1**
4282·408 (6) I	108π + 110	=19550	43·182	+0·001	43·1849	— 3
4285·448 (2) B	108π + 81	=19521	43·118	+0·001	43·1178	±
4294·132 (6) B	**118π + 72**	**=21312**	**42·926**	—	**42·927**	**— 1**
4294·132 (6) B	107π + 173	=19433	42·924	+0·001	42·926	— 2
4299·254 (7) B	**118π + 16**	**=21256**	**42·814**	—	**42·815**	**— 1**
4299·254 (7) B	107π + 123	=19383	42·813	+0·001	42·8138	— 1

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* These values are calculated for the cylinders before regrinding; calculated values after regrinding should be 0·001° higher.

Table VI (continued).

(viii) *Eighth Section* (continued).

Wave-length.	Series C_2 Series B_4.	Total rotation.	Observed rotation per millimetre.	Correction for regrinding.	Calculated rotations per millimetre.	Diff.
	°	°	°	°	°	
4305·458 (2) B	107π + 62	=19322	42·679	+0·001	42·6783	+ 1
4307·910 (8) B	**117π + 102**	**=21162**	**42·625**	—	**42·626**	— **1**
4307·910 (8) B	107π + 37	=19297	42·623	+0·001	42·6249	— 2
4315·089 (5) I	**117π + 20**	**=21080**	**42·469**	—	**42·470**	— **1**
4315·089 (5) I	106π + 147	=19227	42·469	+0·001	42·4693	±
4325·770 (9) B	**116π + 90**	**=20970**	**42·237**	—	**42·240**	— **3**
4325·770 (9) B	106π + 43	=19123	42·239	+0·001	42·2393	±
4337·052 (5) B	**115π + 151**	**=20851**	**41·998**	—	**42·999**	— **1**
4337·052 (5) B	105π + 114	=19014	41·998	+0·001	41·9985	±
4343·278 (2) B	105π + *52*	=18952	41·861	+0·001	41·8665	— 5
4346·561 (2) B	105π + *22*	=18922	41·795	+0·001	41·798	— 3
4352·741 (4) I	**114π + 165**	**=20685**	**41·664**	—	**41·668**	— **4**
4352·741 (4) I	104π + 145	=18865	41·669	+0·001	41·6672	+ 2
4358·506 (2) B	104π + 88	=18808	41·543	+0·001	41·5398	+ 3
4367·584 (2) B	104π + 3	=18723	41·356	+0·001	41·3582	— 2
4369·777 (3) B	**113π + 168**	**=20508**	**41·308**	—	**41·313**	— **5**
4369·777 (3) B	103π + 162	=18702	41·309	+0·001	41·3117	— 3
4375·934 (5) I	**113π + 105**	**=20445**	**41·180**	—	**41·185**	— **5**
4375·934 (5) I	103π + 105	=18645	41·183	+0·001	41·1844	— 1
4383·548 (10) B	**113π + 27**	**=20367**	**41·032**	—	**41·029**	+ **3**
4383·548 (10) B	103π + 34	=18574	41·026	+0·001	41·0277	— 2
4388·422 (2) B	102π + 172	=18532	40·934	+0·001	40·9381	— 4
4401·304 (3) B	102π + 48	=18408	40·660	+0·001	40·667	[— 7]
4401·447 (2) B					40·664	[— 4]
4404·752 (8) B	**111π + 175**	**=20155**	**40·596**	—	**40·597**	— **1**
4404·752 (8) B	102π + 18	=18378	40·594	+0·001	40·5965	— 2
4408·420 (4) B	101π + 168	=18348	40·527	+0·001	40·5224	+ 5
4415·127 (8) B	**111π + 72**	**=20052**	**40·389**	—	**40·389**	±
4415·127 (8) B	101π + 105	=18285	40·388	+0·001	40·3880	±
4422·570 (4) B	101π + 37	=18217	40·238	+0·001	40·2394	— 1
4427·314 (5) I	**110π + 130**	**=19930**	**40·143**	—	**40·146**	— **3**
4427·314 (5) I	100π + 174	=18174	40·143	+0·001	40·1453	— 2
4430·622 (4) B	**110π + 100**	**=19900**	**40·083**	—	**40·081**	+ **2**
4430·622 (4) B	100π + 145	=18145	40·079	+0·001	40·0796	— 1
4433·222 (2) B	100π + 122	=18122	40·028	+0·001	40·0279	±
4442·349 (5) B	**109π + 160**	**=19780**	**39·841**	—	**39·844**	— **3**
4442·349 (5) B	100π + 38	=18038	39·843	+0·001	39·8435	±
4447·727 (5) B	**109π + 110**	**=19730**	**39·741**	—	**39·744**	— **3**
4447·727 (5) B	99π + 169	=17989	39·734	+0·001	39·7429	— 9
4454·387 (3) B	99π + 114	=17934	39·613	+0·001	39·6136	— 1
4459·128 (5) B	**109π + 2**	**=19622**	**39·523**	—	**39·523**	±
4459·128 (5) B	99π + 71	=17891	39·518	+0·001	39·5216	— 4
4461·658 (4) B	99π + 49	=17869	39·469	+0·001	39·4724	— 3
4461·658 (4) B	**108π + 153**	**=19593**	**39·465**	—	**39·473**	[— **8**]
4462·011 (3) B					**39·467**	[— **2**]
4466·556 (5) I	**108π + 110**	**=19550**	**39·378**	—	**39·379**	— **1**
4466·556 (5) I	99π + 7	=17827	39·376	+0·001	39·3782	— 2

Table VI (continued).

(viii) *Eighth Section* (continued).

Wave-length.	Series C_2 Series B_4.	Total rota-tion.	Observed rotation per milli-metre.	Correction for regrinding.	Calcu-lated rotations per milli-metre.	Diff.
	°	°	°	°	°	
4469·390 (4) B	**$108\pi + 84$**	**=19524**	**39·325**	—	**39·325**	±
4469·390 (4) B	$98\pi + 162$	=17802	39·321	+0·001	39·3237	— 3
4476·023 (7) B	**$108\pi + 20$**	**=19460**	**39·196**	—	**39·197**	**— 1**
4476·023 (7) B	$98\pi + 105$	=17745	39·195	+0·001	39·1965	— 1
* 4482·262 (4) B	**$107\pi + 140$**	**=19400**	**39·075**	—	**39·078**	**— 3**
4482·262 (4) B	$98\pi + 52$	=17692	39·078	+0·001	39·0776	±
4484·238 (3) B	$98\pi + 36$	=17676	39·043	+0·001	39·0398	+ 3
4489·744 (3) B	$97\pi + \mathit{165}$	=17625	38·930	+0·001	38·9362	— 6
4494·572 (5) I	**$107\pi + 27$**	**=19287**	**38·848**	—	**38·847**	**+ 1**
4494·572 (5) I	$97\pi + 126$	=17586	38·844	+0·001	38·8461	— 2
4517·530 (2) B	$96\pi + 108$	=17388	38·407	+0·001	38·4150	— 8
4525·154 (3) B	$96\pi + 46$	=17326	38·270	+0·001	38·2714	— 1
4528·624 (7) B	**$105\pi + 71$**	**=18971**	**38·211**	—	**38·211**	±
4528·624 (7) B	$96\pi + 18$	=17298	38·208	+0·001	38·2101	— 2
4531·155 (5) I	**$105\pi + 49$**	**=18949**	**38·168**	—	**38·165**	**+ 3**
4531·155 (5) I	$95\pi + 177$	=17277	38·162	+0·001	38·1636	— 2
4547·853 (3) I	$95\pi + 40$	=17140	37·859	+0·001	37·8642	— 5
4556·128 (3) B	$94\pi + 150$	=17070	37·704	+0·001	37·7077	— 4
4581·529 (2) B	$93\pi + 130$	=16870	37·263	+0·001	37·2559	+ 7
4583·843 (2) B	$93\pi + 108$	=16848	37·213	+0·001	37·2150	— 2
4587·136 (2) B	$93\pi + 81$	=16821	37·154	+0·001	37·157	— 3
4592·658 (4) I	$93\pi + 37$	=16777	37·057	+0·001	37·0596	— 3
4595·368 (2) B	$93\pi + 16$	=16756	37·011	+0·001	37·0121	— 1
4599·903 (2) B	$92\pi + 173$	=16723	36·938	+0·001	36·9328	+ 5
4602·947 (5) I	**$101\pi + 131$**	**=18311**	**36·881**	—	**36·882**	**— 1**
4602·947 (5) I	$92\pi + 136$	=16696	36·878	+0·001	36·8810	— 3
4607·665 (4) B	$92\pi + 100$	=16660	36·799	+0·001	36·7977	+ 1
4611·290 (4) B	$92\pi + 71$	=16631	36·735	+0·001	36·7349	±
4613·217 (3) B	$92\pi + 54$	=16614	36·697	+0·001	36·6913	+ 6
4619·295 (4) B	$92\pi + 9$	=16569	36·598	+0·001	36·5889	+ 9
4625·061 (4) B	$91\pi + 141$	=16521	36·492	+0·001	36·4975	— 5
4630·128 (3) B	$91\pi + 106$	=16486	36·414	+0·001	36·4109	+ 3
4632·919 (3) B	$91\pi + 80$	=16460	36·357	+0·001	37·3633	— 6
4638·020 (4) B	$91\pi + 44$	=16424	36·278	+0·001	36·2774	+ 1
4643·467 (3) B	$91\pi + 3$	=16383	36·187	+0·001	36·1841	+ 3
4647·439 (4) I	$90\pi + 150$	=16350	36·114	+0·001	36·1167	— 3
4654·502 (4) B	$90\pi + 96$	=16296	35·995	+0·001	35·9882	+ 7
4667·460 (4) B 4668·153 (4) B	**$98\pi + 122$**	**=17762**	**35·776**	—	35·783 35·771	[— 7] [+ 5]
4668·153 (4) B	$89\pi + 177$	=16197	35·776	+0·001	35·7699	+ 6
4678·856 (5) B	$89\pi + 94$	=16114	35·593	+0·001	35·5934	±
4691·417 (4) I	$88\pi + 181$	=16021	35·387	+0·001	35·3854	+ 2
4707·288 (5) I	$88\pi + 64$	=15904	35·129	+0·001	35·1182	+11
4736·786 (5) I	$87\pi + 29$	=15689	34·654	+0·001	34·6459	+ 8
4786·810 (3) B	$85\pi + 41$	=15341	33·885	+0·001	33·8770	+ 8
4789·657 (3) I	$85\pi + 16$	=15316	33·830	+0·001	33·8235	+ 6
4859·758 (5) I	$82\pi + 83$	=14843	32·785	+0·001	32·7881	— 3
4872·154 (6) B	$82\pi + 6$	=14766	32·615	+0·001	32·6118	+ 3

* A neighbouring line 4482·176 (3) B may have been included, but, as the calculated rotation for this line is only 0·002°/mm. higher, the effect is negligible.

Table VI (continued).

(viii) *Eighth Section* (continued).

Wave-length.	Series C_2 Series B_4.	Total rotation.	Observed rotation per millimetre.	Correction for regrinding.	Calculated rotations per millimetre.	Diff.
	°	°	°	°	°	
4878·225 (5) **I**	81π + 143	=14723	32·520	+0·001	32·5208	− 1
4891·510 (9) B	81π + 58	=14638	32·333	+0·001	32·3307	+ 2
4903·325 (5) **I**	80π + 161	=14561	32·162	+0·001	32·1630	− 1
4920·521 (10) B	80π + 55	=14455	31·928	+0·001	31·9212	+ 7
4938·828 (5) B	79π + 115	=14335	31·663	+0·001	31·6658	− 3
4957·612 (10) B	79π + 0	=14220	31·409	+0·001	31·4092	±
4983·274 (3) B	78π + 24	=14064	31·065	+0·001	31·0685	− 3
5001·881 (5) **I**	77π + 90	=13950	30·813	+0·001	30·8139	− 1
5006·134 (5) B	77π + 65	=13925	30·758	+0·001	30·7577	±
5041·763 (4) B	76π + *38*	=13718	30·300	+0·001	30·2922	+ 8
5049·827 (5) **I**	75π + 166	=13666	30·186	+0·001	30·1897	− 4
5133·676 (5) B	73π + 55	=13195	29·145	+0·001	29·1405	+ 4
5139·481 (8) B	73π + 21	=13161	29·070	+0·001	29·0699	±
5167·492 (8) **I**	72π + 48	=13008	28·732	+0·001	28·7336	− 2
5227·187 (8) B	70π + 92	=12692	28·034	+0·001	28·0363	− 2
5232·957 (8) **I**	70π + 61	=12661	27·966	+0·001	27·9693	− 3
5269·538 (10) B	69π + *55*	=12475	27·555	+0·001	27·5557	− 1
5283·634 (7) B	68π + 166	=12406	27·403	+0·001	27·3988	+ 4
5324·196 (6) **I**	67π + 144	=12204	26·956	+0·001	26·957	− 1
5328·044 (7) B	67π + 124	=12184	26·912	+0·001	26·9143	− 2
5341·031 (5) B	67π + *61*	=12121	26·773	+0·001	26·7737	− 1
5371·495 (7) **I**	66π + *94*	=11974	26·448	+0·001	26·4528	− 5
5383·366 (5) B	66π + *40*	=11920	26·329	+0·001	26·3266	+ 2

agreement between the observed and calculated rotations could be checked. The average differences for these readings were as follows :—

Quartz Prisms. 344 readings.

$$\text{Casual errors} \quad \pm\frac{1353+1219}{344} \equiv \pm\, 0\cdot0075^\circ/\text{mm.}$$

$$\text{Systematic error} \quad \frac{1353-1219}{344} \equiv +\, 0\cdot0004^\circ/\text{mm.}$$

Glass Prisms. 460 readings.

$$\text{Casual errors} \quad \pm\frac{405+701}{460} \equiv \pm\, 0\cdot0024^\circ/\text{mm.}$$

$$\text{Systematic error} \quad \frac{405-701}{460} \equiv -\, 0\cdot0007^\circ/\text{mm.}$$

Total. 804 readings.

$$\text{Casual errors} \quad \pm\frac{1758+1920}{804} \equiv \pm\, 0\cdot0046^\circ/\text{mm.}$$

$$\text{Systematic error} \quad \frac{1758-1920}{804} \equiv -\, 0\cdot0002^\circ/\text{mm.}$$

It will be seen that on the grand total of 804 readings, the average casual error was less than 0·005°/mm. and the systematic error was only — 0·0002°/mm., *i.e.*, less than two units in the decimal place beyond that to which readings were taken.

(*g*) *Copper, Silver and Cadmium Spectra.*—Readings were taken with the copper and silver-cadmium arcs* in the hope that, by using a less crowded spectrum, and by concentrating attention on a limited number of lines, it might be possible to attain a higher degree of accuracy than when using the iron arc, and perhaps to add one more decimal to the rotations in degrees per millimetre. We also hoped to be able to extend the readings beyond the point, at 2327 A.U., where the iron arc suddenly becomes weak. For this purpose the whole of the available quartz was combined into a single column, which was rather more than half a metre in length before regrinding, namely, 500·831 mm., but after regrinding was rather less than half a metre, namely, 496·474 mm. In practice we were able to extend the measurements over a further range of about 60 A.U. to a wave-length at which the observed rotations exceeded 100,000° and the calculated rotations were greater than 200° per millimetre; but we did not find it practicable to secure any increase of accuracy.

(i) *Copper.*—Two very strong ultra-violet copper lines, at 3247·554 and 3273·965 A.U., have been included in Table VI amongst the data for the iron arc, in which they had already been recorded as known impurities of the spectrum. In addition, we record in Table VII rotations of the old series of measurements for 11 lines of the copper-arc spectrum, and of the new series for 14 lines. Altogether, 19 additional lines were read, ranging from 3208·236 to 2263·09 A.U.

No trustworthy data for the wave-lengths of these additional lines appear to be available, so that no rigid check on the validity of our dispersion formula, or on the accuracy of our readings, was possible. It is, however, of interest to note that in the region from 3208 to 2370 A.U., in which the validity of our equations is proved by readings of the standard lines of the iron-arc spectrum, the wave-lengths given by HUPPERS† yield the following differences between the observed and calculated rotations of the new series:—

$$\pm, \ +7, \ +3, \ +3, \ \pm, \ +6, \ +9, \ +18, \ +12, \ +8, \ +3, \ \pm, \ +2, \ \pm.$$

Since the systematic error deduced from these differences, namely 71/14 ≡ + 0·005°/mm., agrees closely with the positive systematic error (269 − 85)/64 ≡ + 0·003°/mm., recorded for rotations of the iron lines in the same region, we conclude that these wave-lengths (although apparently not based on interferometer readings) are substantially correct. In particular, we regard them as more trustworthy than the wave-lengths given by HASBACH,‡ since these lead to differences which are substantially larger, and are also predominantly negative, instead of positive, thus:—

$$-4, \ -1, \ -7, \ -5, \ -14, \ -5, \ -1, \ +2, \ -3, \ -2, \ -11, \ -18, \ -20, \ -15.$$

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* LOWRY, 'Phil. Mag.,' (vi), vol. 18, p. 320 (1909).

† 'Z. f. wiss. Photogr.,' vol. 13, p. 59 (1913).

‡ 'Z.f. wiss. Photogr.,' vol. 13, p. 399 (1914).

TABLE VII.—Copper Lines.

Hu = HUPPERS, 'Zeit. wiss. Photgr.,' vol. 13, p. 59 (1913).
Ha = HASBACH, 'Zeit. wiss. Photgr.,' vol. 13, p. 399 (1914).

Wave-length.	Observed rotation.	Total rotation.	Observed rotation per millimetre.	Correction for regrinding per millimetre.	Calculated rotations per millimetre.	Diff.
	°	°	°	°	°	
3208·236 (4) Ha 3208·30 (3) Hu	**229π + 82**	**=41302**	**83·191**	—	**83·195** **83·191**	**− 4** ±
3194·103 (6) Ha 3194·23 (5) Hu	**231π + 156**	**=41736**	**84·065**	—	**84·066** **84·058**	**− 1** **+ 7**
3073·803 (4) Ha 3073·94 (3) Hu	**254π + 9***	**=45749**	**92·108**	—	**92·115** **92·105**	**− 7** **+ 3**
3063·416 (6) Ha 3063·53 (5) Hu	**256π + 18**	**=46098**	**92·851**	—	**92·856** **92·848**	**− 5** **+ 3**
3010·840 (5) Ha 3011·02 (4) Hu	**266π + 167**	**=48047**	**96·776**	—	**96·790** **96·776**	**−14** ±
2997·363 (4) Ha 2997·50 (5) Hu	**269π + 162**	**=48582**	**97·854**	—	**97·859** **97·848**	**− 5** **+ 6**
2961·177 (6) Ha 2961·31 (10) Hu	**277π + 175**	**=50035**	**100·781**	—	**100·782** **100·772**	**− 1** **+ 9**
2961·177 (6) Ha 2961·31 (10) Hu	280π + 75	=50475	100·782	+0·008	100·774 100·763	+ 8 +19
2882·937 (4) Ha 2883·11 (4) Hu	**296π + 137***	**=53417**	**107·593**	—	**107·591** **107·575**	**+ 2** **+18**
2824·375 (8) Ha 2824·53 (6) Hu	**312π + 27**	**=56187**	**113·172**	—	**113·175** **113·160**	**− 3** **+12**
2766·388 (8) Ha 2766·48 (6) Hu	**328π + 126**	**=59166**	**119·168**	—	**119·170** **119·160**	**− 2** **+ 8**
2766·388 (8) Ha 2766·48 (6) Hu	331π + 100	=59680	119·162	+0·010	119·160 119·149	+ 2 +13
2618·381 (10) Ha 2618·48 (10) Hu	**377π + 140**	**=68000**	**136·966**	—	**136·977** **136·963**	**−11** **+ 3**
2618·381 (10) Ha 2618·48 (10) Hu	381π + 17	=68597	136·966	+0·016	136·961 136·947	+ 5 +19
2492·142 (8) Ha 2492·24 (4) Hu	**429π + 105**	**=77325**	**155·748**	—	**155·766** **155·748**	**−18** ±
2492·142 (8) Ha 2492·24 (4) Hu	433π + 69	=78009	155·759	+0·020	155·747 155·728	+12 +31
2441·625 (6) Ha 2441·75 (4) Hu	**453π + 100**	**=81640**	**164·444**	—	**164·464** **164·442**	**−20** **+ 2**
2441·625 (6) Ha 2441·75 (4) Hu	457π + 100	=82360	164·443	+0·023	164·440 164·419	+ 3 +24
2406·661 (6) Ha 2406·78 (3) Hu	475π + 99	=85599	170·914	+0·025	170·923 170·900	− 9 +14
2392·629 (8) Ha 2392·72 (5) Hu	483π + 10	=86950	173·611	+0·026	173·641 173·623	−30 −12
2369·877 (6) Ha 2369·95 (3) Hu	**491π + 97**	**=88477**	**178·211**	—	**178·226** **178·211**	**−15** ±
2369·877 (6) Ha 2369·95 (3) Hu	495π + 144	=89244	178·192	+0·027	178·199 178·184	− 7 + 8

* Composite line.

Table VII (continued).

Wave-length.	Observed rotation.	Total rotation.	Observed rotation per millimetre.	Correction for regrinding per millimetre.	Calculated rotations per millimetre.	Diff.
	°	°	°	°	°	
2303·109 (6) Ha	537π + 43	=96703	192·725	+0·033	192·740	−15
2303·17 (5) Hu					192·727	− 2
2293·832 (8) Ha	542π + 45	=97605	194·886	+0·034	194·913	−27
2293·92 (5) Hu					194·892	− 6
2263·09 (6) Ha	562π + 172	=101332	202·328	+0·037	202·398	−70
2263·14 (2) Hu					202·386	−58

TABLE VIII.—Silver-Cadmium Lines.

Hu = HUPPERS, 'Zeit. wiss. Phot.,' vol. 13, pp. 51 and 69 (1913).
MB = MEGGERS and BURNS, 'Bur. Stand.,' vol. 441, p. 185 (1922).
Fr = FRINGS, 'Zeit. wiss. Phot.,' vol. 15, p. 165 (1915).
R = RUBIES, 'An. Soc. Fis. Quim.,' vol. 15, p. 215 (1917).

Wave-length.	Observed rotation.	Total rotation.	Observed rotation per millimetre.	Correction for regrinding per millimetre.	Calculated rotations per millimetre.	Diff.
	°	°	°	°	°	
Cd 3403·6529 MB	**199π + 152**	**=35972**	**72·455**	—	**72·453**	**+ 2**
Cd 3261·18 (3) Hu	**220π + 147**	**=39747**	**80·059**	—	**80·052**	**+ 7**
Cd 2837·03 (20) Hu	**308π + 135**	**=55575**	**111·939**	—	**111·930**	**+ 9**
Ag 2437·79 (9) Fr					**156·156**	**− 1**
[2437·83 (calc.)]	**455π + 95**	**=81995**	165·155	—		
Ag 2437·87 (10) Hu					**165·142**	**+13**
Ag 2331·35 (7) Fr					186·353	+ 1
[2331·35 (calc.)]	518π + 92	=93332	186·354	+0·029		
Ag 2331·45 (3) Hu					186·331	+23
Cd 2329·35 (10) Hu	**515π + 60**	**=92760**	**186·838**	—	**186·836**	**+ 2**
Ag 2324·65 (7) Fr					187·846	−44
[2324·84 (calc.)]	522π + 97	=94057	186·802	+0·030		
Ag 2324·80 (3) Hu					187·813	−11
Ag 2320·23 (8) Fr					188·834	−16
[2320·30 (calc.)]	525π + 66	=94566	188·818	+0·031		
Ag 2320·39 (3) Hu					188·798	+20
Ag 2317·02 (7) Fr					188·557	−18
[2317·10 (calc.)]	527π + 67	=94927	189·539	+0·032		
Ag 2317·16 (2) Hu					189·525	+14
Ag 2309·55 (5) Fr					191·258	−20
[2309·63 (calc.)]	532π + 18	=95778	191·238	+0·033		
Ag 2309·71 (5) Hu					191·220	+18
Ag 2279·93 (2) R					198·243	−43
Ag 2279·96 (7) F	551π + 85	=99265	198·200	+0·036	198·235	−35
[2280·11 (calc.)]						
Ag 2280·14 (3) Hu					198·191	+ 9

The readings of the old series, which extend to shorter wave-lengths than those of the new series, are much less regular, and do not appear to be very trustworthy. It is, however, noteworthy that they agree quite well with the rotations calculated from the wave-lengths of HUPPERS, not only for the last wave-length included in the other series, but also for two wave-lengths beyond it, which are outside the limits covered by our readings of the iron-arc spectrum. The final line, which gave an observed rotation greater than 100,000°, and a rotation per millimetre $> 200°$/mm., shows much larger deviations from the calculated rotations; but it is difficult to know whether these should be attributed to errors in reading the rotation or to errors in the wave-length, since a discrepancy of 0·029 A.U., although unlikely, is by no means impossible in this region of the spectrum, where a change of 1 A.U. corresponds with a difference of rotation of not less than 0·24°/mm.

(ii) *Cadmium.*—The cadmium spectrum was particularly disappointing, since nearly all the well-known ultra-violet lines were too broad to give sharp extinctions with the very long columns of quartz which we were using. Instead, therefore, of being able to read the rotations to another decimal place, we found that no readings at all could be obtained for many of the lines from the photographic plates. The cadmium spectrum, therefore, only gave a few additional readings in a range which was already amply covered by scores of lines of the iron-arc spectrum. It is, however, of interest to note that the new standard cadmium line, 3403·6529 A.U., of MEGGERS and BURNS* showed a difference of only 0·002°/mm. between the observed and calculated rotations, or a deviation of only 1° in the original readings of the total rotation of the column of quartz. The wave-lengths given by HUPPERS for the three other cadmium lines which are included in our new series of readings lead to differences of + 7, + 9 and + 2 between the observed and calculated rotations; these differences are larger than those recorded for the corresponding section of the iron-arc spectrum, but they are small enough to indicate that the wave-lengths given by HUPPERS are again substantially correct.

(iii) *Silver.*—The six silver lines of the old series of readings are all beyond the limits covered by the standard interferometer readings of the iron arc, and the published wave-lengths are grossly divergent. We have, therefore, again been unable to use them to check the validity of our formulæ; but, in view of the fact that these formulæ have been proved to be valid over the whole range from 25,000 to 2373 A.U., there did not appear to be any serious risk in using them for extrapolation over a further range of 100 A.U. The wave-lengths which we have calculated on this basis agree very well with the values of HUPPERS, when these are diminished by 0·08 A.U., in accord with the known correction on ROWLANDS' wave-lengths in this part of the spectrum. We, therefore, conclude that these wave-lengths (which are approximately the mean of the values given by FRINGS and by HUPPERS) are substantially correct.

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* 'Bur. Stand.,' vol. 441, p. 185 (1922).

Wave-Lengths of Ultra-Violet Silver Lines.

Calculated ..	2437·83	2331·35	2324·84	2320·30	2317·10	2309·63	2280·11
HUPPERS (corr.)	0·79	0·37	0·72	0·31	0·08	0·63	0·06

8. *Summary and Conclusion.*

(*a*) *Purpose of the Experiments.*—The measurements of the optical rotatory power of quartz were undertaken originally as a means of testing, in the most drastic way that was possible, the new methods that were being developed for studying the rotatory dispersion of organic compounds. The large and very precise rotatory powers of long columns of quartz provided ideal conditions for such a test, and the validity of the methods thus established has been abundantly confirmed by further experience during the period of nearly 20 years which has elapsed since the work was begun. A second and equally important motive was to provide accurate data for a rigid study of the form of the curves of rotatory dispersion.

(*b*) *Verification of Drude's Equation.*—The most important result of the experiments which have led up to the present paper has been to establish the complete validity of the simplified equation which DRUDE developed in 1898 to represent the rotatory dispersion of transparent media, namely, $\alpha = \Sigma\, k_n / (\lambda^2 - \lambda_n^2)$. Crucial experiments, carried out with the highest degree of accuracy which we can now attain, have shown that this equation provides a complete expression of the rotatory dispersion of (i) a large range of substances, including octyl alcohol and cane sugar,* which obey the law of "simple" rotatory dispersion—

$$\alpha = \frac{k}{\lambda_2 - \lambda_0^2};$$

(ii) substances such as ethyl tartrate† and camphor,‡ which exhibit "anomalous rotatory dispersion," or "quasi-anomalous" rotatory dispersion,§ and therefore require the use of two terms of opposite sign—

$$\alpha = \frac{k_1}{\lambda^2 - \lambda_1^2} - \frac{k_2}{\lambda^2 - \lambda_2^2};$$

and (iii) of substances, such as α-chlorocamphor and α-bromocamphor,‖ which exhibit "complex but normal" dispersion, and require the use of two terms of similar sign, *e.g.*—

$$\alpha = \frac{k_1}{\lambda^2 - \lambda_1^2} + \frac{k_2}{\lambda^2 - \lambda_2^2}.$$

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* LOWRY and RICHARDS, 'J. Chem. Soc.,' vol. 125, pp. 1593 and 2511 (1924).

† LOWRY and CUTTER, 'J. Chem. Soc.,' vol. 121, p. 532 (1922).

‡ LOWRY and CUTTER, 'J. Chem. Soc.,' vol. 127, p. 612 (1925).

§ LOWRY and CUTTER, 'J. Chem. Soc.,' vol. 127, p. 608, footnote (1925).

‖ CUTTER, BURGESS and LOWRY, 'J. Chem. Soc.,' vol. 127, p. 1260 (1925).

The data for quartz are unique in that the range and precision of the measurements now recorded are sufficient to determine more than the four arbitrary constants, which is the maximum for all ordinary organic compounds. We therefore began by adding an infra-red term, with two additional constants, to the three-constant equation, $\alpha = k_1/(\lambda^2 - \lambda_1^2) - k/\lambda^2$, which DRUDE had put forward; but further experience showed that it was possible to use a single small constant to represent the infra-red terms, provided that the two ultra-violet terms were each provided with an independent dispersion-constant and an independent rotation-constant. Our final equations, therefore, contained three terms and five independent constants, as follows :—

$$\alpha = \frac{k_1}{\lambda^2 - \lambda_1^2} - \frac{k_2}{\lambda^2 - \lambda_2^2} - k.$$

(*c*) *Determination of Dispersion-Constants.*—In deriving an equation for the rotatory dispersion of quartz, DRUDE deduced his solitary dispersion-constant from measurements of refraction, instead of calculating it from the rotations themselves. This procedure has been reversed in our own experience. Thus, whilst we were able in 1912 to express our new visual readings by using the dispersion-constants of DRUDE's equation, with the addition of an infra-red term, these constants are inadequate to cover the ultra-violet readings now recorded. We have, therefore, been compelled to break away from the earlier tradition of deducing the dispersion-constants from measurements of absorption or refraction, and to calculate them from the rotations themselves. Experience has proved that these can now be determined with much greater accuracy than was previously possible *either from measurements of refraction or of optical rotatory power.* Thus, whereas all the data formerly available could be expressed by equations in which a zero value was assigned to one of the dispersion-constants, the finite numerical values given in our equations can only be varied within relatively narrow limits if the calculated rotations are to conform to the very precise data which are set out in the present paper. The sensitiveness of the constants thus deduced can be illustrated by comparing the equations (v) and (vi) used to represent the rotatory power of quartz before and after regrinding, namely,

$$\text{(v)}\quad \alpha = \frac{9\cdot5644}{\lambda^2 - 0\cdot012742} - \frac{2\cdot3114}{\lambda^2 - 0\cdot000974} - 0\cdot1915,$$

$$\text{(vi)}\quad \alpha = \frac{9\cdot5639}{\lambda^2 - 0\cdot0127493} - \frac{2\cdot3113}{\lambda^2 - 0\cdot000974} - 0\cdot1905,$$

where a deviation of 0·03°/mm. at wave-length 2327 A.U. is covered by an alteration of 1 part in 20,000 in the rotation-constant and of 1 part in 2,000 in the dispersion-constant of the low-frequency term, with a small compensating correction in the "infra-red" constant, but without calling for any alteration in the constants of the high-frequency term.

Although, therefore, the large number of significant figures used in these equations results from a series of fine adjustments, and might be reduced by a laborious process of readjustment of all the constants simultaneously, we believe that the location of the two characteristic wave-lengths λ_1 and λ_2 at 1130 and 310 A.U., respectively, is substantially correct. Since the characteristic wave-lengths thus deduced are much more precise than any of the values that have been available hitherto, we have been able to reverse DRUDE's procedure to the extent of deriving from the rotations an equation for the refractive dispersion of quartz, which agrees in an exemplary manner with the very exact data of GIFFORD[*] for the refractive indices of the ordinary ray in the visible and ultra-violet regions, and which shows only small deviations in the infra-red region down to 13070 A.U.

The method of deducing the dispersion-constants from the rotatory powers themselves, instead of from cognate data, has also been vindicated in a dramatic manner by the discovery[†] that the characteristic wave-lengths derived from the dispersion-constants are generally greater by about 100 Ångström units than those at which a maximum is recorded in the molecular absorption coefficient of an organic compound. This discrepancy is easily understood if the "selective absorption" is superposed on a broad band of "general absorption," as is actually the case for many organic compounds; but the discovery of this discrepancy was due entirely to the fact that the dispersion-constants were calculated before the absorption-coefficients had been determined, instead of being deduced from them.

(*d*) *Validity of Equations.*

(i) *Photographic Region.*—The proof of the complete validity of the equations which we have used to express the rotatory dispersion of quartz depends on a demonstration that there are no marked systematic differences between the observed and calculated rotations. These differences are summarised in the following table:—

	Old series.		New series.	
	Casual errors.	Systematic error.	Casual errors.	Systematic error.
Section 2—2373 to 2413 A.U.	0·006	−0·0033	0·006	+0·0008
,, 3—2417 to 2562 A.U.	0·014	+0·0010	0·006	+0·0018
,, 4—2563 to 3099 A.U.	0·009	+0·0006	0·005	+0·0031
,, 5—3116 to 3485 A.U.	0·006	−0·0018	0·002	+0·0003
,, 6—3490 to 3542 A.U.	0·004	+0·0014	1 reading only.	
,, 7—3554 to 3814 A.U.	0·002	+0·0004	3 readings only.	
,, 8—3815 to 5383 A.U.	0·003	+0·0006	0·002	−0·0016

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[*] GIFFORD, 'Roy. Soc. Proc.,' vol. 70, p. 336 (1902).

[†] CUTTER, BURGESS and LOWRY, 'J. Chem. Soc.,' vol. 127, p. 1266 (1925).

It will be seen that the largest systematic errors are in Sections 2 and 4, in each of which an average difference of ± 0·003°/mm. is recorded for *one* series of readings with quartz prisms. In each case, however, the other series shows a systematic error of less than + 0·001°/mm. Thus the more numerous readings of the old series give mainly positive differences in the early part of Section 4, and negative differences in the latter, so that the systematic error for the section is only + 0·001°/mm. In a similar manner the readings of the old series with glass prisms, where the casual errors are particularly small, show a "run" of positive differences at the beginning of Section 7; but these differences become irregular in the second half of the section, and remain so throughout Section 8, where there is a slight excess of negative differences, and even the longest run of positive differences shows a systematic error of only + 0·001°/mm. The readings of the new series also show a "run" of negative differences in the middle of Section 8, but these, again, do not exceed − 0·002°/mm. It therefore appears that the old formula for the quartz before regrinding is valid within about 0·001°/mm., and that the new formula for the reground quartz is valid within about 0·002°/mm. Since only integral degrees in the total rotation, equivalent to 0·002°/mm. were read, it is unlikely that any further adjustment of the formula would give rise to a closer agreement, and the validity of the DRUDE formulæ is thus established within the closest possible limits for the whole range of the photographic readings.

(ii) *Visual Region.*—A very gratifying feature of the observations which are now recorded is the evidence that was obtained that differences between the observed and calculated rotations depended more on uncertainties in the values adopted for the wave-lengths of the different lines than on actual errors in the rotations themselves. Thus, when the observations were first worked out, it was impossible to secure any satisfactory agreement between the observed and calculated values because of the existence of a marked discontinuity between the visual and the photographic readings. It was therefore difficult to represent the two sets of observations by a single formula, since a closer agreement could obviously be reached by using one formula to represent the visual and another to represent the photographic series of readings. It was a great relief, therefore, to discover that this divergence disappeared completely when the rotations for the visual lines were re-calculated with the help of newer and more accurate values for the wave-lengths. Not only were the two series of readings thus brought completely into agreement, but the average error of the visual readings published in 1912 was reduced to one half. Thus, whereas formerly the average error for 24 wave-lengths was 0·0015° per millimetre, it was now possible to deduce a formula which gave an average error of only 0·0007° per millimetre for 23 out of the 24 lines, the only reading which showed an increased error being that of the green copper line of wave-length 5218 A.U., with which a more refrangible satellite had been deliberately included.

(iii) *Infra-Red Region.*—The rotations in this portion of the spectrum were expected to be considerably less accurate than the ultra-violet readings, since the extinctions could be read only within about 5°, whereas on the photographic plates they were read to 1°.

In practice, however, the errors were found to be of a similar order of magnitude, and the readings with the galvanometer do not compare unfavourably with those of the most difficult portions of the photographic record. Thus the 13 galvanometric readings with a glass prism, and 6 readings with a quartz prism, in the infra-red spectrometer, gave the following differences between the observed and calculated rotations :—

$$\text{Casual errors} \quad \pm \frac{109 + 119}{19} \equiv \pm 0{\cdot}012^\circ/\text{mm.}$$

$$\text{Systematic error} \; .. \; \frac{109 - 119}{19} \equiv - 0{\cdot}0005^\circ/\text{mm.}$$

More important is the fact that, in the region of maximum sensitiveness, four readings with the glass prism showed a casual error of ± 0·001°/mm. and a systematic error of + 0·001°/mm. at wave-lengths ranging from 16,600 to 18,600 A.U., whilst four similar readings with the quartz prism showed a casual error of ± 0·005°/mm., and a systematic error of — 0·002°/mm. at wave-lengths ranging from 20,000 to 24,000 A.U. Since these systematic errors are considerably smaller than the expected error of reading, there can be no doubt that in this region also the equation cited above represents the data completely, within the limits of accuracy of the measurements now recorded. Whilst, therefore, the errors of reading vary considerably in different portions of the spectrum, and are naturally greater at the extreme limits than in the central portion, we can claim that the rotatory power of quartz at 20° C. is expressed by the equation

$$\alpha = \frac{9{\cdot}5639}{\lambda^2 - 0{\cdot}0127493} - \frac{2{\cdot}3113}{\lambda^2 - 0{\cdot}000974} - 0{\cdot}1905$$

within limits which in no part of the spectrum appreciably exceed ± 0·002°/mm., or 1° on the total rotation of our long column of quartz, and which under favourable conditions fall to less than one-half of this amount.

In conclusion, we wish to express our thanks to Col. J. W. GIFFORD for his co-operation in the first long series of photographic records, which were taken on his large spectrometer at Chard; to Mr. H. R. COURTMAN, who carried through the main series of photographic observations, in addition to doing valuable pioneer work in the measurement of red and infra-red rotations; and, finally, to Mr. H. W. SOUTHGATE, who worked out a very large proportion of the calculated rotations given in the paper. We also wish to express our indebtedness to the Government Grant Committee of the Royal Society for their consistent support in a long and very costly research, and to the Department of Scientific and Industrial Research for a maintenance grant to one of us, by which it was made possible for the research to be carried to completion by a final revision and extension during a further period of three years.

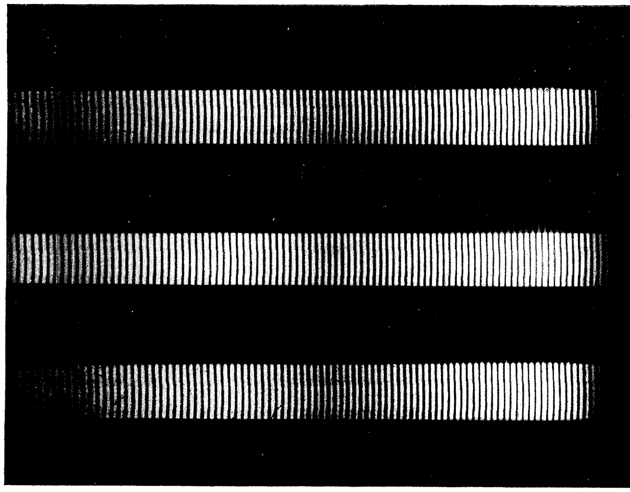

Fig. 2. Quartz Extinctions.

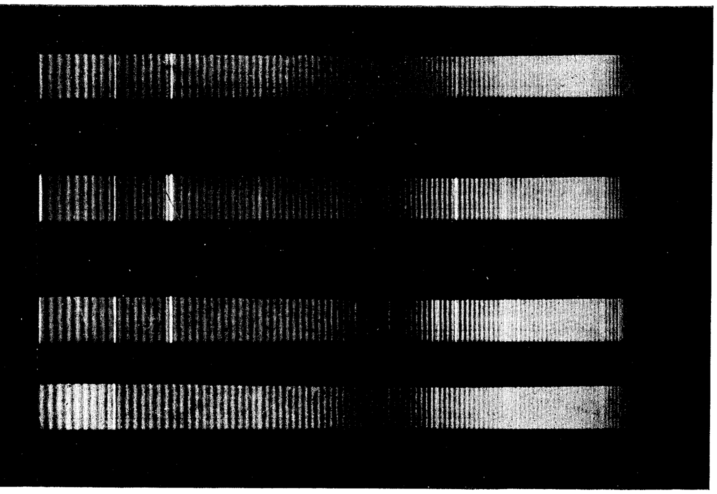

Fig. 3. Étalon Ripples and Standard Lines.

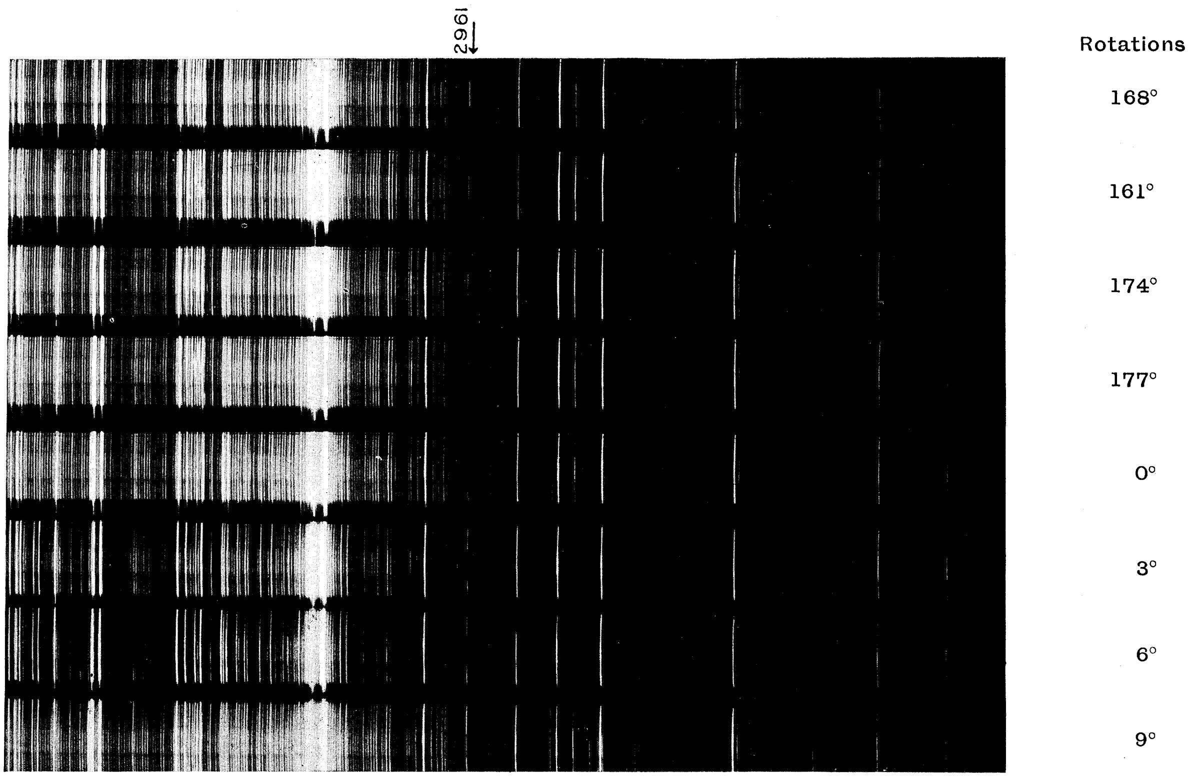

Fig. 4. Copper Arc. (Quartz Prisms.)

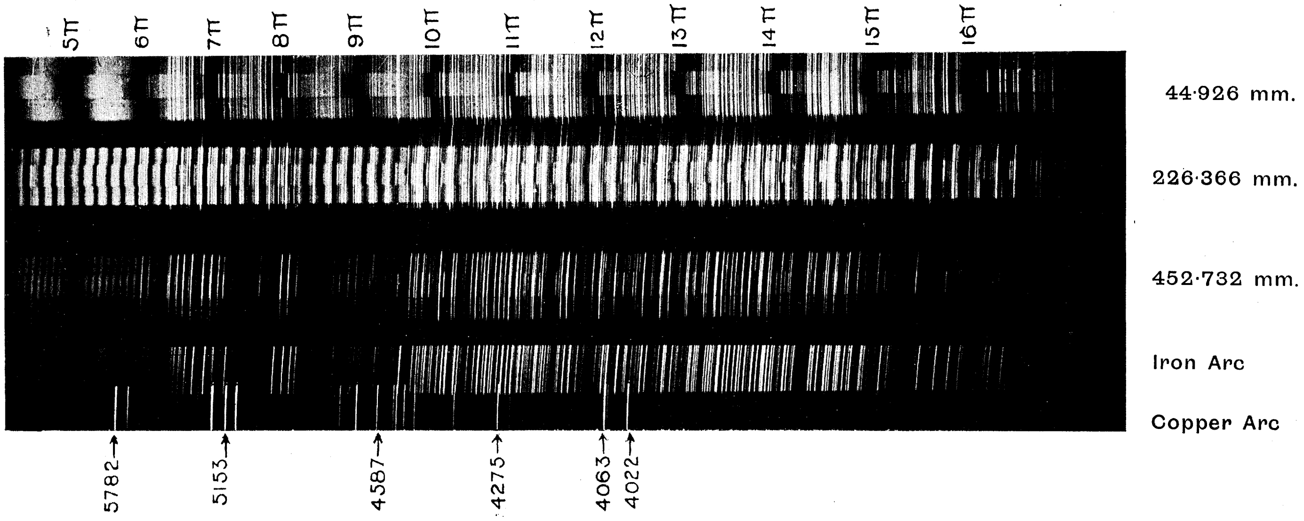

Fig. 7. Extinctions with different lengths of Quartz.

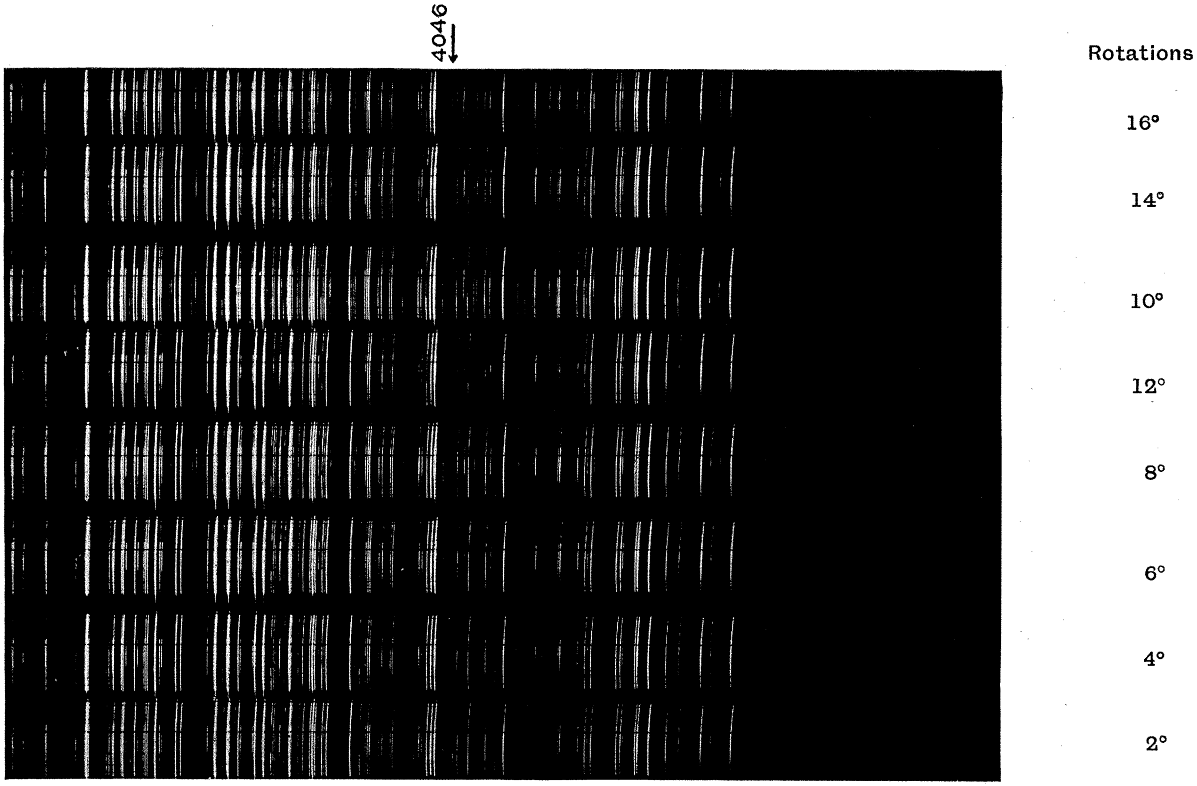

Fig. 5. Iron Arc. (Glass Prisms.)

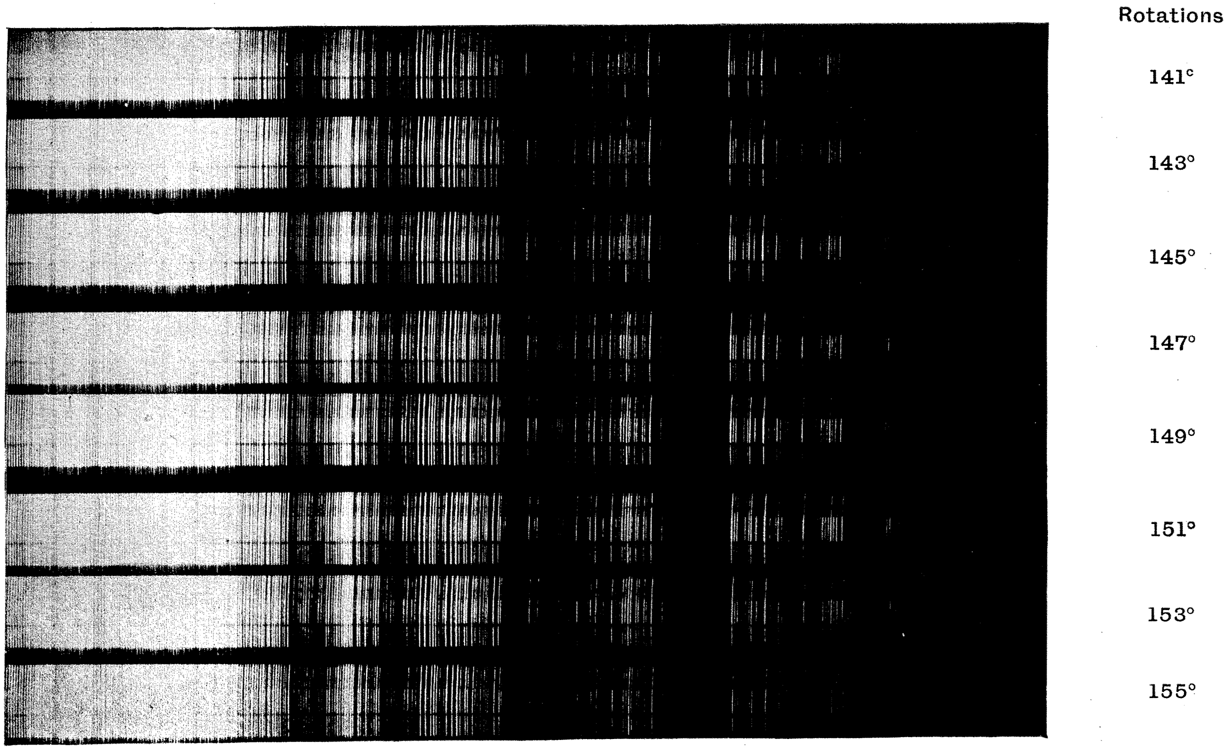

Fig. 6. Iron Arc. (Quartz Prisms.)

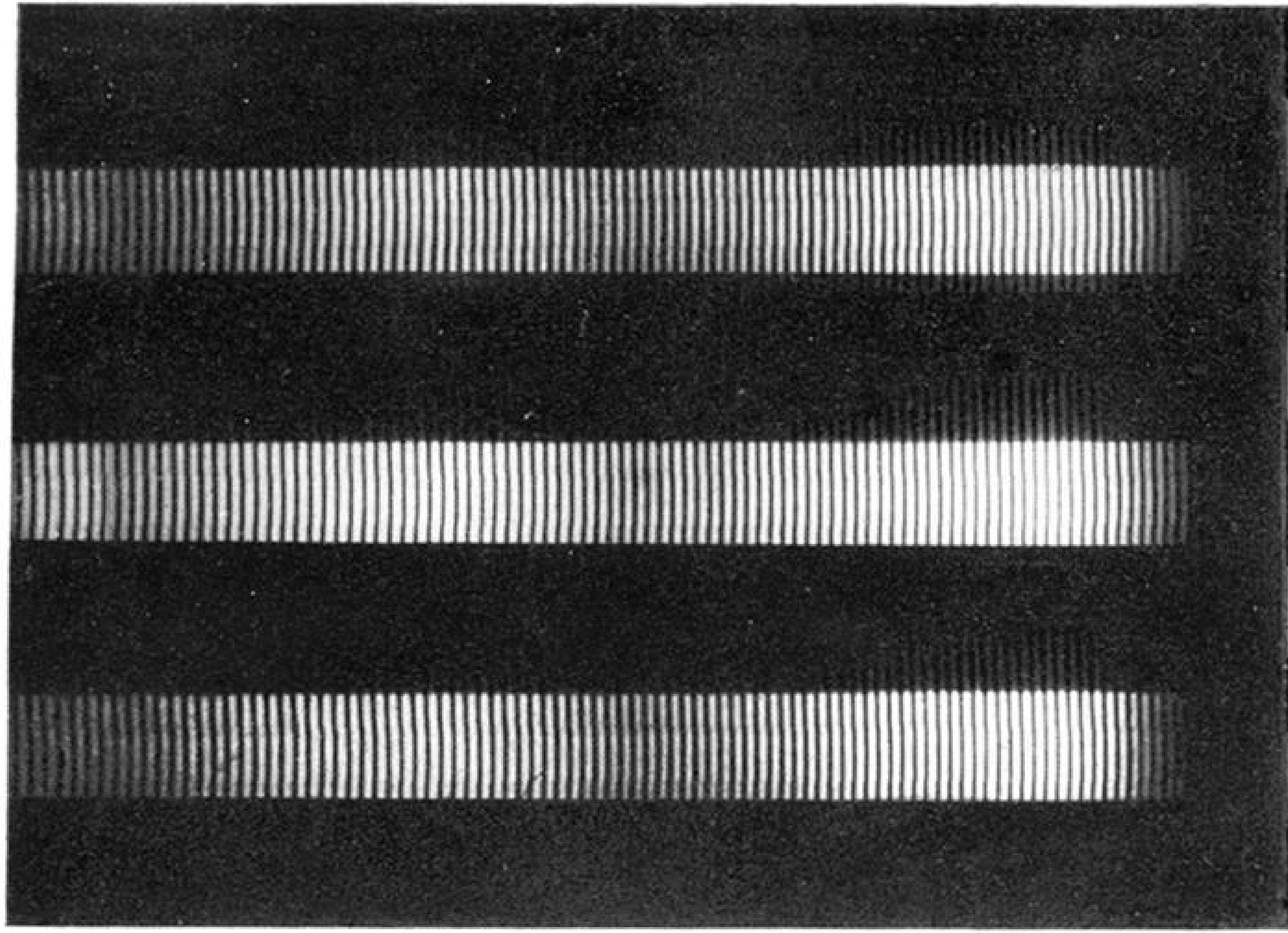

Fig. 2. Quartz Extinctions.

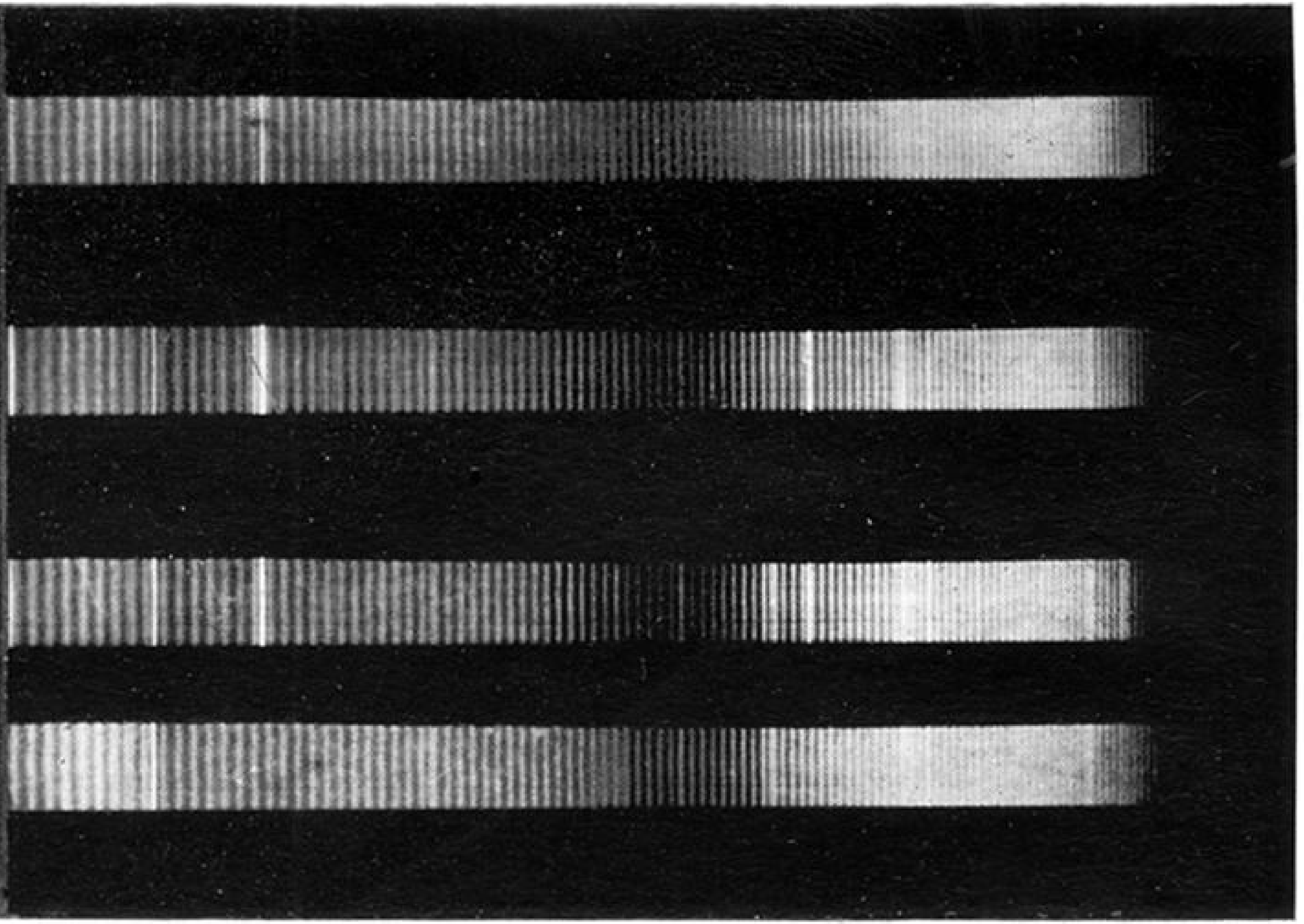

Fig. 3. Etalon Ripples and Standard Lines.

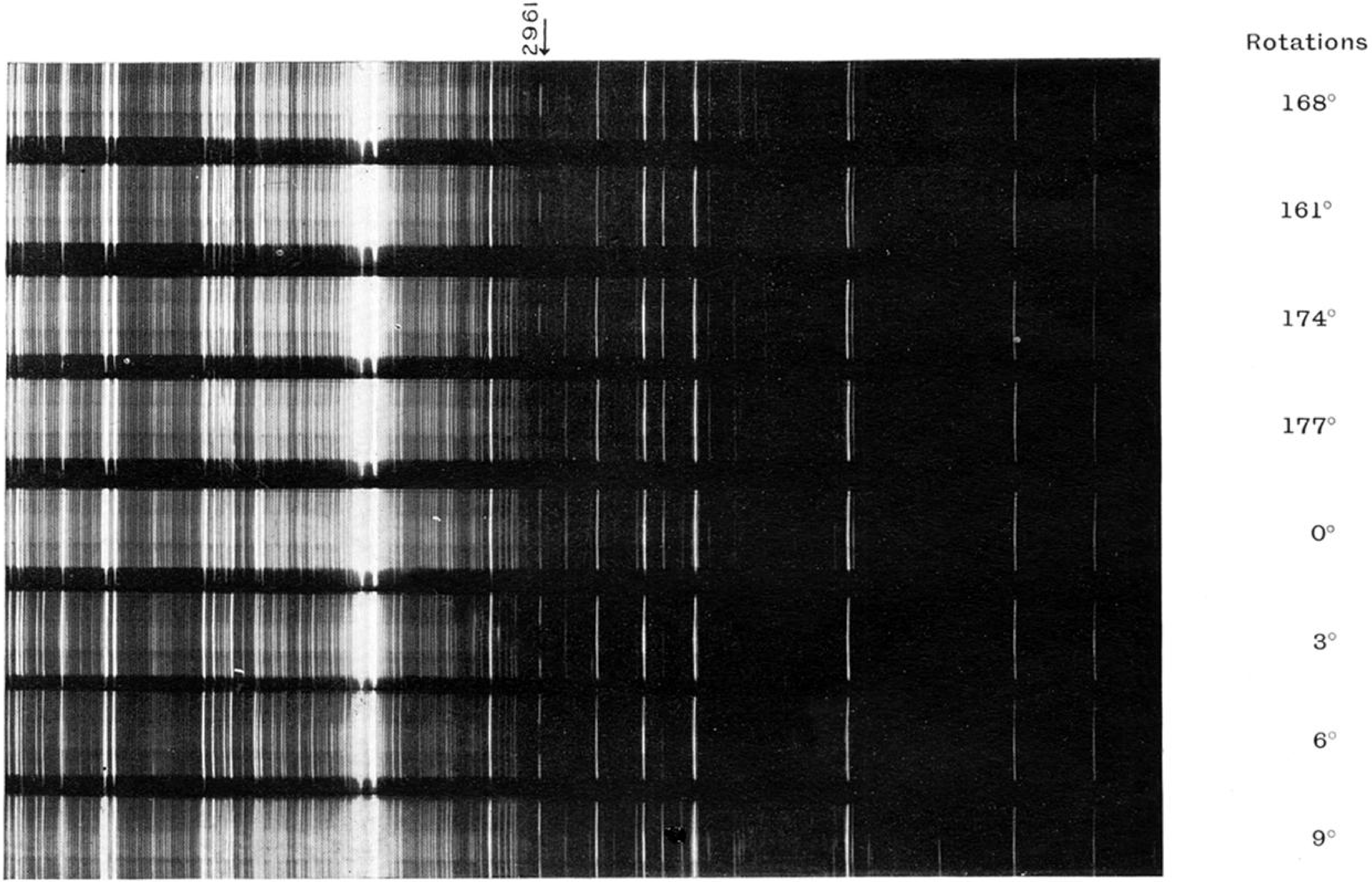

Fig. 4. Copper Arc. (Quartz Prisms.)

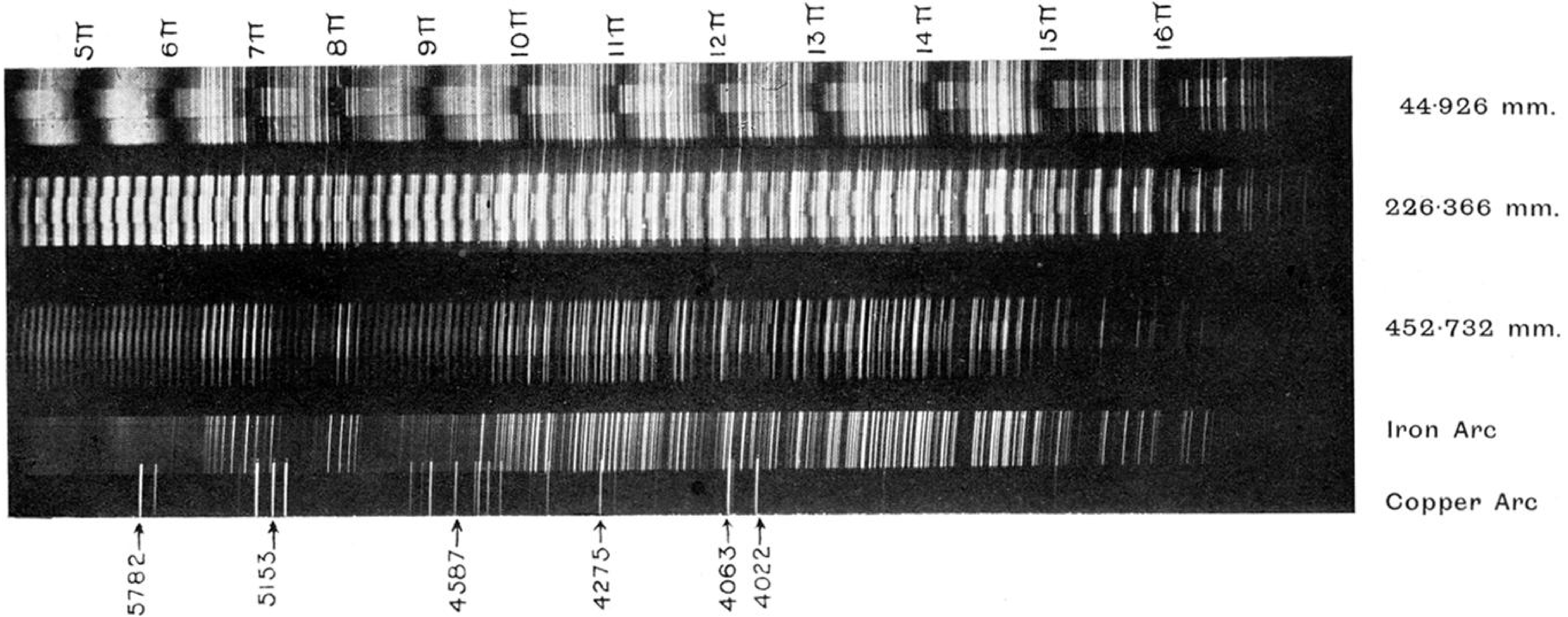

Fig. 7. Extinctions with different lengths of Quartz.

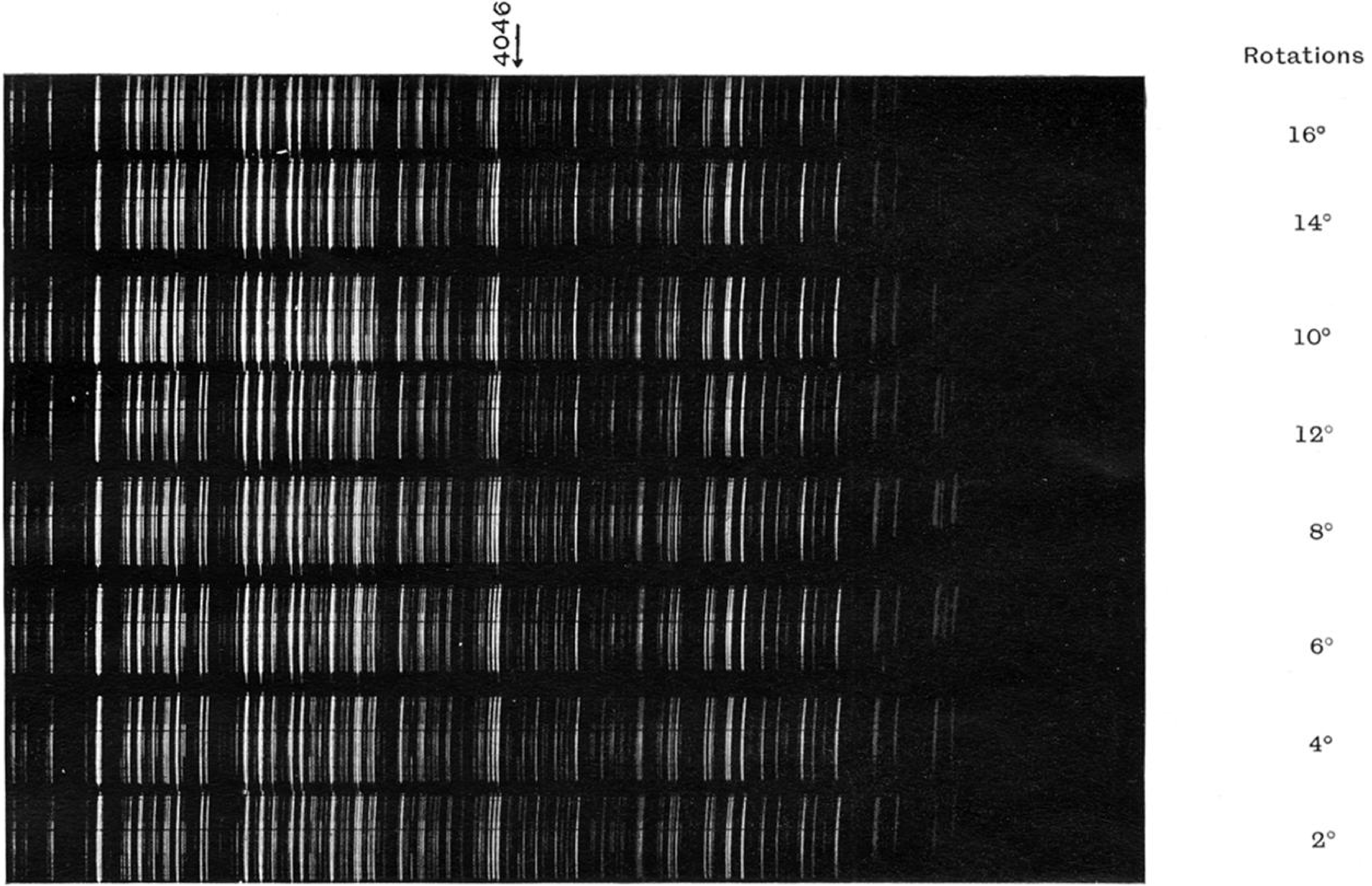

Fig. 5. Iron Arc. (Glass Prisms.)

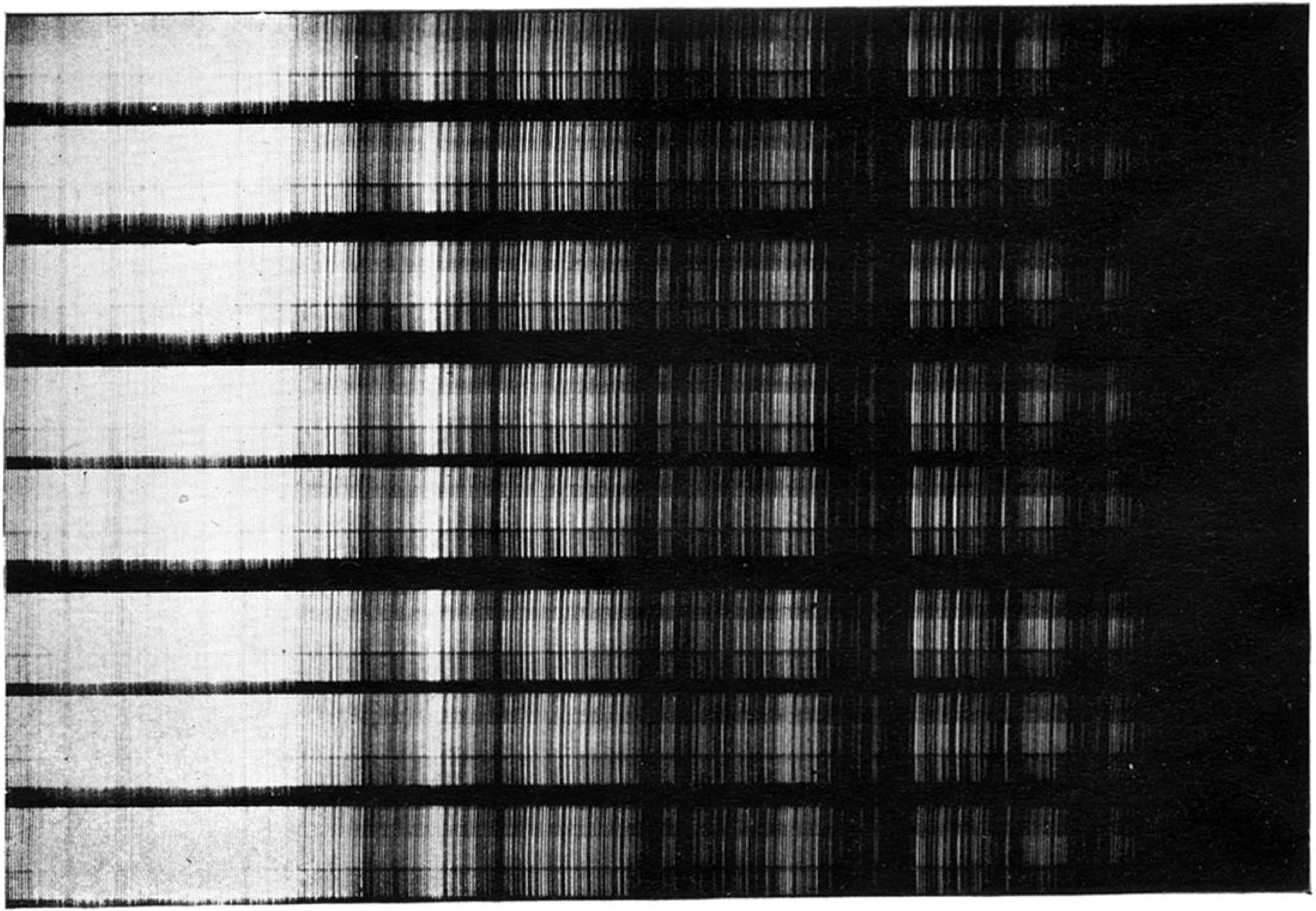

Fig. 6. Iron Arc. (Quartz Prisms.)