The solar rotation in June 1911 from spectrographic observations

192

Phys. 6 Juli 1915

The Solar Rotation in June 1911 from Spectrographic Observations

J. B. HUBRECHT

THE SOLAR ROTATION IN JUNE 1911 FROM SPECTROGRAPHIC OBSERVATIONS

THE SOLAR ROTATION IN JUNE 1911 FROM SPECTROGRAPHIC OBSERVATIONS

PROEFSCHRIFT TER VERKRIJGING VAN DEN GRAAD VAN DOCTOR IN DE WIS- EN STERREKUNDE AAN DE RIJKS-UNIVERSITEIT TE UTRECHT OP GEZAG VAN DEN RECTOR MAGNIFICUS DR. H. SNELLEN HOOGLEERAAR IN DE FACULTEIT DER GENEESKUNDE VOLGENS BESLUIT VAN DEN SENAAT DER UNIVERSITEIT TEGEN DE BEDENKINGEN VAN DE FACULTEIT DER WIS- EN NATUURKUNDE TE VERDEDIGEN OP DINSDAG 6 JULI 1915 DES NAMIDDAGS TE DRIE UUR

DOOR

JAN BASTIAAN HUBRECHT
GEBOREN TE UTRECHT

Cambridge :
Printed at the University Press
1915

Cambridge:
PRINTED BY JOHN CLAY, M.A.
AT THE UNIVERSITY PRESS

AAN DE NAGEDACHTENIS VAN MIJNEN VADER

Mijn dank wensch ik te betuigen aan de Faculteit der Wis- en Natuurkunde welke mij vergunde voor haar te verschijnen met een proefschrift gesteld in de Engelsche taal. Ik gedenk dan tevens de jaren, nu reeds geruimen tijd in het verleden liggend, gedurende welke ik het onderwijs van de toenmalige leden der Faculteit genoten heb. In het bijzonder ben ik veel verschuldigd aan mijnen hooggeachten Promotor, Professor NIJLAND. *Hoewel mijne latere werkzaamheden op het gebied van het zonne-onderzoek niet te Utrecht zijn uitgevoerd, was hij het toch die mijne belangstelling in de physische astronomie heeft wakker gemaakt, niet het minst door het mij indertijd mogelijk te maken deel te nemen aan de eclips-expeditie naar Sumatra.*

Op die expeditie werd ook op andere wijze de grondslag gelegd voor verdere arbeid, door mijne kennismaking met Professor NEWALL. *Om onder zijne leiding te werken vertrok ik in* 1906 *naar Cambridge. Zijne welwillendheid in het ter mijner beschikking stellen van de nieuwste instrumenten aldaar, zijn raad en daad in het oplossen der practische vraagstukken die zich bij het gebruik daarvan voordeden, en zijne voortdurende belangstelling en aanmoedigende critiek in de latere ontwikkeling van het onderzoek hebben het mij mogelijk gemaakt deze bijdrage tot de kennis van de zon te leveren.*

Zonder de bijzonder nauwkeurige metingen voor mij door den heer TUNSTALL *te Manchester, gedurende mijn verblijf aldaar, uitgevoerd, zouden de verkregen uitkomsten zeker niet het gewicht hebben dat de lezer hen, op grond van hunne onderlinge overeenstemming, misschien zal toekennen. Ook zijn deel aan de volgende bladzijden is dus niet gering en moge hier met waardeering herdacht worden.*

TABLE OF CONTENTS

§ 1. *Introductory*

The rotation of the sun as determined by spectroscopic means has been the subject of several important investigations since the publication of Dunér's well-known memoir *Recherches sur la rotation du Soleil* in 1893. Both in this work as in his later research[1] Dunér deals with visual observations only, as does also Halm in his account of the work done on similar lines at Edinburgh[2]. Since then the subject has been taken up photographically by Adams at Mount Wilson[3], Storey and Wilson at Edinburgh[4], J. S. Plaskett and De Lury at Ottawa[5], Evershed and Royds at Kodaikanal[6], Schlesinger at Allegheny[7], H. H. Plaskett again at Ottawa[8] and the present author at Cambridge[9]. The International Solar Union has considered the subject of enough importance to institute a special committee for the solar rotation. This committee met at Mount Wilson in 1910 and again at Bonn in 1913. On the latter occasion the principal subject of discussion was the discordance of the results obtained by the different observers. It was unanimously agreed that the main object of each of the investigators at present occupied with the work should be to clear away this discordance[10]. It is with that object in view that in the present paper the author proposes to deal more at length than is usual with some of the instrumental and observational details of the work as well as with the measurements and reductions. Possibly light may thus be thrown on the causes of these differences which so far seem to be greater than is compatible with the probable error claimed by each investigator for his results.

In a former paper already alluded to[9] the author has published some results obtained at Cambridge. Two sets of observations were dealt with, one concerning only the solar rotation at the equator and made at epochs extending over a considerable range of time (Dec. 1910—Oct. 1911), the other made in the first half of June 1911, giving comparisons of radial velocities at points all round the sun. The latter set consisted of one series of plates out of four which had been taken. The other three series have since been measured by Mr N. Tunstall, a student of the Victoria University of Manchester. It appeared at once that the consistency of his measures was a good deal greater than that of the author's original measurements of the first series, and accordingly this first series was remeasured by Mr Tunstall. The results relating to all four series may thus be regarded as affording homogeneous material for discussion.

[1] *Nova Acta Reg. Soc. Upsala*, 4, 1, No. 6, 1906.
[2] *A.N.* 173, 294, 1907.
[3] *Astrophys. J.*, 26, 203, 1907; 29, 110, 1909; Carnegie Institution of Washington, Publ. 138, 1911.
[4] *M.N.* LXXI, 674, 1911.
[5] *Trans. R.S. of Canada*, 6, 3, 1912.
[6] *M.N.* LXXIII, 554, 1913.
[7] *Publ. Allegheny Obs.*, 3, 13, 1914.
[8] *Journal R. Astr. Soc. of Canada*, 8, 307, 1914.
[9] *M.N.* LXXIII, 5, 1912.
[10] *Trans. Int. Union for Solar research*, IV, 123.

Part I. Observations and Reductions

§ 2. *Instrument and method of observation*

The observations were made with the instruments which are called the McClean Solar Instruments. A cœlostat mirror of 16 inches (40 cm.) diameter reflects the sun's rays on to a secondary mirror of similar size which reflects them in a horizontal direction, due North, on to an achromatic 12-inch (30 cm.) lens having a focal distance of 60 feet (18 m.). These three optical parts are all mounted in a little building immediately South of the Newall dome of the Cambridge observatory. Fig. 1 gives a diagrammatic presentation of their arrangement. *C* is the cœlostat mirror, with its normal perpendicular to the polar axis on which it is rotated by clockwork. The axis is supported in a stout frame which can be moved up or down an inclined bed *ab* worked parallel to the polar axis on a heavy wedge-shaped casting. Thus the cœlostat mirror can on any day of the year be so placed as to direct the reflected beam on to the secondary mirror *S* whatever the sun's declination may be. The whole casting supporting the cœlostat mirror can further be moved East or West parallel to itself along a couple of rails *cd* and *ef* in order to obtain at every hour of the day full illumination of the secondary mirror and therefore also of the image lens *O*. The beam of light travels, unenclosed, right through the Newall dome and the image is formed on the slit of the spectrograph which is installed in a room adjoining the dome on its North side. The image, which at the epoch of observation had a mean diameter of 172 mm., can be moved across the slit by means of cords which work the slow motions of the secondary mirror. Another cord connection makes it possible to move the image lens along a slide *ghik* in the line of the beam and so adjust its focus.

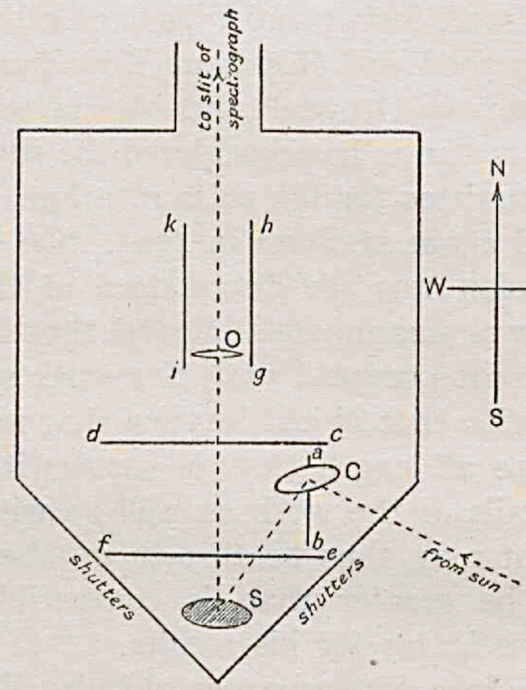

Fig. 1. Plan of cœlostat house.

The spectrograph is a horizontal instrument of the Littrow form, fitted with a plane grating of about 60,000 effective rulings. It was designed by Professor Newall for work on sunspots and solar rotation and described by him elsewhere[1], as well as in the author's paper already referred to. Its description therefore need not be repeated; reference is only made to the most important features of both instrument and method of observation in the following remarks.

[1] *M.N.* LXVIII, 6, 1907.

The whole spectrograph is capable of rotation round its horizontal axis so that the slit can be placed tangentially or radially to any required point of the sun's limb. A scale is provided giving the position angle from an arbitrary zero reading.

The overlapping parts of the spectra of different orders are separated by means of a small angled prism with dispersion at right angles to the dispersion of the grating.

The spectra of the two points of the sun's limb each time to be compared were not photographed simultaneously. The exposure at one point was taken as nearly as possible midway between two half exposures of the other point. By proceeding in this way no error is introduced provided that any gradual change in the position of the lines during the total length of the exposures is of a linear kind. This condition was amply satisfied as appeared from many tests. The divided exposure has not in a single case interfered with the definition of the lines,—a fact which affords sufficient justification of the method.

The region investigated extended from λ 4300 to λ 4400, this being half the region allotted to Cambridge in the cooperative scheme decided upon at the meeting of the Solar Union held at Mount Wilson in 1910. With the great dispersion used (fourth order, 1 Å. u. = 1·13 mm.) one plate does not cover the whole region; two plates had always to be taken with λ 4325 and λ 4375 approximately central on each respectively. Ilford Empress plates were used throughout, giving comparatively fine grain without being too slow.

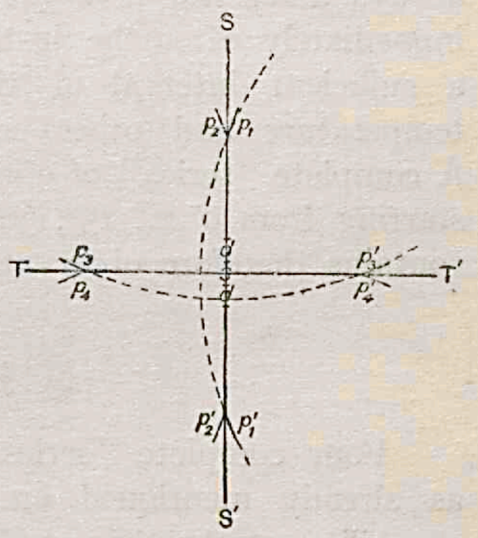

Fig. 2. Slit plate to show method of setting solar image tangential or radial to slit.

With regard to the position angles, that of the parallel is always first found by rotating the instrument until, when letting the solar image trail across the slit plate, it remains tangential to a line drawn upon this plate perpendicularly to the slit. The spectrograph is then further rotated through an angle computed from the Ephemeris given in the *Companion to the Observatory* until the slit is tangential to the sun at a point of the required latitude. Other lines are engraved on the slit plate which make it possible to compare, without again rotating the instrument, the spectra not only at the ends of a solar diameter, but also at points separated by 90° from one another. These are shown diagrammatically in Fig. 2 where SS' is the slit, TT' the line scribed at right angles to the slit already mentioned, while $p_1, p_2 \ldots, p_1', p_2' \ldots$, are short lines scribed in such a way that when, as in the figure, the sun's limb is made to coincide with p_1 and p_1' the centre s of the slit is at a definite distance h inside the point of the sun's limb where the tangent to the limb is parallel to the slit. Coincidence of the limb with p_2 and p_2' would bring upon the centre of the slit a point just inside the limb at the other end of the diameter belonging to the latitude in question. But by bringing the limb in coincidence with p_3 and p_3' or p_4 and p_4' we can throw upon the centre of the slit light from a point just inside the limb at a distance of 90° from the first point. The instrument remains untouched between the two observations required for each plate; in one observation the slit is tangential, in the other the slit radial to the sun's image.

An adjustable diaphragm is placed in front of the slit so that either the central millimetre *s* was exposed (single aperture *s*) or else the two millimetres *d* adjoining it on either side (double aperture *d*).

Throughout the series of observations here discussed, plates were taken comparing pairs of points 90° apart from one another. With the instrument fixed and the slit therefore in one position angle four plates were taken, one comparing the spectrum at a point 1 (Fig. 3) with that at a point 2, the next that at 2 with that at 3, the next 3 with 4, and finally 4 with 1. This was repeated for the second region of the spectrum. The slit was then moved to another position angle by rotating the instrument round its horizontal axis and a second set of eight plates was taken with a different starting point. Care was always taken not to begin the plates of the new set immediately after the instrument had been moved; a sufficient interval of time was given to allow temperature and other conditions to settle down. A complete "series" of observations consists of six of these sets of eight plates, starting from 0° E., 15°, 30°, 45°, 60° and 75° S.E. respectively[1]. Such a series contains therefore observations taken at intervals of 15° round the sun's limb.

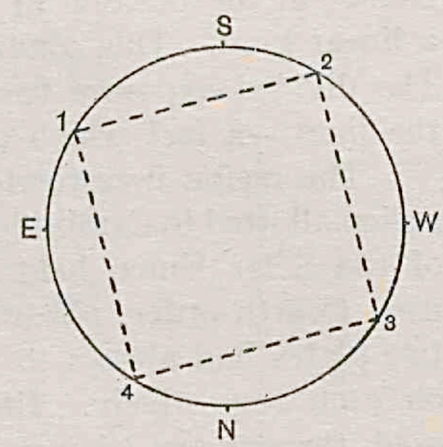

Fig. 3. Group of observations for one position angle of slit.

§ 3. *Record of Observations*

Four complete "series" were secured in the first fortnight of June 1911, as already mentioned on page 1. The almost perfect weather conditions prevailing at the time made it possible to obtain within that short interval the 192 plates involved. In Table I a complete list of these plates is given.

Only plates which have been measured and of which the results are discussed in the present memoir are included in this table. In the fourth column *A* denotes the region λ 4300—λ 4350, *B* the region λ 4350—λ 4400. The exposure times, given in column 5, show considerable variation, especially short exposures (15 seconds) having been possible after a second polishing of the cœlostat mirror on a day when also the atmosphere attained maximum transparency

[1] The notation 0° E., 15° S.E. etc. for points on the sun's limb is used throughout the present publication for the points at the East end of the solar equator, at solar latitude 15° in the solar S.E. quadrant etc.

TABLE I. *List of Plates*

1	2	3	4	5	6	7	8	9	10
Date	Hour	Plate number	Spectral region	Exposure	Latitudes	Temperature Inside	Temperature Outside	Pos. angle spectrograph	Hor. reading cœlostat
1911	A.M.			seconds					
June 1	7.30	N 5	B	60	0° E. *d* 90° S. *s*	16·2	16·3	358° 45′	96
,,	7.38	N 6	B	60	90° S. *s* 0° W. *d*	16·2	16·6	,,	,,
,,	7.45	N 7	B	60	0° W. *d* 90° N. *s*	16·2	16·7	,,	,,
,,	7.50	N 8	B	60	90° N. *s* 0° E. *d*	16·3	16·9	,,	,,
,,	7.59	N 9	A	60	0° E. *d* 90° S. *s*	16·3	17·0	,,	,, } *
,,	8.6	N 10	A	60	90° S. *s* 0° W. *d*	16·3	17·1	,,	,,
,,	8.20	N 11	A	60	90° N. *s* 0° E. *d*	16·3	17·5	,,	,,
,,	10.20	N 20	A	60	30° S.E. *d* 60° S.W. *s*	17·1	20·6	,,	0
,,	10.30	N 21	A	60	60° S.W. *s* 30° N.W. *d*	17·1	20·7	,,	,,
,,	10.36	N 22	A	60	30° N.W. *d* 60° N.E. *s*	17·2	20·8	,,	,,
,,	10.42	N 23	A	60	60° N.E. *s* 30° S.E. *d*	17·2	21·1	,,	,,
,,	11.0	N 24	B	60	30° N.W. *d* 60° N.E. *s*	17·4	21·2	,,	,, } †
,,	11.6	N 25	B	60	60° N.E. *s* 30° S.E. *d*	17·4	21·4	,,	,,
,,	11.43	N 26	B	60	45° N.W. *d* 45° N.E. *s*	17·8	22·6	13° 30′	,, } ‡
,,	11.49	N 27	B	60	45° N.E. *s* 45° S.E. *d*	17·8	22·7	,,	,,
,,	11.58	N 28	A	60	45° S.E. *d* 45° S.W. *s*	17·9	22·8	,,	,,
	P.M.								
,,	12.4	N 29	A	60	45° S.W. *s* 45° N.W. *d*	17·9	22·9	,,	,,
,,	12.10	N 30	A	60	45° N.W. *d* 45° N.E. *s*	18·0	23·0	,,	,,
,,	12.16	N 31	A	60	45° N.E. *s* 45° S.E. *d*	18·1	23·1	,,	,,
,,	12.29	N 32	A	60	15° S.E. *d* 75° S.W. *s*	18·1	23·2	,,	96
,,	12.34	N 33	A	60	75° S.W. *s* 15° N.W. *d*	18·2	23·3	,,	,,
,,	12.43	N 34	A	60	15° N.W. *d* 75° N.E. *s*	18·3	23·3	,,	,,
,,	12.50	N 35	A	60	75° N.E. *s* 15° S.E. *d*	18·4	23·4	,,	,,
,,	12.57	N 36	B	60	15° S.E. *d* 75° S.W. *s*	18·4	23·6	,,	,,
,,	1.4	N 37	B	60	75° S.W. *s* 15° N.W. *d*	18·5	23·7	,,	,,
,,	1.9	N 38	B	60	15° N.W. *d* 75° N.E. *s*	18·6	23·7	,,	,,
,,	1.14	N 39	B	60	75° N.E. *s* 15° S.E. *d*	18·6	23·7	,,	,,
,,	3.12	N 40	A	60	15° S.E. *d* 75° S.W. *s*	19·3	24·1	343° 30′	0
,,	3.20	N 41	A	60	75° S.W. *s* 15° N.W. *d*	19·4	24·1	,,	,,
,,	3.33	N 42	A	60	15° N.W. *d* 75° N.E. *s*	19·5	24·1	,,	,,
,,	3.38	N 43	A	60	75° N.E. *s* 15° S.E. *d*	19·5	24·2	,,	,,
,,	3.48	N 44	B	60	15° S.E. *d* 75° S.W. *s*	19·6	24·2	,,	,,
,,	3.54	N 45	B	60	75° S.W. *s* 15° N.W. *d*	19·6	24·2	,,	,,
,,	4.0	N 46	B	60	15° N.W. *d* 75° N.E. *s*	19·7	24·1	,,	,,
,,	4.5	N 47	B	60	75° N.E. *s* 15° S.E. *d*	19·7	24·0	,,	,,
,,	4.29	N 48	B	60	0° E. *d* 90° S. *s*	19·8	24·0	328° 30′	,,
,,	4.34	N 49	B	60	90° S. *s* 0° W. *d*	19·8	23·9	,,	,,
,,	4.39	N 50	B	60	0° W. *d* 90° N. *s*	19·8	23·9	,,	,,
,,	4.45	N 51	B	60	90° N. *s* 0° E. *d*	19·8	23·8	,,	,,
	A.M.								
June 2	11.37	N 56	A	150	0° E. *d* 90° S. *s*	16·6	20·6	329° 12′	,,
,,	11.46	N 57	A	150	90° S. *s* 0° W. *d*	16·6	20·9	,,	,,
	P.M.								
,,	12.33	N 58	A	150	0° W. *d* 90° N. *s*	16·8	21·5	,,	,,
,,	12.43	N 59	A	150	90° N. *s* 0° E. *d*	16·9	21·7	,,	,,
,,	3.34	N 60	B	150	30° S.E. *d* 60° S.W. *s*	18·1	22·6	359° 12′	,, } §
,,	3.44	N 61	B	150	60° S.W. *s* 30° N.W. *d*	18·1	22·7	,,	,,
,,	4.49	N 62	A	60	0° W. *d* 90° N. *s*	18·6	22·4	329° 12′	,, ‖
	P.M.								
June 3	1.25	N 63	B	60	45° S.E. *d* 45° S.W. *s*	18·5	22·0	44° 30′	96 } ¶
,,	1.35	N 64	B	60	45° S.W. *s* 45° N W. *d*	18·5	22·1	,,	,,
	A.M.								
June 4	10.50	N 65	B	60	60° S.E. *d* 30° S.W. *s*	18·4	20·3	29° 30′	,,
,,	10.57	N 66	B	60	30° S.W. *s* 60° N.W. *d*	18·4	20·5	,,	,,

* Set completed by N 62.

† Set completed by N 60 and N 61.

‡ Set completed by N 63 and N 64.

§ To go with N 24 and N 25.

‖ To go with plates N 9–11. Mirrors polished before taking this plate.

¶ To go with N 26 and N 27.

TABLE I. *List of Plates* (*continued*)

Date	Hour	Plate number	Spectral region	Exposure	Latitudes	Temperature Inside	Temperature Outside	Pos. angle spectrograph	Hor. reading cœlostat
1911	A.M.			seconds					
June 4	11.2	N 67	B	60	60° N.W. *d* 30° N.E. *s*	18·5	20·7	29° 30′	96
,,	11.7	N 68	B	60	30° N.E. *s* 60° S.E. *d*	18·5	20·8	,,	,,
,,	11.16	N 69	A	60	60° S.E. *d* 30° S.W. *s*	18·5	21·0	,,	,,
,,	11.21	N 70	A	60	30° S.W. *s* 60° N.W. *d*	18·6	21·0	,,	,,
,,	11.27	N 71	A	60	60° N.W. *d* 30° N.E. *s*	18·6	21·4	,,	,,
,,	11.33	N 72	A	60	30° N.E. *s* 60° S.E. *d*	18·7	21·7	,,	,,
June 5	7.17	N 77	A	120	75° N.W. *d* 15° N.E. *s*	18·6	17·6	75° 18′	,, } *
,,	7.25	N 78	A	120	15° N.E. *s* 75° S.E. *d*	18·6	17·8	,,	,, } *
,,	7.34	N 79	B	120	75° S.E. *d* 15° S.W. *s*	18·6	17·9	,,	,,
,,	7.42	N 80	B	120	15° S.W. *s* 75° N.W. *d*	18·6	18·0	,,	,,
,,	7.50	N 81	B	120	75° N.W. *d* 15° N.E. *s*	18·6	18·0	,,	,,
,,	7.58	N 82	B	120	15° N.E. *s* 75° S.E. *d*	18·6	18·2	,,	,,
,,	8.8	N 83	A	120	75° S.E. *d* 15° S.W. *s*	18·6	18·6	,,	,, } †
,,	8.16	N 84	A	120	15° S.W. *s* 75° N.W. *d*	18·6	18·9	,,	,, } †
,,	9.22	N 85	A	120	45° S.E. *d* 45° S.W. *s*	18·8	20·2	45° 12′	,,
,,	9.31	N 86	A	120	45° S.W. *s* 45° N.W. *d*	18·8	20·4	,,	,,
,,	9.39	N 87	A	120	45° N.W. *d* 45° N.E. *s*	18·9	20·7	,,	,,
,,	9.45	N 88	A	120	45° N.E. *s* 45° S.E. *d*	18·9	20·9	,,	,,
,,	10.31	N 89	B	120	45° S.E. *d* 45° S.W. *s*	19·2	21·8	15° 12′	o
,,	10.38	N 90	B	120	45° S.W. *s* 45° N.W. *d*	19·3	22·0	,,	,,
,,	10.45	N 91	B	120	45° N.W. *d* 45° N.E. *s*	19·4	22·3	,,	,,
,,	10.53	N 92	B	120	45° N.E. *s* 45° S.E. *d*	19·4	22·5	,,	,,
,,	11.21	N 93	B	120	30° S.E. *d* 60° S.W. *s*	19·6	23·0	0° 12′	,,
,,	11.28	N 94	B	120	60° S.W. *s* 30° N.W. *d*	19·7	23·0	,,	,,
,,	11.38	N 95	B	120	30° N.W. *d* 60° N.E. *s*	19·7	23·2	,,	,,
,,	11.47	N 96	B	120	60° N.E. *s* 30° S.E. *d*	19·8	23·5	,,	,,
,,	11.56	N 97	A	120	30° S.E. *d* 60° S.W. *s*	19·9	23·8	,,	,,
	P.M.								
,,	12.4	N 98	A	120	60° S.W. *s* 30° N.W. *d*	19·9	23·8	,,	,,
,,	12.10	N 99	A	120	30° N.W. *d* 60° N.E. *s*	20·0	23·8	,,	,,
,,	12.20	N 100	A	120	60° N.E. *s* 30° S.E. *d*	20·0	24·0	,,	,,
,,	3.12	N 105	A	120	15° S.E. *d* 75° S.W. *s*	21·0	25·4	345° 12′	,,
,,	3.20	N 106	A	120	75° S.W. *s* 15° N.W. *d*	21·0	25·7	,,	,,
,,	3.27	N 107	A	120	15° N.W. *d* 75° N.E. *s*	21·1	25·8	,,	,,
,,	3.34	N 108	A	120	75° N.E. *s* 15° S.E. *d*	21·1	25·8	,,	,,
,,	3.44	N 109	B	120	15° S.E. *d* 75° S.W. *s*	21·2	25·8	,,	,,
,,	3.52	N 110	B	120	75° S.W. *s* 15° N.W. *d*	21·2	25·8	,,	,,
,,	3.59	N 111	B	120	15° N.W. *d* 75° N.E. *s*	21·3	25·8	,,	,,
,,	4.6	N 112	B	120	75° N.E. *s* 15° S.E. *d*	21·3	25·8	,,	,,
	A.M.								
June 6	6.55	N 113	B	180	0° E. *d* 90° S. *s*	18·7	16·9	0° 42′	96
,,	7.5	N 114	B	180	90° S. *s* 0° W. *d*	18·7	17·0	,,	,,
,,	7.15	N 115	B	180	0° W. *d* 90° N. *s*	18·7	17·1	,,	,,
,,	7.25	N 116	B	180	90° N. *s* 0° E. *d*	18·7	17·3	,,	,,
,,	7.40	N 117	A	150	0° E. *d* 90° S. *s*	18·7	17·5	,,	,,
,,	7.50	N 118	A	150	90° S. *s* 0° W. *d*	18·7	17·8	,,	,,
,,	8.3	N 119	A	180	0° W. *d* 90° N. *s*	18·7	18·0	,,	,,
,,	8.12	N 120	A	180	90° N. *s* 0° E. *d*	18·7	18·0	,,	,,
	P.M.								
,,	12.39	N 129	A	120	60° S.E. *d* 30° S.W. *s*	19·9	22·2	30° 42′	o } ‡
,,	12.54	N 130	A	120	30° S.W. *s* 60° N.W. *d*	19·9	22·4	,,	,, } ‡
	A.M.								
June 7	10.23	N 131	B	90	60° S.E. *d* 30° S.W. *s*	15·9	17·0	31° 0′	,,
,,	10.30	N 132	B	90	30° S.W. *s* 60° N.W. *d*	16·0	17·0	,,	,,
,,	10.38	N 133	B	90	60° N.W. *d* 30° N.E. *s*	16·0	17·0	,,	,,
,,	10.45	N 134	B	90	30° N.E. *s* 60° S.E. *d*	16·1	17·1	,,	,,
,,	10.55	N 135	A	60	60° N.W. *d* 30° N.E. *s*	16·1	17·4	,,	,, } §
,,	11.2	N 136	A	60	30° N.E. *s* 60° S.E. *d*	16·2	17·5	,,	,, } §

* Set completed by N 83 and N 84.

† To go with N 77 and N 78.

‡ Cœlostat mirror polished. Set completed by N 135 and N 136.

§ To go with N 129 and N 130.

TABLE I. *List of Plates* (*continued*)

Date	Hour	Plate number	Spectral region	Exposure	Latitudes	Temperature Inside	Temperature Outside	Pos. angle spectrograph	Hor. reading cœlostat
1911 June 7	A.M. 11.30	N 137	A	second 45	75° S.E. *d* 15° S.W. *s*	16·3	17·9	46° 0′	0
,,	11.35	N 138	A	45	15° S.W. *s* 75° N.W. *d*	16·3	17·9	,,	,,
,,	11.40	N 139	A	45	75° N.W. *d* 15° N.E. *s*	16·3	18·1	,,	,,
,,	11.43	N 140	A	30	15° N.E. *s* 75° S.E. *d*	16·3	18·1	,,	,,
,,	11.53	N 141	B	30	75° S.E. *d* 15° S.W. *s*	16·4	18·3	,,	,,
,,	11.56	N 142	B	30	15° S.W. *s* 75° N.W. *d*	16·4	18·3	,,	,,
,,	P.M. 12.2	N 143	B	30	75° N.W. *d* 15° N.E. *s*	16·4	18·5	,,	,,
,,	12.6	N 144	B	20	15° N.E. *s* 75° S.E. *d*	16·5	18·5	,,	,,
,,	12.23	N 145	B	15	45° S.E. *d* 45° S.W. *s*	16·6	18·8	,,	96
,,	12.26	N 146	B	15	45° S.W. *s* 45° N.W. *d*	16·6	18·8	,,	,,
,,	12.29	N 147	B	15	45° N.W. *d* 45° N.E. *s*	16·6	18·8	,,	,,
,,	12.33	N 148	B	15	45° N.E. *s* 45° S.E. *d*	16·5	18·8	,,	,,
,,	12.37	N 149	A	15	45° S.E. *d* 45° S.W. *s*	16·6	18·9	,,	,,
,,	12.41	N 150	A	15	45° S.W. *s* 45° N.W. *d*	16·7	18·9	,,	,,
,,	12.44	N 151	A	15	45° N.W. *d* 45° N.E. *s*	16·7	19·0	,,	,,
,,	12.48	N 152	A	15	45° N.E. *s* 45° S.E. *d*	16·7	19·0	,,	,,
,,	2.48	N 153	B	20	15° S.E. *d* 75° S.W. *s*	17·1	20·0	346° 0′	0
,,	2.53	N 154	B	20	75° S.W. *s* 15° N.W. *d*	17·1	20·3	,,	,,
,,	2.57	N 155	B	20	15° N.W. *d* 75° N.E. *s*	17·2	20·5	,,	,,
,,	3.0	N 156	B	20	75° N.E. *s* 15° S.E. *d*	17·2	20·5	,,	,,
,,	3.5	N 157	A	20	15° S.E. *d* 75° S.W. *s*	17·3	20·5	,,	,,
,,	3.9	N 158	A	20	75° S.W. *s* 15° N.W. *d*	17·3	20·6	,,	,,
,,	3.12	N 159	A	20	15° N.W. *d* 75° N.E. *s*	17·3	20·6	,,	,,
,,	3.15	N 160	A	20	75° N.E. *s* 15° S.E. *d*	17·3	20·7	,,	,,
,,	3.40	N 161	A	20	30° S.E. *d* 60° S.W. *s*	17·4	20·8	1° 0′	,,
,,	3.43	N 162	A	20	60° S.W. *s* 30° N.W. *d*	17·5	20·9	,,	,,
,,	3.47	N 163	A	20	30° N.W. *d* 60° N.E. *s*	17·5	20·8	,,	,,
,,	3.51	N 164	A	20	60° N.E. *s* 30° S.E. *d*	17·5	20·9	,,	,,
,,	3.56	N 165	B	30	30° S.E. *d* 60° S.W. *s*	17·5	20·9	,,	,,
,,	3.59	N 166	B	30	60° S.W. *s* 30° N.W. *d*	17·6	20·9	,,	,,
,,	4.3	N 167	B	30	30° N.W. *d* 60° N.E. *s*	17·6	20·9	,,	,,
,,	4.7	N 168	B	30	60° N.E. *s* 30° S.E. *d*	17·6	20·9	,,	,,
June 8	A.M. 7.25	N 177	A	40	60° S.E. *d* 30° S.W. *s*	15·0	15·0	61° 30′	96
,,	7.29	N 178	A	40	30° S.W. *s* 60° N.W. *d*	15·0	15·0	,,	,,
,,	7.33	N 179	A	40	60° N.W. *d* 30° N.E. *s*	15·0	15·0	,,	,,
,,	7.37	N 180	A	40	30° N.E. *s* 60° S.E. *d*	15·0	15·1	,,	,,
,,	7.43	N 181	B	40	60° S.E. *d* 30° S.W. *s*	15·0	15·2	,,	,,
,,	7.50	N 182	B	40	30° S.W. *s* 60° N.W. *d*	15·0	15·3	,,	,,
,,	7.56	N 183	B	40	60° N.W. *d* 30° N.E. *s*	15·0	15·6	,,	,,
,,	8.0	N 184	B	40	30° N.E. *s* 60° S.E. *d*	15·0	15·7	,,	,,
,,	9.45	N 187	A	30	75° S.E. *d* 15° S.W. *s*	15·7	18·2	46° 30′	0
,,	9.50	N 188	A	30	15° S.W. *s* 75° N.W. *d*	15·7	18·5	,,	,,
,,	9.54	N 189	A	30	75° N.W. *d* 15° N.E. *s*	15·7	18·6	,,	,,
,,	9.57	N 190	A	30	15° N.E. *s* 75° S.E. *d*	15·7	18·7	,,	,,
,,	10.7	N 191	B	30	75° S.E. *d* 15° S.W. *s*	15·8	18·9	,,	,,
,,	10.11	N 192	B	30	15° S.W. *s* 75° N.W. *d*	15·9	19·0	,,	,,
,,	10.17	N 193	B	30	75° N.W. *d* 15° N.E. *s*	15·9	19·2	,,	,,
,,	10.21	N 194	B	30	15° N.E. *s* 75° S.E. *d*	15·9	19·3	,,	,,
,,	11.9	N 195	B	30	0° E. *d* 90° S. *s*	16·5	20·6	331° 30′	,,
,,	11.14	N 196	B	30	90° S. *s* 0° W. *d*	16·6	20·8	,,	,,
,,	11.18	N 197	B	30	0° W. *d* 90° N. *s*	16·6	20·9	,,	,,
,,	11.23	N 198	B	30	90° N. *s* 0° E. *d*	16·6	21·0	,,	,,
,,	11.29	N 199	A	30	0° E. *d* 90° S. *s*	16·7	21·1	,,	,,
,,	11.33	N 200	A	30	90° S. *s* 0° W. *d*	16·7	21·1	,,	,,
,,	11.37	N 201	A	30	0° W. *d* 90° N. *s*	16·8	21·2	,,	,,
,,	11.43	N 202	A	30	90° N. *s* 0° E. *d*	16·9	21·3	,,	,,
June 9	A.M. 7.18	N 207	A	90	45° S. . *d* 45° S.W. *s*	17·7	16·8	46° 0′	96

Table I. *List of Plates (concluded)*

1	2	3	4	5	6	7	8	9	10
						Temperature			
Date	Hour	Plate number	Spectral region	Ex-posure	Latitudes	Inside	Outside	Pos. angle spectro-graph	Hor. reading cœlostat
1911	A.M.			seconds					
June 9	7.24	N 208	A	90	45° S.W. *s* 45° N.W. *d*	17·8	16·9	46° 0′	96
,,	7.30	N 209	A	60	45° N.W. *d* 45° N.E. *s*	17·8	17·0	,,	,,
,,	7.35	N 210	A	60	45° N.E. *s* 45° S.E. *d*	17·8	17·0	,,	,,
,,	7.42	N 211	B	50	45° S.E. *d* 45° S.W. *s*	17·8	17·1	,,	,,
,,	7.46	N 212	B	50	45° S.W. *s* 45° N.W. *d*	17·8	17·2	,,	,,
,,	7.52	N 213	B	40	45° N.W. *d* 45° N.E. *s*	17·8	17·4	,,	,,
,,	7.56	N 214	B	40	45° N.E. *s* 45° S.E. *d*	17·8	17·4	,,	,,
	A.M.								
June 11	8.45	N 215	B	50	30° S.E. *d* 60° S.W. *s*	11·7	13·0	32° 0′	,,
,,	8.50	N 216	B	50	60° S.W. *s* 30° N.W. *d*	11·7	13·1	,,	,,
,,	8.56	N 217	B	80	30° N.W. *d* 60° N.E. *s*	11·7	13·2	,,	,,
,,	9.7	N 218	B	60	60° N.E. *s* 30° S.E. *d*	11·8	13·6	,,	,,
,,	9.19	N 219	A	60	30° S.E. *d* 60° S.W. *s*	11·8	13·9	,,	,,
,,	9.25	N 220	A	60	60° S.W. *s* 30° N.W. *d*	11·9	13·9	,,	,,
,,	9.30	N 221	A	60	30° N.W. *d* 60° N.E. *s*	11·9	14·0	,,	,,
,,	9.35	N 222	A	60	60° N.E. *s* 30° S.E. *d*	11·9	14·1	,,	0
,,	10.30	N 231	A	60	60° S.E. *d* 30° S.W. *s*	12·3	15·4	,,	,,
,,	10.38	N 232	A	60	30° S.W. *s* 60° N.W. *d*	12·3	15·6	,,	,,
,,	10.43	N 233	A	60	60° N.W. *d* 30° N.E. *s*	12·4	15·7	,,	,,
,,	10.48	N 234	A	60	30° N.E. *s* 60° S.E. *d*	12·4	15·9	,,	,,
,,	11.0	N 235	B	60	60° S.E. *d* 30° S.W. *s*	12·6	16·1	,,	,,
,,	11.7	N 236	B	60	30° S.W. *s* 60° N.W. *d*	12·6	16·2	,,	,,
,,	11.17	N 237	B	60	60° N.W. *d* 30° N.E. *s*	12·7	16·4	,,	,,
,,	11.23	N 238	B	60	30° N.E. *s* 60° S.E. *d*	12·7	16·6	,,	,,
	A.M.								
June 12	11.28	N 239	B	60	75° S.E. *d* 15° S.W. *s*	14·7	17·0	47° 0′	,,
,,	11.32	N 240	B	60	15° S.W. *s* 75° N.W. *d*	14·7	17·1	,,	,,
,,	11.37	N 241	B	60	75° N.W. *d* 15° N.E. *s*	14·8	17·2	,,	,,
,,	11.43	N 242	B	60	15° N.E. *s* 75° S.E. *d*	14·8	17·3	,,	,,
	P.M.								
,,	12.30	N 243	A	60	75° S.E. *d* 15° S.W. *s*	15·0	18·0	,,	,,
	A.M.								
June 15	8.7	N 244	A	60	15° S.W. *s* 75° N.W. *d*	10·8	11·8	79° 24′	96
,,	8.13	N 245	A	60	75° N.W. *d* 15° N.E. *s*	10·8	11·8	,,	,,
,,	8.22	N 246	A	60	15° N.E. *s* 75° S.E. *d*	10·8	11·9	,,	,,

(June 7th). The sixth column gives the latitudes of the two points on the solar limb compared. The letters *d* and *s* denote double or single opening in front of the slit, according to the position of the diaphragm mentioned in the preceding paragraph. The slit was in the case of the double opening always tangential to the sun's limb, in the other case always radial. The second latitude given in this column was always the one taken in one exposure between two half-exposures at the other. Columns 7 and 8 give the temperatures inside the tube of the spectrograph, half-way between grating and slit, and of the room. It is seen that the thick felt cover which was carefully fitted round the instrument has succeeded in making the variations inside small and regular. Column 9 gives the position angle of the spectrograph. This angle is dependent on (i) the position of the North point of the sun's image on the slit plate, (ii) the angle between sun's axis and North point for the date and (iii) the latitude of the required point. The first alters slightly with the date, and it also alters largely with the figure given in column 10 and referring to the adjustment in horizontal position of the cœlostat mirror mentioned on page 2. Two positions were found, 96 cm. apart, which had the advantage of giving two positions for the North point separated by exactly 30°. It was thus sometimes possible after having taken a series of eight plates for one position angle of the spectrograph, involving four points all round the sun at 90° apart, to move only the cœlostat mirror and then at once, without rotating the instrument, to take a similar set of plates involving four new latitudes differing by 30° from the first four and thus also forming part of the required series. From footnotes attached to the last column, it can be seen that sometimes sets of eight plates, belonging together, were taken at different moments or even on different dates, owing to rejected plates or other causes.

§ 4. *Measurements*

As has been stated, all the measurements of these plates, discussed in the present memoir, were made by Mr Tunstall.

The measuring instrument used is the Zeiss comparator *B* (1909), similar to the one previously described by Professor Newall[1]. Two microscopes are fixedly mounted over a slide which holds the plate underneath the one and, at a fixed distance corresponding to the distance between the microscopes, a silver scale 100 mm. long and divided into $\frac{1}{10}$ mm. underneath the other. The eyepiece of the scale microscope contains a micrometer arrangement allowing for the setting of a double wire symmetrically over the nearest scale mark on the proper side. The micrometer head is divided into 100 parts, while tenths of these divisions can be estimated. In this way one ten-thousandth of a millimeter can be read off; the actual settings of the micrometer wire in the scale microscope were found by special trial to be accurate within one or two units of this last decimal. The bisection of spectral lines viewed through the other microscope is achieved by the movement of the carriage bearing both plate and scale, actuated by direct pressure of the finger without making use of the slow motion screw. Suitable trials have shown that no advance in accuracy is obtained by using the slow motion, while a great loss of time would be incurred. Anticipating a more complete discussion of the measurements it may be stated that Mr Tunstall's average probable error (due to both plate and scale settings) per displacement of one line was 0·0004 mm. It is thus seen that the simple push method, advocated by Professor Newall at the time of his first adoption of the Zeiss instrument, is thoroughly justified, also for solar work. The excellent workmanship of the sliding parts has made the method possible. When clean vaseline is applied, the smallest pressure of the finger keeps the slide in motion with a minute velocity, while as soon as this pressure is relaxed the slide stops dead at once.

The plate was mounted on the stage parallel to the run of the slide (but see also page 49). The wires in the plate microscope were then adjusted parallel to

[1] *M.N.* LXV, 648.

the spectrum lines. A diaphragm or mask allows the observer to see either only the central spectrum or only the two other spectra above and below. The settings were made in the following succession. Bringing the wire into coincidence with the first line in the top spectrum, the corresponding scale reading was noted. The mask was then moved to the other position and the wire brought into coincidence with the line as it now appeared in its displaced position. All bias is thus eliminated except that in favour of setting wire and line to coincidence in the same manner in both cases, supposing, for example, that there was anything to choose between setting the wire on the centre of gravity of the line or midway between the two edges. But it is clear that a bias of this kind favours consistent measurement. Without touching the mask the slide is now moved and the wire set on the next line in the central strip. The mask is then moved and coincidence made between wire and line as visible in the upper strip. On the third line the first setting is made in this upper spectrum, the second in the central, and so on alternately. When the last line has been reached a return is made, but now setting on central and lower spectrum until the first line is reached again. The plate is taken out and replaced end for end on the stage and the whole process is repeated. For each single measured displacement of a line we have thus eight settings, four on the single spectrum and four on the double, consisting of two on the upper and two on the lower spectrum.

TABLE II. *Selected lines*

Plates *A*				Plates *B*			
Wave length	Element	Intensity	Remarks	Wave length	Element	Intensity	Remarks
4299·149	Ca	3		4351·000	Ti	1	
4302·085	Ti	2	Enhanced	4352·908	Fe	4	
4314·248	Sc	3		4358·670	Fe	2	
4315·138	Ti	3	Enhanced	4366·061	Fe	2	
4320·907	Sc	3		4371·442	Cr	2	
4326·923	Fe	2		4373·415	Cr	1	
4331·811	Ni	2		4373·727	Fe	2	
4337·725	Cr	3		4376·107	Fe	6	Chromospheric line
4338·084	Ti	4	Enhanced	4379·396	V	4	
4339·882	Cr	3		4385·144	Cr	2	
4343·861	Fe	2		4388·571	Fe	3	
4344·670	Cr	4		4390·149	V	2	
4346·725	Fe	2		4395·201	Ti	3	Enhanced
4347·403	Fe	1		4396·008	Ti	1	
4349·107	Fe	2		4400·555	Sc	3	

The whole measuring instrument was set up in a niche of blackened cardboard and covered up in such a way that no light whatever reaches the unused eye. This considerably reduces the strain; an added advantage can be gained by using one eye always for the plate microscope and the other for the scale microscope. Artificial light was employed, providing uniform constant illumination for both plate and scale. A thick glass plate in front of the illuminating arrangement diminished its heating effect on plate and scale.

Under such conditions of measurement Mr Tunstall was able to make 60 settings in 20 to 25 minutes and to devote as much as four hours a day to measuring without undue strain on his eyes. It is to be noted that he employed the ordinary eyepiece throughout. The author's method of employing a cylindrical lens, as in the measures discussed in the earlier paper, and as described in detail at the time[1], was tried by him but rejected in favour of the ordinary method.

Fifteen lines were measured in each of the two spectral regions, i.e. on each plate. Table II gives the wave lengths, origins and intensities of the lines, while it also shows which of them belong to the class of enhanced lines. No elements of atomic weight greater than 59 have lines in this part of the spectrum, while on the other hand the exposures were such that the hydrogen line H_γ at 4341 was unsuitable for measurement.

§ 5. *Reduction to velocities*

To obtain the wave length differences from the measured displacements the dispersion

$$\frac{d\lambda}{ds}$$

must be known. This dispersion varies from one end of the plate to the other, as well as from plate to plate. The general formula for the grating spectroscope is

$$m\lambda = b\ (\sin i + \sin\theta) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1),$$

where m is the order of the spectrum, b the interval between two adjacent lines on the grating, i the angle of incidence and θ the angle of emergence. In our observations we had always $m = 4$ and $b = 16933$, when expressed in Ångström units. This formula has to be differentiated, keeping i constant, in order to get the dispersion along the plate. We get

$$\frac{d\lambda}{d\theta} = \frac{b}{m}\cos\theta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2).$$

Now it is clear that

$$\frac{d\theta}{ds} = \frac{1}{f},$$

where f is the focal distance. We thus have

$$\frac{d\lambda}{ds} = \frac{b}{mf}\cos\theta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

for the mean dispersion. To find the correcting term wanted giving its variation with the wave length on one plate we deduce

$$d\left(\frac{d\lambda}{ds}\right) = -\frac{b}{mf}\sin\theta\, d\theta$$

or

$$d\left(\frac{d\lambda}{ds}\right) = -\frac{b}{mf}\sin\theta\frac{d\theta}{d\lambda}\Delta\lambda \quad \ldots\ldots\ldots\ldots\ldots\ldots (4),$$

[1] *M.N.* LXXIII, 28, 1912.

and so, putting in $\frac{d\theta}{d\lambda}$ from (2)

$$d\left(\frac{d\lambda}{ds}\right) = -\frac{1}{f}\tan\theta\,\Delta\lambda \qquad (5).$$

As to the variation of $\left(\frac{d\lambda}{ds}\right)$ from the centre of one spectral region to the centre of the other, there we get a different formula. In that case the grating has been turned on going from one plate to the other so both i and θ have changed, but for the centres of the plates respectively i and θ are equal and we have

$$m\lambda = 2b\sin\theta \qquad (6)$$

and

$$d\lambda = \frac{2b}{m}\cos\theta\,d\theta \qquad (7).$$

For the change in the dispersion in this case we thus get, by putting this into (4),

$$d\left(\frac{d\lambda}{ds}\right) = -\frac{1}{2f}\tan\theta\,\Delta\lambda \qquad (8).$$

In Table III are given the numerical values for the dispersion for a pair of plates. The figures for the observed dispersion are directly obtained from the measured distance in mm. between two lines and their difference in wave length

TABLE III. *Comparison, for two plates, of observed and calculated dispersion (Ångström units per millimetre)*

	Mean wave length	Observed dispersion	Observed mean dispersion	Calculated dispersion
	4307	0·8818		0·8818
Plate N 208	4320	0·8799	0·8792	0·8797
(region *A*)	4333	0·8776	(for λ 4324)	0·8779
	4344	0·8765		0·8764
	4355	0·8781		0·8788
Plate N 215	4366	0·8770	0·8757	0·8773
(region *B*)	4379	0·8757	(for λ 4377)	0·8754
	4393	0·8734		0·8734

according to Rowland's table, the mean of these wave lengths being given in the preceding column. The next column gives the observed mean dispersion for the whole plate from the two lines at either end. From this mean dispersion the calculated dispersion in the last column is obtained by applying the variation found from formula (5), giving to θ the value which we get from (3). The agreement between observed and calculated dispersion is seen to be close, while the difference between the observed mean dispersions for regions A and B has the value which it should have according to (8).

Accordingly, in the reduction a dispersion factor was employed for each line calculated in the same way as those in the last column of Table III. For each plate the observed mean dispersion had to be determined. Its general mean value for the A plates is 0·8795, for the B plates 0·8758, the range being in either case not more than 12 units of the last decimal. The values were seen to group themselves in sets of four, corresponding to sets of plates taken in immediate succession with the instrument untouched. Some evidence of correlation between dispersion and temperature appeared, as was to be expected. A double entry table could now be constructed giving the dispersion factor for each line for each value of the mean dispersion.

TABLE IV. *Coefficients to convert displacements into velocities*

Mean dispersion A plates..	0·8790	0·8792	0·8794	0·8796	0·8798	0·8800
Wave length						
4299·149	62·45	62·46	62·47	62·49	62·50	62·52
4302·085	62·38	62·39	62·40	62·42	62·43	62·45
4314·248	62·10	62·11	62·12	62·14	62·15	62·17
4315·138	62·07	62·08	62·09	62·11	62·12	62·14
4320·907	61·92	61·93	61·94	61·96	61·97	61·99
4326·923	61·78	61·79	61·80	61·82	61·83	61·85
4331·811	61·66	61·67	61·68	61·70	61·71	61·73
4337·725	61·51	61·52	61·53	61·55	61·56	61·58
4338·084	61·51	61·52	61·53	61·55	61·56	61·58
4339·882	61·47	61·48	61·49	61·51	61·52	61·54
4343·861	61·36	61·37	61·38	61·40	61·41	61·43
4344·670	61·33	61·34	61·35	61·37	61·38	61·40
4346·725	61·30	61·31	61·32	61·34	61·35	61·37
4347·403	61·29	61·30	61·31	61·33	61·34	61·36
4349·107	61·23	61·24	61·25	61·27	61·28	61·30
Mean dispersion B plates..	0·8754	0·8756	0·8758	0·8760	0·8762	0·8764
Wave length						
4351·000	61·46	61·48	61·49	61·50	61·52	61·53
4352·908	61·41	61·43	61·44	61·45	61·47	61·48
4358·670	61·27	61·29	61·30	61·31	61·33	61·34
4366·061	61·11	61·13	61·14	61·15	61·17	61·18
4371·442	60·98	61·00	61·01	61·02	61·04	61·05
4373·415	60·94	60·96	60·97	60·98	61·00	61·01
4373·727	60·91	60·93	60·94	60·95	60·97	60·98
4376·107	60·87	60·89	60·90	60·91	60·93	60·94
4379·396	60·79	60·81	60·82	60·83	60·85	60·86
4385·144	60·64	60·66	60·67	60·68	60·70	60·71
4388·571	60·56	60·58	60·59	60·60	60·62	60·63
4390·149	60·53	60·55	60·56	60·57	60·59	60·60
4395·201	60·41	60·43	60·44	60·45	60·47	60·48
4396·008	60·38	60·40	60·41	60·42	60·44	60·45
4400·555	60·29	60·31	60·32	60·33	60·35	60·36

In practice this step was combined with the next, that of obtaining the velocity v in the line of sight from the wave length difference. The Doppler principle gives us

$$\frac{v}{V}=\frac{d\lambda}{\lambda}\text{..........................(9)},$$

so that for each wave length difference we get a further factor varying in inverse ratio with the wave length to convert $d\lambda$ into km. per second, if V, the velocity of light, is so expressed. The result of the combination is given in Table IV, where the figures represent the values of

$$\frac{d\lambda}{ds} \times \frac{V}{\lambda} \times \frac{R}{R-h},$$

of which product the third factor, constant for all plates and all lines and little different from unity, will be explained in the next section.

§ 6. *Additional corrections*

The correction for not exactly setting on the limb is applied by the introduction of the factor

$$\frac{R}{R-h},$$

just alluded to, into the velocity coefficient. R is the sun's radius in mm. and h the distance, radially, inside the limb. The latter distance is determined by the manner in which the solar image is set on the slit plate, as is seen from Fig. 2. The factor is in our case equal to 1·014. Variations in the diameter of the image, caused by differences in the focus of the image lens, were found to change the factor in maximo by one in one thousand and could therefore be neglected.

The application of the factor is further only rigorously correct in the case of a body rotating as a solid. Only then are we fully justified to take, as was tacitly done by the method of measurement, the mean of the displacements between the central spectrum and each of the adjoining spectra as representing the displacement between the two points exactly central on the slit for the two latitudes. The error, due to polar retardation, thus introduced amounts, however, for our observations in maximo to 0·0005 km. per second and has been neglected.

TABLE V. *Additional corrections for setting due to polar retardation*

ϕ_1	ϕ_2	Additive correction	ϕ_1	ϕ_2	Additive correction	ϕ_1	ϕ_2	Additive correction	ϕ_1	ϕ_2	Additive correction
		km./sec.			km./sec.			km./sec.			km./sec.
0°E.	90°S.	0	90°S.	0°W.	0	0°W.	90°N.	0	90°N.	0°E.	0
15°S.E.	75°S.W.	+ 0·005	75°S.W.	15°N.W.	− 0·003	15°N.W.	75°N.E.	− 0·0 5	75°N.E.	15°S.E.	+ 0·003
30°S.E.	60°S.W.	+ 0·011	60°S.W.	30°N.W.	− 0·003	30°N.W.	60°N.E.	− 0·011	60°N.E.	30°S.E.	+ 0·003
45°S.E.	45°S.W.	+ 0·014	45°S.W.	45°N.W.	0	45°N.W.	45°N.E.	− 0·014	45°N.E.	45°S.E.	0
60°S.E.	30°S.W.	+ 0·011	30°S.W.	60°N.W.	+ 0·003	60°N.W.	30°N.E.	− 0·011	30°N.E.	60°S.E.	− 0·003
75°S.E.	15°S.W.	+ 0·003	15°S.W.	75°N.W.	+ 0·003	75°N.W.	15°N.E.	− 0·003	15°N.E.	75°S.E.	− 0·003

But the same phenomenon of polar retardation must affect the factor in another way, as the points thus centrally on the slit being *radially* inside the limb are situated on solar parallels different from those belonging to the latitudes to which we have set. This error is eliminated by applying a correction, tabulated in Table V. Owing to its smallness it has been possible to convert it into an additive term, while only a rough approximation of the retardation was necessary to determine its amount[1].

The errors introduced in the setting by bad definition of the sun's limb may sometimes have amounted to as much as $\frac{1}{2}$ % and so must have been quite comparable to these latter corrections. In the total results taken together they will, however, be largely eliminated owing to their accidental nature.

With two other corrections we can deal very shortly.

The heliographic latitude of the earth was very small during the entire fortnight of observation, as the earth passed through the node of the ecliptic with the solar equator on June 6th, 1911. In maximo it amounted to 1° 10′ (on June 15th). The correcting factor, equal to the secant of this angle, necessary to convert velocities in the line of sight to tangential velocities parallel to the plane of the solar equator thus amounted in maximo to 1·0002 and could therefore be neglected for the whole of the material.

Neither was any account taken of a possible correction for the effect of the glare caused by the scattered and integrated light of the whole disc. From some experimental plates it had been found that on a day when the glare was so strong that the light of the sun's limb was only three times as intense as the light of the sky immediately adjoining, the displacements were diminished to about two-thirds of the normal value. For ordinary days, when this ratio of sun to sky is about 50, the diminution can therefore be assumed negligible. Moreover, during the fortnight of observation the sky was generally abnormally transparent.

Corrections remain to be applied for the motion of the observer. As we are dealing exclusively with *differences* of velocities in the line of sight, no account need be taken of the observer's own motion in that direction, except in so far as this might affect the value of V. It is readily seen that neither the daily motion nor the earth's orbital motion contains components in this direction large enough to have any influence on the results in this way.

The motion, however, in the direction perpendicular to the line of sight causes, as is well known, synodic velocities to be observed whereas sidereal ones are the objective of the research. In the present case of comparison each time of two points situated 90° apart the corrections for these two points will generally be different. Dunér's tables given in his second memoir[2] enable us to construct a special table of corrections to be applied to convert our figures into sidereal values. The use of Dunér's tables is facilitated in the present case on account of the proximity of the earth to the node between the ecliptic and the solar equator, $\odot - \Omega$ being smaller than 10° during the complete period of observation. The error introduced by using the same corrections for the whole of the material

[1] The correction term to be applied at one point of latitude comes out as

$$- C \sin^2 \phi \cos \phi \left(\frac{2h}{R} - \frac{h^2}{R^2}\right),$$

where C is the constant of the polar retardation. The formula for the other, neglected, correction contains R^3 in the denominator.

[2] *Nova Acta Reg. Soc. Upsala*, 4, 1, No. 6, 1906, pp. 23 and 24.

is for the same reason very small; in no case does it exceed 0·001 km. per second. The variation in the earth's orbital velocity during the period has an equally negligible effect.

TABLE VI. *Corrections to convert synodic into sidereal values*

ϕ_1	ϕ_2	Additive correction	ϕ_1	ϕ_2	Additive correction	ϕ_1	ϕ_2	Additive correction	ϕ_1	ϕ_2	Additive correction
		km./sec.			km./sec.			km /sec.			km./sec.
0°E.	90°S.	− 0·150	90°S.	0°W.	− 0·116	0°W.	90°N.	+ 0·150	90°N.	0°E.	+ 0·116
15°S.E.	75°S.W.	− 0·175	75°S.W.	15°N.W.	− 0·074	15°N.W.	75°N.E.	+ 0·175	75°N.E.	15°S.E.	+ 0·074
30°S.E.	60°S.W.	− 0·188	60°S.W.	30°N.W.	− 0·026	30°N.W.	60°N.E.	+ 0·188	60°N.E.	30°S.E.	+ 0·026
45°S.E.	45°S.W.	− 0·189	45°S.W.	45°N.W.	+ 0·024	45°N.W.	45°N.E.	+ 0·189	45°N.E.	45°S.E.	− 0·024
60°S.E.	30°S.W.	− 0·176	30°S.W.	60°N.W.	+ 0·072	60°N.W.	30°N.E.	+ 0·176	30°N.E.	60°S.E.	− 0·072
75°S.E.	15°S.W.	− 0·151	15°S.W.	75°N.W.	+ 0·115	75°N.W.	15°N.E.	+ 0·151	15°N.E.	75°S.E.	− 0·115

Finally, the observer's component velocity, perpendicular to the line of sight, due to the earth's daily motion, amounts at the latitude of Cambridge in maximo to about $\frac{1}{100}$th of the orbital velocity component. Corrections for this motion would be smaller in the same proportion to those of Table VI and are also left out of account.

§ 7. *Complete table of results*

We can now give a table of the results, line for line and plate for plate, as directly measured and after reduction to km. per second. A further reduction to angular velocity is not possible until we have been able to deduce the velocities at each point on the sun's limb separately from the point 90° away. The table (Table VII) gives only the differences of velocities at such pairs of latitudes. The reduction of each displacement was completed, in accordance with the two preceding paragraphs, in two stages. First, the proper velocity coefficient found from Table IV converted displacement into velocity-differences in km. per second and introduced the general correction for setting, while, secondly, an *additive* quantity Δv, composed of two terms from Tables V and VI, constant for each pair of plates (*A* and *B* regions) and given in the upper rubric in the table, introduced the special correction for setting and converted into sidereal values. The table gives the measured displacements Δs and the completely corrected sidereal velocity-differences $v_{\phi_1} - v_{\phi_2}$, but not the figures belonging to the intermediate stage. For each plate the observed mean dispersion $d\lambda/ds$ (see page 12) is also given. As regards sign, velocities away from the observer have been taken as positive, in accordance with the usual custom.

The material is divided into four complete series, each consisting of 48 plates, and each containing observations all round the sun's limb in the manner described on page 4. The division into series is to some extent chronological as is seen from the outside dates for each:

Series I June 1st—5th, 1911 Series III June 5th—8th, 1911
Series II June 1st—7th, 1911 Series IV June 7th—15th, 1911

The grouping within each series always brings together on one page a set of eight plates which contain observations regarding four points of the limb all round the sun at 90° apart (cp. page 4 and Fig. 3).

TABLE VII. *Results from all plates, line for line*

SERIES I

	$\phi_1 =$ 0° E. $\phi_2 =$ 90° S. $\Delta v = -0{\cdot}150$		$\phi_1 =$ 90° S. $\phi_2 =$ 0° W. $\Delta v = -0{\cdot}116$		$\phi_1 =$ 0° W. $\phi_2 =$ 90° N. $\Delta v = +0{\cdot}150$		$\phi_1 =$ 90° N. $\phi_2 =$ 0° E. $\Delta v = +0{\cdot}116$	
	Δs	$v\phi_1 - v\phi_2$	Δs	$v\phi_1 - v\phi_2$	Δs	$v\phi_1 - v\phi_2$	Δs	$v\phi_1 - v\phi_2$
λ	N 9 $\frac{d\lambda}{ds} = 0{\cdot}8794$		N 10 $\frac{d\lambda}{ds} = 0{\cdot}8794$		N 62 $\frac{d\lambda}{ds} = 0{\cdot}8797$		N 11 $\frac{d\lambda}{ds} = 0{\cdot}8794$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4299·149	− 0·0284	− 1·924	− 0·0277	− 1·846	+ 0·0284	+ 1·925	+ 0·0288	+ 1·915
4302·085	− 293	− 1·978	− 278	− 1·850	+ 284	+ 1·923	+ 288	+ 1·913
4314·248	− 269	− 1·821	− 280	− 1·855	+ 288	+ 1·940	+ 284	+ 1·880
4315·138	− 282	− 1·901	− 282	− 1·867	+ 276	+ 1·864	+ 286	+ 1·892
4320·907	− 276	− 1·860	− 278	− 1·838	+ 277	+ 1·867	+ 282	+ 1·863
4326·923	− 282	− 1·893	− 288	− 1·896	+ 275	+ 1·850	+ 290	+ 1·908
4331·811	− 285	− 1·908	− 276	− 1·818	+ 286	+ 1·915	+ 270	+ 1·781
4337·725	− 277	− 1·854	− 270	− 1·777	+ 284	+ 1·898	+ 280	+ 1·839
4338·084	− 286	− 1·910	− 283	− 1·857	+ 279	+ 1·867	+ 286	+ 1·876
4339·882	− 278	− 1·859	− 294	− 1·924	+ 279	+ 1·866	+ 280	+ 1·838
4343·861	− 278	− 1·856	− 282	− 1·847	+ 282	+ 1·882	+ 281	+ 1·841
4344·670	− 282	− 1·880	− 272	− 1·785	+ 288	+ 1·918	+ 278	+ 1·821
4346·725	− 280	− 1·867	− 272	− 1·784	+ 278	+ 1·855	+ 272	+ 1·784
4347·403	− 285	− 1·897	− 286	− 1·869	+ 285	+ 1·898	+ 276	+ 1·808
4349·107	− 289	− 1·920	− 284	− 1·855	+ 274	+ 1·829	+ 276	+ 1·806
	N 6 $\frac{d\lambda}{ds} = 0{\cdot}8753$		N 5 $\frac{d\lambda}{ds} = 0{\cdot}8755$		N 7 $\frac{d\lambda}{ds} = 0{\cdot}8755$		N 8 $\frac{d\lambda}{ds} = 0{\cdot}8755$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4351·000	− 0·0282	− 1·883	− 0·0288	− 1·885	+ 0·0279	+ 1·865	+ 0·0281	+ 1·843
4352·908	− 280	− 1·869	− 280	− 1·835	+ 276	+ 1·845	+ 284	+ 1·860
4358·670	− 284	− 1·890	− 279	− 1·825	+ 280	+ 1·866	+ 283	+ 1·850
4366·061	− 276	− 1·837	− 281	− 1·833	+ 290	+ 1·922	+ 288	+ 1·876
4371·442	− 276	− 1·833	− 290	− 1·884	+ 292	+ 1·931	+ 278	+ 1·811
4373·415	− 284	− 1·881	− 284	− 1·847	+ 280	+ 1·856	+ 292	+ 1·895
4373·727	− 289	− 1·910	− 286	− 1·858	+ 285	+ 1·886	+ 279	+ 1·816
4376·107	− 276	− 1·830	− 285	− 1·851	+ 280	+ 1·854	+ 285	+ 1·851
4379·396	− 280	− 1·852	− 278	− 1·806	+ 278	+ 1·840	+ 274	+ 1·782
4385·144	− 284	− 1·872	− 283	− 1·832	+ 282	+ 1·860	+ 276	+ 1·790
4388·571	− 278	− 1·834	− 290	− 1·872	+ 285	+ 1·876	+ 281	+ 1·818
4390·149	− 286	− 1·881	− 290	− 1·871	+ 290	+ 1·905	+ 283	+ 1·829
4395·201	− 278	− 1·829	− 275	− 1·777	+ 280	+ 1·841	+ 282	+ 1·819
4396·008	− 282	− 1·853	− 288	− 1·855	+ 278	+ 1·829	+ 282	+ 1·819
4400·555	− 280	− 1·838	− 281	− 1·810	+ 278	+ 1·826	+ 278	+ 1·792

TABLE VII. *Results from all plates, line for line (continued)*

SERIES I (*continued*)

	$\phi_1=15°$ S.E. $\phi_2=75°$ S.W. $\Delta v=-0·170$		$\phi_1=75°$ S.W. $\phi_2=15°$ N.W. $\Delta v=-0·077$		$\phi_1=15°$ N.W. $\phi_2=75°$ N.E. $\Delta v=+0·170$		$\phi_1=75°$ N.E. $\phi_2=15°$ S.E. $\Delta v=+0·077$	
	Δs	$v_{\phi_1}-v_{\phi_2}$	Δs	$v_{\phi_1}-v_{\phi_2}$	Δs	$v_{\phi_1}-v_{\phi_2}$	Δs	$v_{\phi_1}-v_{\phi_2}$
λ	N 32 $\frac{d\lambda}{ds}=0·8797$		N 33 $\frac{d\lambda}{ds}=0·8797$		N 34 $\frac{d\lambda}{ds}=0·8796$		N 35 $\frac{d\lambda}{ds}=0·8797$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4299·149	− 0·0334	− 2·257	− 0·0220	− 1·452	+ 0·0340	+ 2·295	+ 0·0204	+ 1·352
4302·085	− 317	− 2·149	− 216	− 1·425	+ 336	+ 2·267	+ 202	+ 1·338
4314·248	− 311	− 2·103	− 234	− 1·531	+ 340	+ 2·283	+ 210	+ 1·382
4315·138	− 319	− 2·151	− 217	− 1·425	+ 331	+ 2·226	+ 202	+ 1·332
4320·907	− 323	− 2·171	− 212	− 1·391	+ 336	+ 2·252	+ 212	+ 1·391
4326·923	− 320	− 2·148	− 222	− 1·449	+ 343	+ 2·290	+ 194	+ 1·276
4331·811	− 316	− 2·120	− 222	− 1·447	+ 339	+ 2·262	+ 210	+ 1·373
4337·725	− 327	− 2·183	− 210	− 1·370	+ 344	+ 2·287	+ 198	+ 1·296
4338·084	− 315	− 2·109	− 221	− 1·437	+ 338	+ 2·250	+ 200	+ 1·308
4339·882	− 326	− 2·175	− 224	− 1·455	+ 344	+ 2·286	+ 200	+ 1·307
4343·861	− 318	− 2·123	− 216	− 1·403	+ 333	+ 2·215	+ 192	+ 1·256
4344·670	− 317	− 2·115	− 220	− 1·427	+ 347	+ 2·299	+ 207	+ 1·347
4346·725	− 328	− 2·182	− 218	− 1·414	+ 346	+ 2·292	+ 206	+ 1·341
4347·403	− 319	− 2·126	− 218	− 1·414	+ 345	+ 2·286	+ 192	+ 1·255
4349·107	− 317	− 2·112	− 230	− 1·486	+ 350	+ 2·315	+ 198	+ 1·290
	N 36 $\frac{d\lambda}{ds}=0·8757$		N 37 $\frac{d\lambda}{ds}=0·8757$		N 38 $\frac{d\lambda}{ds}=0·8760$		N 39 $\frac{d\lambda}{ds}=0·8757$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4351·000	− 0·0320	− 2·138	− 0·0233	− 1·510	+ 0·0332	+ 2·211	+ 0·0212	+ 1·381
4352·908	− 312	− 2·087	− 216	− 1·404	+ 338	+ 2·247	+ 208	+ 1·355
4358·670	− 320	− 2·132	− 217	− 1·407	+ 340	+ 2·254	+ 196	+ 1·278
4366·061	− 322	− 2·139	− 228	− 1·471	+ 331	+ 2·194	+ 202	+ 1·312
4371·442	− 320	− 2·122	− 214	− 1·383	+ 350	+ 2·305	+ 196	+ 1·273
4373·415	− 315	− 2·090	− 218	− 1·406	+ 345	+ 2·274	+ 196	+ 1·272
4373·727	− 324	− 2·144	− 234	− 1·503	+ 333	+ 2·199	+ 203	+ 1·314
4376·107	− 321	− 2·125	− 215	− 1·386	+ 339	+ 2·235	+ 208	+ 1·344
4379·396	− 316	− 2·092	− 212	− 1·366	+ 334	+ 2·201	+ 213	+ 1·372
4385·144	− 321	− 2·118	− 224	− 1·436	+ 346	+ 2·269	+ 207	+ 1·333
4388·571	− 327	− 2·151	− 208	− 1·337	+ 343	+ 2·248	+ 211	+ 1·355
4390·149	− 318	− 2·096	− 237	− 1·512	+ 348	+ 2·278	+ 195	+ 1·258
4395·201	− 322	− 2·116	− 216	− 1·382	+ 332	+ 2·176	+ 200	+ 1·286
4396·008	− 321	− 2·109	− 234	− 1·491	+ 334	+ 2·188	+ 202	+ 1·297
4400·555	− 331	− 2·166	− 218	− 1·392	+ 338	+ 2·209	+ 198	+ 1·271

TABLE VII. *Results from all plates, line for line* (*continued*)

SERIES I (*continued*)

	$\phi_1 = 30°$ S.E. $\phi_2 = 60°$ S.W. $\Delta v = -0{\cdot}177$		$\phi_1 = 60°$ S.W. $\phi_2 = 30°$ N.W. $\Delta v = -0{\cdot}029$		$\phi_1 = 30°$ N.W. $\phi_2 = 60°$ N.E. $\Delta v = +0{\cdot}177$		$\phi_1 = 60°$ N.E. $\phi_2 = 30°$ S.E. $\Delta v = +0{\cdot}029$	
	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$
λ	N 20 $\frac{d\lambda}{ds} = 0{\cdot}8794$		N 21 $\frac{d\lambda}{ds} = 0{\cdot}8793$		N 22 $\frac{d\lambda}{ds} = 0{\cdot}8793$		N 23 $\frac{d\lambda}{ds} = 0{\cdot}8793$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4299·149	− 0·0332	− 2·251	− 0·0130	− 0·841	+ 0·0347	+ 2·345	+ 0·0116	+ 0·754
4302·085	− 322	− 2·186	− 128	− 0·828	+ 348	+ 2·349	+ 123	+ 0·797
4314·248	− 340	− 2·289	− 134	− 0·861	+ 355	+ 2·382	+ 110	+ 0·712
4315·138	− 338	− 2·276	− 124	− 0·799	+ 345	+ 2·319	+ 109	+ 0·706
4320·907	− 318	− 2·147	− 132	− 0·847	+ 359	+ 2·401	+ 117	+ 0·754
4326·923	− 326	− 2·192	− 126	− 0·808	+ 350	+ 2·340	+ 108	+ 0·696
4331·811	− 324	− 2·175	− 132	− 0·843	+ 350	+ 2·336	+ 112	+ 0·720
4337·725	− 326	− 2·183	− 138	− 0·878	+ 346	+ 2·306	+ 111	+ 0·712
4338·084	− 332	− 2·220	− 128	− 0·817	+ 352	+ 2·343	+ 110	+ 0·706
4339·882	− 319	− 2·139	− 132	− 0·841	+ 355	+ 2·360	+ 109	+ 0·699
4343·861	− 335	− 2·233	− 120	− 0·766	+ 348	+ 2·313	+ 113	+ 0·723
4344·670	− 330	− 2·202	− 132	− 0·839	+ 357	+ 2·367	+ 116	+ 0·741
4346·725	− 334	− 2·225	− 136	− 0·863	+ 340	+ 2·262	+ 98	+ 0·630
4347·403	− 324	− 2·163	− 128	− 0·814	+ 345	+ 2·292	+ 108	+ 0·691
4349·107	− 331	− 2·204	− 132	− 0·838	+ 344	+ 2·284	+ 108	+ 0·691
	N 60 $\frac{d\lambda}{ds} = 0{\cdot}8757$		N 61 $\frac{d\lambda}{ds} = 0{\cdot}8757$		N 24 $\frac{d\lambda}{ds} = 0{\cdot}8757$		N 25 $\frac{d\lambda}{ds} = 0{\cdot}8756$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4351·000	− 0·0332	− 2·218	− 0·0127	− 0·810	+ 0·0353	+ 2·347	+ 0·0111	+ 0·711
4352·908	− 323	− 2·161	− 122	− 0·778	+ 346	+ 2·302	+ 116	+ 0·742
4358·670	− 336	− 2·236	− 136	− 0·863	+ 347	+ 2·304	+ 112	+ 0·715
4366·061	− 329	− 2·188	− 126	− 0·799	+ 354	+ 2·341	+ 120	+ 0·763
4371·442	− 320	− 2·129	− 122	− 0·773	+ 357	+ 2·355	+ 116	+ 0·737
4373·415	− 330	− 2·189	− 143	− 0·901	+ 346	+ 2·286	+ 113	+ 0·718
4373·727	− 338	− 2·237	− 126	− 0·797	+ 341	+ 2·255	+ 114	+ 0·724
4376·107	− 330	− 2·186	− 140	− 0·881	+ 344	+ 2·272	+ 106	+ 0·674
4379·396	− 326	− 2·159	− 128	− 0·807	+ 353	+ 2·324	+ 103	+ 0·655
4385·144	− 329	− 2·173	− 130	− 0·818	+ 348	+ 2·288	+ 114	+ 0·721
4388·571	− 333	− 2·188	− 126	− 0·792	+ 349	+ 2·291	+ 114	+ 0·720
4390·149	− 327	− 2·157	− 120	− 0·756	+ 345	+ 2·266	+ 116	+ 0·731
4395·201	− 333	− 2·189	− 130	− 0·815	+ 331	+ 2·177	+ 117	+ 0·736
4396·008	− 335	− 2·200	− 140	− 0·875	+ 347	+ 2·273	+ 108	+ 0·681
4400·555	− 332	− 2·179	− 126	− 0·789	+ 348	+ 2·276	+ 117	+ 0·735

TABLE VII. *Results from all plates, line for line (continued)*

SERIES I (*continued*)

	$\phi_1 = 45°$ S.E. $\phi_2 = 45°$ S.W. $\Delta v = -0{\cdot}175$		$\phi_1 = 45°$ S.W. $\phi_2 = 45°$ N.W. $\Delta v = +0{\cdot}024$		$\phi_1 = 45°$ N.W. $\phi_2 = 45°$ N.E. $\Delta v = +0{\cdot}175$		$\phi_1 = 45°$ N.E. $\phi_2 = 45°$ S.E. $\Delta v = -0{\cdot}024$	
	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$
λ	N 28 $\frac{d\lambda}{ds}=0{\cdot}8796$		N 29 $\frac{d\lambda}{ds}=0{\cdot}8797$		N 30 $\frac{d\lambda}{ds}=0{\cdot}8797$		N 31 $\frac{d\lambda}{ds}=0{\cdot}8796$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4299·149	− 0·0334	− 2·262	− 0·0014	− 0·063	+ 0·0352	+ 2·375	− 0·0003	− 0·043
4302·085	− 336	− 2·272	− 10	− 0·038	+ 343	+ 2·316	− 14	− 0·111
4314·248	− 342	− 2·300	− 8	− 0·026	+ 362	+ 2·424	− 9	− 0·080
4315·138	− 356	− 2·386	0	+ 0·024	+ 368	+ 2·461	− 8	− 0·074
4320·907	− 340	− 2·282	− 17	− 0·081	+ 352	+ 2·356	+ 2	− 0·012
4326·923	− 349	− 2·333	− 6	− 0·013	+ 371	+ 2·469	− 4	− 0·049
4331·811	− 340	− 2·273	− 13	− 0·056	+ 333	+ 2·230	− 8	− 0·073
4337·725	− 340	− 2·268	− 12	− 0·050	+ 350	+ 2·329	− 7	− 0·067
4338·084	− 342	− 2·280	− 11	− 0·044	+ 356	+ 2·366	− 10	− 0·086
4339·882	− 346	− 2·303	− 8	− 0·025	+ 364	+ 2·414	+ 4	+ 0·001
4343·861	− 340	− 2·263	− 16	− 0·074	+ 362	+ 2·398	− 18	− 0·135
4344·670	− 339	− 2·255	− 12	− 0·050	+ 359	+ 2·378	− 15	− 0·116
4346·725	− 338	− 2·248	− 12	− 0·050	+ 358	+ 2·371	− 6	− 0·061
4347·403	− 322	− 2·150	− 6	− 0·013	+ 352	+ 2·334	− 4	− 0·049
4349·107	− 356	− 2·356	− 9	− 0·031	+ 361	+ 2·387	− 16	− 0·122
	N 63 $\frac{d\lambda}{ds}=0{\cdot}8759$		N 64 $\frac{d\lambda}{ds}=0{\cdot}8758$		N 26 $\frac{d\lambda}{ds}=0{\cdot}8756$		N 27 $\frac{d\lambda}{ds}=0{\cdot}8756$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4351·000	− 0·0338	− 2·253	− 0·0011	− 0·044	+ 0·0360	+ 2·389	− 0·0008	− 0·073
4352·908	− 335	− 2·233	− 18	− 0·087	+ 355	+ 2·356	0	− 0·024
4358·670	− 348	− 2·308	+ 3	+ 0·042	+ 364	+ 2·406	− 4	− 0·049
4366·061	− 342	− 2·266	+ 4	+ 0·048	+ 356	+ 2·352	− 6	− 0·061
4371·442	− 323	− 2·146	− 6	− 0·013	+ 357	+ 2·353	− 10	− 0·085
4373·415	− 347	− 2·291	− 10	− 0·037	+ 358	+ 2·358	− 10	− 0·085
4373·727	− 346	− 2·284	− 6	− 0·013	+ 361	+ 2·375	+ 5	+ 0·006
4376·107	− 334	− 2·209	− 2	+ 0·012	+ 358	+ 2·355	− 10	− 0·085
4379·396	− 348	− 2·291	− 19	− 0·098	+ 360	+ 2·364	− 2	− 0·036
4385·144	− 348	− 2·286	− 5	− 0·006	+ 358	+ 2·347	+ 11	+ 0·043
4388·571	− 330	− 2·173	− 13	− 0·055	+ 360	+ 2·356	+ 1	− 0·018
4390·149	− 342	− 2·246	− 4	0	+ 366	+ 2·391	− 2	− 0·036
4395·201	− 339	− 2·224	+ 4	+ 0·048	+ 363	+ 2·369	− 4	− 0·048
4396·008	− 339	− 2·223	− 12	− 0·048	+ 359	+ 2·344	− 6	− 0·060
4400·555	− 342	− 2·238	− 7	− 0·018	+ 356	+ 2·322	− 6	− 0·060

TABLE VII. *Results from all plates, line for line* (*continued*)

SERIES I (*continued*)

	$\phi_1=60°$ S.E. $\phi_2=30°$ S.W. $\Delta v=-0·165$		$\phi_1=30°$ S.W. $\phi_2=60°$ N.W. $\Delta v=+0·075$		$\phi_1=60°$ N.W. $\phi_2=30°$ N.E. $\Delta v=+0·165$		$\phi_1=30°$ N.E. $\phi_2=60°$ S.E. $\Delta v=-0·075$	
	Δs	$v_{\phi_1}-v_{\phi_2}$	Δs	$v_{\phi_1}-v_{\phi_2}$	Δs	$v_{\phi_1}-v_{\phi_2}$	Δs	$v_{\phi_1}-v_{\phi_2}$
λ	N 69 $\frac{d\lambda}{ds}=0·8795$		N 70 $\frac{d\lambda}{ds}=0·8795$		N 71 $\frac{d\lambda}{ds}=0·8795$		N 72 $\frac{d\lambda}{ds}=0·8795$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4299·149	− 0·0330	− 2·227	+ 0·0120	+ 0·825	+ 0·0347	+ 2·333	− 0·0133	− 0·906
4302·085	− 318	− 2·150	+ 110	+ 0·762	+ 351	+ 2·356	− 123	− 0·843
4314·248	− 339	− 2·271	+ 108	+ 0·746	+ 348	+ 2·327	− 124	− 0·845
4315·138	− 330	− 2·214	+ 117	+ 0·801	+ 350	+ 2·339	− 128	− 0·870
4320·907	− 332	− 2·222	+ 111	+ 0·763	+ 354	+ 2·358	− 132	− 0·893
4326·923	− 329	− 2·199	+ 110	+ 0·755	+ 350	+ 2·328	− 127	− 0·860
4331·811	− 336	− 2·238	+ 114	+ 0·778	+ 349	+ 2·318	− 138	− 0·877
4337·725	− 320	− 2·134	+ 110	+ 0·752	+ 357	+ 2·362	− 128	− 0·863
4338·084	− 326	− 2·171	+ 110	+ 0·752	+ 352	+ 2·331	− 127	− 0·857
4339·882	− 324	− 2·158	+ 110	+ 0·751	+ 343	+ 2·274	− 127	− 0·856
4343·861	− 333	− 2·209	+ 112	+ 0·762	+ 348	+ 2·301	− 133	− 0·891
4344·670	− 336	− 2·277	+ 112	+ 0·762	+ 338	+ 2·239	− 126	− 0·847
4346·725	− 331	− 2·195	+ 98	+ 0·676	+ 354	+ 2·336	− 139	− 0·927
4347·403	− 343	− 2·268	+ 122	+ 0·823	+ 353	+ 2·330	− 128	− 0·860
4349·107	− 337	− 2·229	+ 120	+ 0·818	+ 347	+ 2·291	− 126	− 0·847
	N 65 $\frac{d\lambda}{ds}=0·8760$		N 66 $\frac{d\lambda}{ds}=0·8760$		N 67 $\frac{d\lambda}{ds}=0·8760$		N 68 $\frac{d\lambda}{ds}=0·8761$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4351·000	− 0·0333	− 2·213	+ 0·0113	+ 0·770	+ 0·0353	+ 2·336	− 0·0129	− 0·868
4352·908	− 335	− 2·224	+ 118	+ 0·800	+ 343	+ 2·273	− 137	− 0·917
4358·670	− 330	− 2·188	+ 104	+ 0·713	+ 343	+ 2·268	− 125	− 0·841
4366·061	− 336	− 2·220	+ 117	+ 0·790	+ 345	+ 2·275	− 134	− 0·894
4371·442	− 331	− 2·185	+ 113	+ 0·765	+ 344	+ 2·264	− 127	− 0·850
4373·415	− 338	− 2·226	+ 114	+ 0·770	+ 343	+ 2·257	− 131	− 0·874
4373·727	− 336	− 2·213	+ 107	+ 0·727	+ 355	+ 2·329	− 123	− 0·825
4376·107	− 332	− 2·187	+ 121	+ 0·812	+ 346	+ 2·272	− 122	− 0·818
4379·396	− 333	− 2·185	+ 108	+ 0·732	+ 343	+ 2·251	− 130	− 0·866
4385·144	− 338	− 2·216	+ 113	+ 0·761	+ 349	+ 2·283	− 130	− 0·864
4388·571	− 333	− 2·183	+ 112	+ 0·754	+ 352	+ 2·298	− 128	− 0·851
4390·149	− 334	− 2·188	+ 116	+ 0·778	+ 353	+ 2·303	− 132	− 0·875
4395·201	− 333	− 2·178	+ 116	+ 0·776	+ 347	+ 2·263	− 127	− 0·843
4396·008	− 335	− 2·189	+ 110	+ 0·740	+ 347	+ 2·262	− 129	− 0·854
4400·555	− 339	− 2·210	+ 119	+ 0·793	+ 353	+ 2·295	− 126	− 0·835

TABLE VII. *Results from all plates, line for line* (*continued*)

SERIES I (*concluded*)

	$\phi_1=$ 75° S.E. $\phi_2=$ 15° S.W. $\Delta v=-0{\cdot}148$		$\phi_1=$ 15° S.W. $\phi_2=$ 75° N.W. $\Delta v=+0{\cdot}118$		$\phi_1=$ 75° N.W. $\phi_2=$ 15° N.E. $\Delta v=+0{\cdot}148$		$\phi_1=$ 15° N.E. $\phi_2=$ 75° S.E. $\Delta v=-0{\cdot}118$	
	Δs	$v\phi_1-v\phi_2$	Δs	$v\phi_1-v\phi_2$	Δs	$v\phi_1-v\phi_2$	Δs	$v\phi_1-v\phi_2$
λ	N 83 $\frac{d\lambda}{ds}=0{\cdot}8796$		N 84 $\frac{d\lambda}{ds}=0{\cdot}8796$		N 77 $\frac{d\lambda}{ds}=0{\cdot}8797$		N 78 $\frac{d\lambda}{ds}=0{\cdot}8796$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4299·149	− 0·0322	− 2·160	+ 0·0207	+ 1·412	+ 0·0328	+ 2·198	− 0·0218	− 1·480
4302·085	− 325	− 2·177	+ 202	+ 1·379	+ 338	+ 2·258	− 210	− 1·429
4314·248	− 324	− 2·161	+ 212	+ 1·435	+ 352	+ 2·335	− 220	− 1·485
4315·138	− 326	− 2·173	+ 202	+ 1·373	+ 332	+ 2·210	− 216	− 1·460
4320·907	− 325	− 2·162	+ 197	+ 1·339	+ 330	+ 2·193	− 212	− 1·432
4326·923	− 322	− 2·138	+ 203	+ 1·373	+ 334	+ 2·213	− 224	− 1·503
4331·811	− 322	− 2·135	+ 196	+ 1·327	+ 336	+ 2·221	− 218	− 1·463
4337·725	− 325	− 2·148	+ 203	+ 1·367	+ 336	+ 2·216	− 212	− 1·423
4338·084	− 321	− 2·124	+ 203	+ 1·367	+ 340	+ 2·241	− 219	− 1·466
4339·882	− 322	− 2·129	+ 208	+ 1·397	+ 338	+ 2·227	− 214	− 1·434
4343·861	− 323	− 2·131	+ 210	+ 1·407	+ 342	+ 2·248	− 216	− 1·444
4344·670	− 318	− 2·100	+ 202	+ 1·358	+ 333	+ 2·192	− 226	− 1·505
4346·725	− 320	− 2·111	+ 205	+ 1·376	+ 342	+ 2·246	− 226	− 1·504
4347·403	− 321	− 2·117	+ 199	+ 1·338	+ 340	+ 2·233	− 220	− 1·467
4349·107	− 325	− 2·139	+ 205	+ 1·374	+ 342	+ 2·243	− 228	− 1·515
	N 79 $\frac{d\lambda}{ds}=0{\cdot}8758$		N 80 $\frac{d\lambda}{ds}=0{\cdot}8759$		N 81 $\frac{d\lambda}{ds}=0{\cdot}8760$		N 82 $\frac{d\lambda}{ds}=0{\cdot}8759$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4351·000	− 0·0333	− 2·196	+ 0·0214	+ 1·434	+ 0·0337	+ 2·220	− 0·0218	− 1·459
4352·908	− 314	− 2·077	+ 200	+ 1·347	+ 335	+ 2·206	− 219	− 1·464
4358·670	− 326	− 2·147	+ 202	+ 1·356	+ 333	+ 2·190	− 219	− 1·461
4366·061	− 313	− 2·062	+ 197	+ 1·323	+ 348	+ 2·276	− 218	− 1·451
4371·442	− 330	− 2·161	+ 204	+ 1·363	+ 336	+ 2·198	− 216	− 1·436
4373·415	− 315	− 2·069	+ 204	+ 1·362	+ 334	+ 2·185	− 222	− 1·472
4373·727	− 327	− 2·141	+ 200	+ 1·337	+ 347	+ 2·263	− 222	− 1·471
4376·107	− 319	− 2·091	+ 197	+ 1·318	+ 340	+ 2·219	− 212	− 1·409
4379·396	− 318	− 2·082	+ 194	+ 1·298	+ 328	+ 2·143	− 222	− 1·468
4385·144	− 324	− 2·114	+ 201	+ 1·338	+ 346	+ 2·247	− 221	− 1·459
4388·571	− 318	− 2·075	+ 216	+ 1·419	+ 330	+ 2·148	− 220	− 1·451
4390·149	− 320	− 2·086	+ 196	+ 1·305	+ 335	+ 2·177	− 220	− 1·450
4395·201	− 316	− 2·058	+ 202	+ 1·339	+ 341	+ 2·209	− 224	− 1·472
4396·008	− 317	− 2·063	+ 194	+ 1·290	+ 322	+ 2·093	− 219	− 1·441
4400·555	− 318	− 2·066	+ 212	+ 1·397	+ 322	+ 2·090	− 214	− 1·409

TABLE VII. *Results from all plates, line for line (continued)*

SERIES II

	$\phi_1 =$ 0° E. $\phi_2 =$ 90° S. $\Delta v = -0{\cdot}150$		$\phi_1 =$ 90° S. $\phi_2 =$ 0° W. $\Delta v = -0{\cdot}116$		$\phi_1 =$ 0° W. $\phi_2 =$ 90° N. $\Delta v = +0{\cdot}150$		$\phi_1 =$ 90° N. $\phi_2 =$ 0° E. $\Delta v = +0{\cdot}116$	
λ	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$
	N 56 $\frac{d\lambda}{ds} = 0{\cdot}8796$		N 57 $\frac{d\lambda}{ds} = 0{\cdot}8797$		N 58 $\frac{d\lambda}{ds} = 0{\cdot}8796$		N 59 $\frac{d\lambda}{ds} = 0{\cdot}8797$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4299·149	− 0·0279	− 1·893	− 0·0280	− 1·866	+ 0·0283	+ 1·918	+ 0·0274	+ 1·828
4302·085	− 295	− 1·991	− 272	− 1·814	+ 308	+ 2·072	+ 281	+ 1·870
4314·248	− 296	− 1·989	− 276	− 1·831	+ 272	+ 1·840	+ 263	+ 1·750
4315·138	− 274	− 1·852	− 285	− 1·886	+ 287	+ 1·932	+ 302	+ 1·992
4320·907	− 284	− 1·910	− 281	− 1·857	+ 300	+ 2·009	+ 280	+ 1·851
4326·923	− 285	− 1·912	− 278	− 1·835	+ 264	+ 1·782	+ 257	+ 1·705
4331·811	− 279	− 1·871	− 273	− 1·800	+ 269	+ 1·810	+ 300	+ 1·967
4337·725	− 308	− 2·046	− 284	− 1·864	+ 300	+ 1·996	+ 282	+ 1·852
4338·084	− 280	− 1·873	− 270	− 1·778	+ 284	+ 1·898	+ 279	+ 1·833
4339·882	− 306	− 2·032	− 294	− 1·924	+ 290	+ 1·934	+ 288	+ 1·887
4343·861	− 277	− 1·851	− 278	− 1·823	+ 287	+ 1·912	+ 231	+ 1·534
4344·670	− 279	− 1·862	− 299	− 1·951	+ 285	+ 1·899	+ 318	+ 2·068
4346·725	− 273	− 1·825	− 279	− 1·827	+ 274	+ 1·831	+ 281	+ 1·840
4347·403	− 274	− 1·830	− 276	− 1·809	+ 263	+ 1·763	+ 285	+ 1·864
4349·107	− 270	− 1·804	− 297	− 1·936	+ 282	+ 1·878	+ 284	+ 1·856
	N 48 $\frac{d\lambda}{ds} = 0{\cdot}8763$		N 49 $\frac{d\lambda}{ds} = 0{\cdot}8764$		N 50 $\frac{d\lambda}{ds} = 0{\cdot}8763$		N 51 $\frac{d\lambda}{ds} = 0{\cdot}8762$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4351·000	− 0·0278	− 1·860	− 0·0279	− 1·833	+ 0·0253	+ 1·707	+ 0·0293	+ 1·919
4352·908	− 281	− 1·877	− 275	− 1·807	+ 275	+ 1·841	+ 301	+ 1·966
4358·670	− 262	− 1·757	− 302	− 1·968	+ 279	+ 1·861	+ 270	+ 1·772
4366·061	− 278	− 1·851	− 287	− 1·872	+ 261	+ 1·747	+ 285	+ 1·860
4371·442	− 288	− 1·908	− 286	− 1·862	+ 305	+ 2·012	+ 275	+ 1·795
4373·415	− 272	− 1·809	− 252	− 1·653	+ 252	+ 1·687	+ 270	+ 1·763
4373·727	− 296	− 1·955	− 234	− 1·543	+ 285	+ 1·888	+ 273	+ 1·781
4376·107	− 279	− 1·850	− 271	− 1·767	+ 289	+ 1·911	+ 289	+ 1·877
4379·396	− 325	− 2·127	− 255	− 1·668	+ 289	+ 1·909	+ 273	+ 1·776
4385·144	− 291	− 1·917	− 273	− 1·773	+ 275	+ 1·819	+ 266	+ 1·731
4388·571	− 265	− 1·757	− 271	− 1·759	+ 290	+ 1·908	+ 273	+ 1·771
4390·149	− 260	− 1·725	− 279	− 1·807	+ 271	+ 1·792	+ 285	+ 1·843
4395·201	− 270	− 1·783	− 287	− 1·852	+ 268	+ 1·771	+ 276	+ 1·785
4396·008	− 262	− 1·734	− 294	− 1·893	+ 293	+ 1·921	+ 281	+ 1·815
4400·555	− 264	− 1·743	− 268	− 1·734	+ 299	+ 1·954	+ 286	+ 1·842

TABLE VII. *Results from all plates, line for line (continued)*

SERIES II (*continued*)

	$\phi_1 = 15°$ S.E. $\phi_2 = 75°$ S.W. $\Delta v = -0·170$		$\phi_1 = 75°$ S.W. $\phi_2 = 15°$ N.W. $\Delta v = -0·077$		$\phi_1 = 15°$ N.W. $\phi_2 = 75°$ N.E. $\Delta v = +0·170$		$\phi_1 = 75°$ N.E. $\phi_2 = 15°$ S.E. $\Delta v = +0·077$	
	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$
λ	N 40 $\frac{d\lambda}{ds} = 0·8797$		N 41 $\frac{d\lambda}{ds} = 0·8796$		N 42 $\frac{d\lambda}{ds} = 0·8797$		N 43 $\frac{d\lambda}{ds} = 0·8798$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4299·149	− 0·0316	− 2·145	− 0·0224	− 1·477	+ 0·0341	+ 2·301	+ 0·0198	+ 1·314
4302·085	− 327	− 2·212	− 219	− 1·444	+ 339	+ 2·286	+ 204	+ 1·350
4314·248	− 325	− 2·190	− 225	− 1·475	+ 339	+ 2·277	+ 197	+ 1·301
4315·138	− 319	− 2·150	− 216	− 1·419	+ 340	+ 2·282	+ 211	+ 1·388
4320·907	− 324	− 2·178	− 226	− 1·478	+ 345	+ 2·308	+ 204	+ 1·341
4326·923	− 312	− 2·099	− 219	− 1·431	+ 344	+ 2·297	+ 199	+ 1·307
4331·811	− 322	− 2·157	− 216	− 1·410	+ 343	+ 2·286	+ 198	+ 1·299
4337·725	− 317	− 2·121	− 222	− 1·444	+ 336	+ 2·239	+ 206	+ 1·345
4338·084	− 314	− 2·103	− 219	− 1·425	+ 341	+ 2·269	+ 207	+ 1·351
4339·882	− 318	− 2·126	− 220	− 1·430	+ 338	+ 2·249	+ 196	+ 1·283
4343·861	− 322	− 2·147	− 225	− 1·459	+ 332	+ 2·209	+ 207	+ 1·348
4344·670	− 319	− 2·128	− 214	− 1·390	+ 339	+ 2·251	+ 199	+ 1·298
4346·725	− 320	− 2·133	− 218	− 1·414	+ 346	+ 2·292	+ 203	+ 1·322
4347·403	− 324	− 2·157	− 218	− 1·414	+ 329	+ 2·188	+ 188	+ 1·230
4349·107	− 314	− 2·094	− 214	− 1·388	+ 347	+ 2·196	+ 197	+ 1·284
	N 44 $\frac{d\lambda}{ds} = 0·8764$		N 45 $\frac{d\lambda}{ds} = 0·8762$		N 46 $\frac{d\lambda}{ds} = 0·8762$		N 47 $\frac{d\lambda}{ds} = 0·8762$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4351·000	− 0·0322	− 2·151	− 0·0226	− 1·467	+ 0·0340	+ 2·262	+ 0·0200	+ 1·307
4352·908	− 321	− 2·143	− 214	− 1·392	+ 341	+ 2·268	+ 205	+ 1·337
4358·670	− 309	− 2·065	− 218	− 1·414	+ 327	+ 2·175	+ 199	+ 1·297
4366·061	− 318	− 2·115	− 219	− 1·417	+ 340	+ 2·250	+ 204	+ 1·325
4371·442	− 323	− 2·142	− 220	− 1·420	+ 338	+ 2·233	+ 207	+ 1·340
4373·415	− 323	− 2·140	− 218	− 1·407	+ 340	+ 2·244	+ 197	+ 1·279
4373·727	− 329	− 2·176	− 219	− 1·412	+ 340	+ 2·243	+ 205	+ 1·327
4376·107	− 327	− 2·162	− 227	− 1·460	+ 346	+ 2·278	+ 199	+ 1·288
4379·396	− 307	− 2·038	− 226	− 1·452	+ 340	+ 2·239	+ 191	+ 1·239
4385·144	− 319	− 2·106	− 223	− 1·431	+ 341	+ 2·240	+ 201	+ 1·297
4388·571	− 326	− 2·146	− 227	− 1·453	+ 343	+ 2·249	+ 207	+ 1·332
4390·149	− 316	− 2·085	− 226	− 1·446	+ 336	+ 2·206	+ 197	+ 1·271
4395·201	− 322	− 2·117	− 218	− 1·395	+ 333	+ 2·184	+ 201	+ 1·292
4396·008	− 315	− 2·074	− 223	− 1·425	+ 339	+ 2·219	+ 207	+ 1·328
4400·555	− 329	− 2·156	− 214	− 1·368	+ 341	+ 2·228	+ 200	+ 1·284

TABLE VII. *Results from all plates, line for line (continued)*

SERIES II (*continued*)

	$\phi_1 = 30°$ S.E., $\phi_2 = 60°$ S.W., $\Delta v = -0{\cdot}177$		$\phi_1 = 60°$ S.W., $\phi_2 = 30°$ N.W., $\Delta v = -0{\cdot}029$		$\phi_1 = 30°$ N.W., $\phi_2 = 60°$ N.E., $\Delta v = +0{\cdot}177$		$\phi_1 = 60°$ N.E., $\phi_2 = 30°$ S.E., $\Delta v = +0{\cdot}029$	
	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$
λ	N 97, $\frac{d\lambda}{ds} = 0{\cdot}8800$		N 98, $\frac{d\lambda}{ds} = 0{\cdot}8797$		N 99, $\frac{d\lambda}{ds} = 0{\cdot}8798$		N 100, $\frac{d\lambda}{ds} = 0{\cdot}8798$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4299·149	− 0·0307	− 2·096	− 0·0113	− 0·735	+ 0·0313	+ 2·133	+ 0·0107	+ 0·698
4302·085	− 330	− 2·237	− 118	− 0·766	+ 344	+ 2·325	+ 114	+ 0·741
4314·248	− 330	− 2·228	− 124	− 0·800	+ 330	+ 2·228	+ 115	+ 0·744
4315·138	− 310	− 2·103	− 108	− 0·700	+ 338	+ 2·277	+ 112	+ 0·723
4320·907	− 349	− 2·340	− 140	− 0·897	+ 357	+ 2·389	+ 111	+ 0·717
4326·923	− 337	− 2·261	− 130	− 0·833	+ 344	+ 2·304	+ 124	+ 0·796
4331·811	− 339	− 2·269	− 137	− 0·874	+ 340	+ 2·275	+ 120	+ 0·770
4337·725	− 320	− 2·147	− 140	− 0·891	+ 350	+ 2·332	+ 120	+ 0·768
4338·084	− 324	− 2·172	− 130	− 0·829	+ 355	+ 2·362	+ 110	+ 0·706
4339·882	− 320	− 2·146	− 133	− 0·847	+ 361	+ 2·398	+ 103	+ 0·663
4343·861	− 327	− 2·185	− 134	− 0·852	+ 352	+ 2·339	+ 111	+ 0·711
4344·670	− 327	− 2·184	− 128	− 0·815	+ 343	+ 2·282	+ 106	+ 0·680
4346·725	− 338	− 2·251	− 113	− 0·722	+ 353	+ 2·343	+ 117	+ 0·747
4347·403	− 333	− 2·220	− 133	− 0·845	+ 361	+ 2·391	+ 101	+ 0·649
4349·107	− 324	− 2·163	− 144	− 0·911	+ 372	+ 2·457	+ 112	+ 0·715
	N 93, $\frac{d\lambda}{ds} = 0{\cdot}8732$		N 94, $\frac{d\lambda}{ds} = 0{\cdot}8760$		N 95, $\frac{d\lambda}{ds} = 0{\cdot}8762$		N 96, $\frac{d\lambda}{ds} = 0{\cdot}8761$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4351·000	− 0·0325	− 2·169	− 0·0136	− 0·866	+ 0·0353	+ 2·348	+ 0·0107	+ 0·687
4352·908	− 336	− 2·235	− 132	− 0·840	+ 323	+ 2·162	+ 103	+ 0·662
4358·670	− 332	− 2·206	− 130	− 0·826	+ 358	+ 2·372	+ 117	+ 0·746
4366·061	− 306	− 2·042	− 112	− 0·714	+ 352	+ 2·330	+ 120	+ 0·763
4371·442	− 339	− 2·239	− 132	− 0·835	+ 350	+ 2·313	+ 121	+ 0·767
4373·415	− 328	− 2·170	− 141	− 0 889	+ 353	+ 2·330	+ 120	+ 0·761
4373·727	− 305	− 2·030	− 140	− 0·883	+ 346	+ 2·286	+ 111	+ 0·706
4376·107	− 322	− 2·132	− 115	− 0·730	+ 351	+ 2·315	+ 114	+ 0·723
4379·396	− 315	− 2·087	− 126	− 0·796	+ 342	+ 2·258	+ 110	+ 0·698
4385·144	− 328	− 2·161	− 130	− 0·818	+ 347	+ 2·283	+ 113	+ 0·715
4388·571	− 329	− 2·164	− 136	− 0·853	+ 365	+ 2·389	+ 105	+ 0·665
4390·149	− 337	− 2·211	− 145	− 0·907	+ 332	+ 2·188	+ 100	+ 0·635
4395·201	− 316	− 2·081	− 111	− 0·700	+ 330	+ 2·172	+ 110	+ 0·694
4396·008	− 330	− 2·164	− 130	− 0·815	+ 344	+ 2·256	+ 104	+ 0·657
4400·555	− 312	− 2·053	− 139	− 0·868	+ 346	+ 2·265	+ 110	+ 0·693

TABLE VII. *Results from all plates, line for line* (*continued*)

SERIES II (*continued*)

λ	$\phi_1 = 45°$ S.E. $\phi_2 = 45°$ S.W. $\Delta v = -0{\cdot}175$		$\phi_1 = 45°$ S.W. $\phi_2 = 45°$ N.W. $\Delta v = +0{\cdot}024$		$\phi_1 = 45°$ N.W. $\phi_2 = 45°$ N.E. $\Delta v = +0{\cdot}175$		$\phi_1 = 45°$ N.E. $\phi_2 = 45°$ S.E. $\Delta v = -0{\cdot}024$	
	Δs	$v\phi_1 - v\phi_2$	Δs	$v\phi_1 - v\phi_2$	Δs	$v\phi_1 - v\phi_2$	Δs	$v\phi_1 - v\phi_2$
	N 85 $\frac{d\lambda}{ds}=0{\cdot}8796$		N 86 $\frac{d\lambda}{ds}=0{\cdot}8797$		N 87 $\frac{d\lambda}{ds}=0{\cdot}8797$		N 88 $\frac{d\lambda}{ds}=0{\cdot}8797$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4299·149	− 0·0347	− 2·343	0	+ 0·024	+ 0·0361	+ 2·431	− 0·0009	− 0·080
4302·085	− 335	− 2·266	− 0·0010	− 0·038	+ 354	+ 2·385	− 5	− 0·055
4314·248	− 354	− 2·375	− 2	+ 0·012	+ 360	+ 2·412	− 5	− 0·055
4315·138	− 330	− 2·255	− 15	− 0·069	+ 346	+ 2·436	− 11	− 0·092
4320·907	− 335	− 2·251	− 9	− 0·031	+ 360	+ 2·405	− 12	− 0·098
4326·923	− 349	− 2·333	− 4	− 0·001	+ 362	+ 2·413	0	− 0·024
4331·811	− 325	− 2·180	− 14	− 0·062	+ 351	+ 2·341	− 3	− 0·043
4337·725	− 348	− 2·317	+ 4	+ 0·049	+ 355	+ 2·360	− 1	− 0·030
4338·084	− 347	− 2·311	− 10	− 0·038	+ 357	+ 2·373	− 5	− 0·055
4339·882	− 346	− 2·303	− 5	− 0·007	+ 352	+ 2·340	− 4	− 0·049
4343·861	− 352	− 2·336	− 3	+ 0·006	+ 363	+ 2·404	− 13	− 0·104
4344·670	− 325	− 2·170	− 20	− 0·099	+ 360	+ 2·384	− 10	− 0·085
4346·725	− 346	− 2·297	0	+ 0·024	+ 355	+ 2·353	− 12	− 0·098
4347·403	− 337	− 2·242	− 4	− 0·001	+ 352	+ 2·334	− 9	− 0·079
4349·107	− 360	− 2·381	− 19	− 0·092	+ 364	+ 2·405	− 1	− 0·030
	N 89 $\frac{d\lambda}{ds}=0{\cdot}8758$		N 90 $\frac{d\lambda}{ds}=0{\cdot}8761$		N 91 $\frac{d\lambda}{ds}=0{\cdot}8756$		N 92 $\frac{d\lambda}{ds}=0{\cdot}8760$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4351·000	− 0·0343	− 2·284	− 0·0010	− 0·037	+ 0·0359	+ 2·382	− 0·0008	− 0·073
4352·908	− 342	− 2·276	− 8	− 0·025	+ 359	+ 2·381	− 6	− 0·061
4358·670	− 342	− 2·271	− 8	− 0·025	+ 353	+ 2·339	− 4	− 0·049
4366·061	− 350	− 2·315	− 3	+ 0·006	+ 360	+ 2·376	− 12	− 0·097
4371·442	− 340	− 2·249	− 4	0	+ 356	+ 2·347	+ 2	− 0·012
4373·415	− 335	− 2·218	− 9	− 0·030	+ 362	+ 2·382	− 16	− 0·122
4373·727	− 346	− 2·284	− 10	− 0·037	+ 357	+ 2·351	− 7	− 0·067
4376·107	− 342	− 2·258	− 7	− 0·019	+ 355	+ 2·337	− 10	− 0·085
4379·396	− 347	− 2·285	− 9	− 0·031	+ 357	+ 2·346	− 10	− 0·085
4385·144	− 342	− 2·250	− 10	− 0·037	+ 356	+ 2·335	− 7	− 0·066
4388·571	− 334	− 2·199	− 11	− 0·043	+ 360	+ 2·356	− 6	− 0·060
4390·149	− 344	− 2·258	− 2	+ 0·012	+ 359	+ 2·349	+ 6	+ 0·012
4395·201	− 342	− 2·242	− 2	+ 0·012	+ 352	+ 2·303	− 18	− 0·085
4396·008	− 345	− 2·259	− 8	− 0·024	+ 368	+ 2·398	− 5	− 0·054
4400·555	− 358	− 2·334	− 2	+ 0·012	+ 350	+ 2·286	− 3	− 0·042

TABLE VII. *Results from all plates, line for line* (*continued*)

SERIES II (*continued*)

	ϕ_1 = 60° S.E. ϕ_2 = 30° S.W. $\Delta v = -0{\cdot}165$		ϕ_1 = 30° S.W. ϕ_2 = 60° N.W. $\Delta v = +0{\cdot}075$		ϕ_1 = 60° N.W. ϕ_2 = 30° N.E. $\Delta v = +0{\cdot}165$		ϕ_1 = 30° N.E. ϕ_2 = 60° S.E. $\Delta v = -0{\cdot}075$	
	Δs	$v\phi_1 - v\phi_2$	Δs	$v\phi_1 - v\phi_2$	Δs	$v\phi_1 - v\phi_2$	Δs	$v\phi_1 - v\phi_2$
λ	N 129 $\frac{d\lambda}{ds}=0{\cdot}8795$		N 130 $\frac{d\lambda}{ds}=0{\cdot}8797$		N 135 $\frac{d\lambda}{ds}=0{\cdot}8794$		N 136 $\frac{d\lambda}{ds}=0{\cdot}8795$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4299·149	− 0·0331	− 2·233	+ 0·0107	+ 0·744	+ 0·0344	+ 2·314	− 0·0130	− 0·887
4302·085	− 324	− 2·187	+ 116	+ 0·799	+ 336	+ 2·262	− 135	− 0·918
4314·248	− 345	− 2·309	+ 110	+ 0·758	+ 358	+ 2·389	− 123	− 0·839
4315·138	− 324	− 2·177	+ 116	+ 0·795	+ 351	+ 2·345	− 128	− 0·870
4320·907	− 329	− 2·203	+ 110	+ 0·756	+ 347	+ 2·315	− 135	− 0·911
4326·923	− 332	− 2·217	+ 112	+ 0·767	+ 344	+ 2·291	− 123	− 0·835
4331·811	− 326	− 2·176	+ 108	+ 0·741	+ 342	+ 2·275	− 130	− 0·877
4337·725	− 331	− 2·202	+ 108	+ 0·740	+ 345	+ 2·288	− 127	− 0·857
4338·084	− 332	− 2·208	+ 115	+ 0·783	+ 347	+ 2·301	− 130	− 0·875
4339·882	− 334	− 2·219	+ 106	+ 0·727	+ 347	+ 2·299	− 135	− 0·905
4343·861	− 327	− 2·172	+ 107	+ 0·732	+ 355	+ 2·344	− 134	− 0·898
4344·670	− 325	− 2·159	+ 118	+ 0·799	+ 344	+ 2·276	− 128	− 0·860
4346·725	− 337	− 2·232	+ 116	+ 0·786	+ 356	+ 2·348	− 128	− 0·860
4347·403	− 332	− 2·201	+ 110	+ 0·750	+ 350	+ 2·311	− 127	− 0·854
4349·107	− 319	− 2·119	+ 112	+ 0·761	+ 351	+ 2·315	− 133	− 0·890
	N 131 $\frac{d\lambda}{ds}=0{\cdot}8758$		N 132 $\frac{d\lambda}{ds}=0{\cdot}8759$		N 133 $\frac{d\lambda}{ds}=0{\cdot}8759$		N 134 $\frac{d\lambda}{ds}=0{\cdot}8759$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4351·000	− 0·0340	− 2·256	+ 0·0107	+ 0·733	+ 0·0346	+ 2·293	− 0·0130	− 0·874
4352·908	− 321	− 2·137	+ 105	+ 0·720	+ 352	+ 2·328	− 135	− 0·904
4358·670	− 325	− 2·157	+ 124	+ 0·835	+ 349	+ 2·304	− 122	− 0·823
4366·061	− 327	− 2·164	+ 107	+ 0·729	+ 354	+ 2·329	− 133	− 0·888
4371·442	− 342	− 2·252	+ 109	+ 0·740	+ 345	+ 2·270	− 136	− 0·905
4373·415	− 326	− 2·153	+ 120	+ 0·807	+ 356	+ 2·336	− 124	− 0·831
4373·727	− 330	− 2·176	+ 108	+ 0·733	+ 350	+ 2·298	− 130	− 0·867
4376·107	− 335	− 2·205	+ 111	+ 0·751	+ 344	+ 2·260	− 127	− 0·848
4379·396	− 338	− 2·221	+ 111	+ 0·750	+ 349	+ 2·288	− 132	− 0·878
4385·144	− 329	− 2·161	+ 112	+ 0·755	+ 345	+ 2·258	− 133	− 0·881
4388·571	− 333	− 2·183	+ 115	+ 0·772	+ 354	+ 2·310	− 122	− 0·814
4390·149	− 328	− 2·151	+ 109	+ 0·735	+ 345	+ 2·254	− 125	− 0·832
4395·201	− 333	− 2·178	+ 111	+ 0·746	+ 351	+ 2·286	− 126	− 0·837
4396·008	− 329	− 2·152	+ 110	+ 0·740	+ 345	+ 2·249	− 131	− 0·866
4400·555	− 329	− 2·150	+ 105	+ 0·708	+ 337	+ 2·198	− 126	− 0·835

TABLE VII. *Results from all plates, line for line* (*continued*)

SERIES II (*concluded*)

	$\phi_1 = 75°$ S.E. $\phi_2 = 15°$ S.W. $\Delta v = -0·148$		$\phi_1 = 15°$ S.W. $\phi_2 = 75°$ N.W. $\Delta v = +0·118$		$\phi_1 = 75°$ N.W. $\phi_2 = 15°$ N.E. $\Delta v = +0·148$		$\phi_1 = 15°$ N.E. $\phi_2 = 75°$ S.E. $\Delta v = -0·118$	
	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$
λ	N 137 $\frac{d\lambda}{ds} = 0·8794$		N 138 $\frac{d\lambda}{ds} = 0·8794$		N 139 $\frac{d\lambda}{ds} = 0·8793$		N 140 $\frac{d\lambda}{ds} = 0·8794$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4299·149	− 0·0327	− 2·191	+ 0·0202	+ 1·380	+ 0·0343	+ 2·291	− 0·0217	− 1·474
4302·085	− 303	− 2·039	+ 206	+ 1·403	+ 340	+ 2·270	− 227	− 1·534
4314·248	− 331	− 2·204	+ 196	+ 1·336	+ 337	+ 2·241	− 216	− 1·460
4315·138	− 315	− 2·104	+ 203	+ 1·378	+ 345	+ 2·290	− 217	− 1·465
4320·907	− 335	− 2·223	+ 207	+ 1·400	+ 347	+ 2·297	− 224	− 1·505
4326·923	− 310	− 2·064	+ 203	+ 1·373	+ 332	+ 2·200	− 219	− 1·471
4331·811	− 321	− 2·128	+ 204	+ 1·376	+ 331	+ 2·190	− 212	− 1·426
4337·725	− 318	− 2·104	+ 204	+ 1·373	+ 338	+ 2·228	− 216	− 1·447
4338·084	− 320	− 2·117	+ 202	+ 1·361	+ 339	+ 2·234	− 223	− 1·490
4339·882	− 321	− 2·122	+ 199	+ 1·342	+ 341	+ 2·245	− 214	− 1·434
4343·861	− 322	− 2·124	+ 183	+ 1·241	+ 336	+ 2·210	− 215	− 1·438
4344·670	− 314	− 2·074	+ 203	+ 1·363	+ 342	+ 2·246	− 212	− 1·419
4346·725	− 318	− 2·098	+ 197	+ 1·326	+ 346	+ 2·270	− 224	− 1·492
4347·403	− 316	− 2·085	+ 205	+ 1·375	+ 343	+ 2·251	− 217	− 1·448
4349·107	− 326	− 2·145	+ 203	+ 1·361	+ 342	+ 2·243	− 228	− 1·515
	N 141 $\frac{d\lambda}{ds} = 0·8754$		N 142 $\frac{d\lambda}{ds} = 0·8756$		N 143 $\frac{d\lambda}{ds} = 0·8755$		N 144 $\frac{d\lambda}{ds} = 0·8755$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4351·000	− 0·0311	− 2·060	+ 0·0202	+ 1·360	+ 0·0337	+ 2·220	− 0·0220	− 1·470
4352·908	− 317	− 2·095	+ 198	+ 1·334	+ 339	+ 2·230	− 228	− 1·518
4358·670	− 313	− 2·066	+ 193	+ 1·301	+ 320	+ 2·109	− 215	− 1·436
4366·061	− 328	− 2·153	+ 225	+ 1·493	+ 350	+ 2·287	− 216	− 1·438
4371·442	− 316	− 2·075	+ 210	+ 1·399	+ 340	+ 2·222	− 221	− 1·466
4373·415	− 325	− 2·129	+ 203	+ 1·355	+ 334	+ 2·184	− 236	− 1·556
4373·727	− 316	− 2·073	+ 200	+ 1·336	+ 342	+ 2·231	− 218	− 1·446
4376·107	− 314	− 2·060	+ 206	+ 1·372	+ 344	+ 2·242	− 214	− 1·421
4379·396	− 330	− 2·154	+ 200	+ 1·334	+ 364	+ 2·361	− 230	− 1·516
4385·144	− 318	− 2·077	+ 202	+ 1·343	+ 330	+ 2·149	− 225	− 1·483
4388·571	− 321	− 2·092	+ 201	+ 1·335	+ 344	+ 2·232	− 226	− 1·487
4390·149	− 319	− 2·079	+ 200	+ 1·329	+ 345	+ 2·237	− 220	− 1·450
4395·201	− 325	− 2·112	+ 192	+ 1·278	+ 341	+ 2·208	− 213	− 1·405
4396·008	− 325	− 2·111	+ 205	+ 1·356	+ 338	+ 2·189	− 228	− 1·495
4400·555	− 325	− 2·108	+ 200	+ 1·324	+ 341	+ 2·204	− 218	− 1·433

TABLE VII. *Results from all plates, line for line (continued)*

SERIES III

λ	$\phi_1 = 0°$ E. $\phi_2 = 90°$ S. $\Delta v = -0{\cdot}150$		$\phi_1 = 90°$ S. $\phi_2 = 0°$ W. $\Delta v = -0{\cdot}116$		$\phi_1 = 0°$ W. $\phi_2 = 90°$ N. $\Delta v = +0{\cdot}150$		$\phi_1 = 90°$ N. $\phi_2 = 0°$ E. $\Delta v = +0{\cdot}116$	
	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$
	N 117 $\frac{d\lambda}{ds} = 0{\cdot}8797$		N 118 $\frac{d\lambda}{ds} = 0{\cdot}8796$		N 119 $\frac{d\lambda}{ds} = 0{\cdot}8794$		N 120 $\frac{d\lambda}{ds} = 0{\cdot}8796$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4299·149	− 0·0282	− 1·912	− 0·0278	− 1·853	+ 0·0274	+ 1·856	+ 0·0277	+ 1·847
4302·085	− 288	− 1·948	− 283	− 1·882	+ 285	+ 1·929	+ 265	+ 1·770
4314·248	− 264	− 1·791	− 265	− 1·763	+ 271	+ 1·834	+ 280	+ 1·856
4315·138	− 294	− 1·976	− 290	− 1·917	+ 285	+ 1·920	+ 275	+ 1·824
4320·907	− 276	− 1·860	− 280	− 1·851	+ 289	+ 1·941	+ 280	+ 1·851
4326·923	− 278	− 1·869	− 281	− 1·853	+ 284	+ 1·906	+ 291	+ 1·915
4331·811	− 265	− 1·785	− 273	− 1·800	+ 282	+ 1·890	+ 259	+ 1·714
4337·725	− 275	− 1·843	− 284	− 1·864	+ 283	+ 1·892	+ 284	+ 1·864
4338·084	− 293	− 1·953	− 276	− 1·815	+ 279	+ 1·867	+ 278	+ 1·827
4339·882	− 282	− 1·885	− 282	− 1·851	+ 278	+ 1·860	+ 272	+ 1·789
4343·861	− 283	− 1·888	− 279	− 1·829	+ 281	+ 1·875	+ 291	+ 1·903
4344·670	− 284	− 1·893	− 280	− 1·834	+ 274	+ 1·831	+ 289	+ 1·890
4346·725	− 274	− 1·831	− 278	− 1·821	+ 283	+ 1·886	+ 282	+ 1·846
4347·403	− 268	− 1·794	− 277	− 1·815	+ 279	+ 1·861	+ 285	+ 1·864
4349·107	− 275	− 1·835	− 275	− 1·801	+ 271	+ 1·810	+ 281	+ 1·838
	N 113 $\frac{d\lambda}{ds} = 0{\cdot}8760$		N 114 $\frac{d\lambda}{ds} = 0{\cdot}8758$		N 115 $\frac{d\lambda}{ds} = 0{\cdot}8758$		N 116 $\frac{d\lambda}{ds} = 0{\cdot}8759$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4351·000	− 0·0282	− 1·884	− 0·0277	− 1·819	+ 0·0281	+ 1·878	+ 0·0279	+ 1·832
4352·908	− 270	− 1·809	− 281	− 1·842	+ 282	+ 1·883	+ 303	+ 1·978
4358·670	− 288	− 1·915	− 290	− 1·893	+ 292	+ 1·940	+ 267	+ 1·753
4366·061	− 280	− 1·862	− 282	− 1·840	+ 267	+ 1·783	+ 280	+ 1·828
4371·442	− 283	− 1·877	− 278	− 1·812	+ 300	+ 1·980	+ 284	+ 1·849
4373·415	− 279	− 1·851	− 287	− 1·866	+ 314	+ 2·065	+ 280	+ 1·823
4373·727	− 273	− 1·814	− 278	− 1·810	+ 294	+ 1·942	+ 335	+ 2·157
4376·107	− 277	− 1·837	− 271	− 1·766	+ 295	+ 1·947	+ 275	+ 1·791
4379·396	− 284	− 1·877	− 272	− 1·770	+ 268	+ 1·780	+ 287	+ 1·861
4385·144	− 289	− 1·903	− 282	− 1·827	+ 263	+ 1·746	+ 287	+ 1·857
4388·571	− 280	− 1·847	− 289	− 1·867	+ 287	+ 1·889	+ 271	+ 1·758
4390·149	− 282	− 1·858	− 274	− 1·775	+ 276	+ 1·821	+ 283	+ 1·830
4395·201	− 276	− 1·818	− 279	− 1·802	+ 266	+ 1·758	+ 257	+ 1·669
4396·008	− 287	− 1·884	− 281	− 1·813	+ 296	+ 1·938	+ 288	+ 1·856
4400·555	− 288	− 1·887	− 284	− 1·829	+ 290	+ 1·899	+ 270	+ 1·745

TABLE VII. *Results from all plates, line for line (continued)*

SERIES III *(continued)*

λ	$\phi_1 = 15°$ S.E., $\phi_2 = 75°$ S.W., $\Delta v = -0{\cdot}170$		$\phi_1 = 75°$ S.W., $\phi_2 = 15°$ N.W., $\Delta v = -0{\cdot}077$		$\phi_1 = 15°$ N.W., $\phi_2 = 75°$ N.E., $\Delta v = +0{\cdot}170$		$\phi_1 = 75°$ N.E., $\phi_2 = 15°$ S.E., $\Delta v = +0{\cdot}077$	
	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$
	N 105, $\frac{d\lambda}{ds} = 0{\cdot}8795$		N 106, $\frac{d\lambda}{ds} = 0{\cdot}8795$		N 107, $\frac{d\lambda}{ds} = 0{\cdot}8797$		N 108, $\frac{d\lambda}{ds} = 0{\cdot}8795$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4299·149	− 0·0317	− 2·151	− 0·0236	− 1·552	+ 0·0335	+ 2·263	+ 0·0206	+ 1·367
4302·085	− 319	− 2·161	− 232	− 1·525	+ 337	+ 2·273	+ 202	+ 1·338
4314·248	− 310	− 2·096	− 207	− 1·363	+ 343	+ 2·301	+ 201	+ 1·326
4315·138	− 327	− 2·201	− 238	− 1·555	+ 350	+ 2·344	+ 197	+ 1·301
4320·907	− 319	− 2·150	− 236	− 1·542	+ 336	+ 2·255	+ 195	+ 1·287
4326·923	− 315	− 2·117	− 207	− 1·357	+ 330	+ 2·210	+ 212	+ 1·388
4331·811	− 317	− 2·126	− 200	− 1·311	+ 357	+ 2·373	+ 211	+ 1·379
4337·725	− 334	− 2·226	− 228	− 1·480	+ 333	+ 2·219	+ 195	+ 1·277
4338·084	− 313	− 2·096	− 215	− 1·400	+ 322	+ 2·152	+ 212	+ 1·382
4339·882	− 313	− 2·095	− 212	− 1·381	+ 330	+ 2·200	+ 197	+ 1·289
4343·861	− 320	− 2·135	− 225	− 1·459	+ 328	+ 2·184	+ 223	+ 1·446
4344·670	− 323	− 2·152	− 218	− 1·415	+ 345	+ 2·287	+ 190	+ 1·243
4346·725	− 320	− 2·133	− 230	− 1·488	+ 346	+ 2·292	+ 192	+ 1·255
4347·403	− 316	− 2·108	− 217	− 1·408	+ 335	+ 2·225	+ 203	+ 1·322
4349·107	− 316	− 2·106	− 218	− 1·413	+ 352	+ 2·327	+ 197	+ 1·284
	N 109, $\frac{d\lambda}{ds} = 0{\cdot}8760$		N 110, $\frac{d\lambda}{ds} = 0{\cdot}8760$		N 111, $\frac{d\lambda}{ds} = 0{\cdot}8757$		N 112, $\frac{d\lambda}{ds} = 0{\cdot}8758$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4351·000	− 0·0319	− 2·132	− 0·0212	− 1·381	+ 0·0340	+ 2·261	+ 0·0200	+ 1·307
4352·908	− 327	− 2·179	− 222	− 1·441	+ 344	+ 2·284	+ 200	+ 1·306
4358·670	− 322	− 2·144	− 220	− 1·426	+ 327	+ 2·175	+ 211	+ 1·370
4366·061	− 312	− 2·076	− 213	− 1·379	+ 336	+ 2·224	+ 217	+ 1·404
4371·442	− 311	− 2·067	− 248	− 1·590	+ 337	+ 2·226	+ 227	+ 1·462
4373·415	− 318	− 2·109	− 221	− 1·424	+ 332	+ 2·194	+ 190	+ 1·235
4373·727	− 327	− 2·163	− 225	− 1·448	+ 343	+ 2·260	+ 202	+ 1·308
4376·107	− 326	− 2·155	− 228	− 1·466	+ 344	+ 2·265	+ 187	+ 1·216
4379·396	− 316	− 2·092	− 212	− 1·366	+ 315	+ 2·086	+ 200	+ 1·293
4385·144	− 320	− 2·111	− 222	− 1·424	+ 344	+ 2·257	+ 213	+ 1·369
4388·571	− 328	− 2·157	− 223	− 1·428	+ 348	+ 2·279	+ 191	+ 1·234
4390·149	− 320	− 2·108	− 211	− 1·355	+ 321	+ 2·114	+ 206	+ 1·325
4395·201	− 318	− 2·092	− 226	− 1·443	+ 337	+ 2·207	+ 200	+ 1·286
4396·008	− 314	− 2·067	− 222	− 1·418	+ 328	+ 2·151	+ 194	+ 1·249
4400·555	− 327	− 2·142	− 221	− 1·410	+ 348	+ 2·269	+ 197	+ 1·265

TABLE VII. *Results from all plates, line for line (continued)*

SERIES III (*continued*)

	$\phi_1 = 30°$ S.E. $\phi_2 = 60°$ S.W. $\Delta v = -0{\cdot}177$		$\phi_1 = 60°$ S.W. $\phi_2 = 30°$ N.W. $\Delta v = -0{\cdot}029$		$\phi_1 = 30°$ N.W. $\phi_2 = 60°$ N.E. $\Delta v = +0{\cdot}177$		$\phi_1 = 60°$ N.E. $\phi_2 = 30°$ S.E. $\Delta v = +0{\cdot}029$	
	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$
λ	N 161 $\frac{d\lambda}{ds} = 0{\cdot}8796$		N 162 $\frac{d\lambda}{ds} = 0{\cdot}8795$		N 163 $\frac{d\lambda}{ds} = 0{\cdot}8796$		N 164 $\frac{d\lambda}{ds} = 0{\cdot}8795$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4299·149	− 0·0334	− 2·264	− 0·0124	− 0·804	+ 0·0350	+ 2·364	+ 0·0106	+ 0·691
4302·085	− 330	− 2·237	− 138	− 0·890	+ 336	+ 2·274	+ 111	+ 0·722
4314·248	− 339	− 2·284	− 132	− 0·849	+ 348	+ 2·339	+ 104	+ 0·675
4315·138	− 330	− 2·233	− 129	− 0·830	+ 347	+ 2·332	+ 113	+ 0·731
4320·907	− 335	− 2·253	− 128	− 0·822	+ 358	+ 2·395	+ 110	+ 0·711
4326·923	− 324	− 2·180	− 121	− 0·777	+ 349	+ 2·335	+ 106	+ 0·684
4331·811	− 334	− 2·238	− 113	− 0·726	+ 350	+ 2·336	+ 112	+ 0·720
4337·725	− 326	− 2·184	− 129	− 0·823	+ 351	+ 2·338	+ 109	+ 0·700
4338·084	− 331	− 2·214	− 135	− 0·860	+ 340	+ 2·270	+ 104	+ 0·669
4339·882	− 330	− 2·213	− 125	− 0·798	+ 345	+ 2·299	+ 107	+ 0·687
4343·861	− 334	− 2·228	− 128	− 0·815	+ 351	+ 2·332	+ 112	+ 0·717
4344·670	− 335	− 2·232	− 128	− 0·815	+ 349	+ 2·319	+ 112	+ 0·716
4346·725	− 339	− 2·256	− 120	− 0·765	+ 351	+ 2·330	+ 113	+ 0·722
4347·403	− 340	− 2·262	− 137	− 0·869	+ 359	+ 2·379	+ 115	+ 0·734
4349·107	− 338	− 2·248	− 120	− 0·764	+ 338	+ 2·248	+ 124	+ 0·789
	N 165 $\frac{d\lambda}{ds} = 0{\cdot}8759$		N 166 $\frac{d\lambda}{ds} = 0{\cdot}8760$		N 167 $\frac{d\lambda}{ds} = 0{\cdot}8760$		N 168 $\frac{d\lambda}{ds} = 0{\cdot}8759$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4351·000	− 0·0333	− 2·225	− 0·0131	− 0·835	+ 0·0347	+ 2·311	+ 0·0114	+ 0·730
4352·908	− 338	− 2·254	− 127	− 0·809	+ 346	+ 2·303	+ 115	+ 0·736
4358·670	− 331	− 2·206	− 127	− 0·808	+ 348	+ 2·311	+ 108	+ 0·691
4366·061	− 325	− 2·164	− 137	− 0·867	+ 353	+ 2·336	+ 124	+ 0·787
4371·442	− 330	− 2·191	− 117	− 0·743	+ 351	+ 2·319	+ 114	+ 0·725
4373·415	− 332	− 2·202	− 135	− 0·852	+ 344	+ 2·275	+ 114	+ 0·724
4373·727	− 329	− 2·182	− 131	− 0·827	+ 351	+ 2·317	+ 107	+ 0·681
4376·107	− 330	− 2·187	− 135	− 0·851	+ 343	+ 2·260	+ 109	+ 0·693
4379·396	− 336	− 2·221	− 129	− 0·814	+ 346	+ 2·282	+ 111	+ 0·704
4385·144	− 330	− 2·179	− 133	− 0·836	+ 355	+ 2·331	+ 117	+ 0·739
4388·571	− 315	− 2·086	− 130	− 0·817	+ 347	+ 2·280	+ 117	+ 0·738
4390·149	− 332	− 2·188	− 127	− 0·798	+ 344	+ 2·261	+ 111	+ 0·701
4395·201	− 338	− 2·220	− 127	− 0·797	+ 344	+ 2·257	+ 107	+ 0·676
4396·008	− 344	− 2·255	− 130	− 0·814	+ 344	+ 2·255	+ 109	+ 0·688
4400·555	− 342	− 2·240	− 118	− 0·741	+ 345	+ 2·258	+ 121	+ 0·759

TABLE VII. *Results from all plates, line for line (continued)*

SERIES III *(continued)*

λ	$\phi_1 = 45°$ S.E. $\phi_2 = 45°$ S.W. $\Delta v = -0.175$		$\phi_1 = 45°$ S.W. $\phi_2 = 45°$ N.W. $\Delta v = +0.024$		$\phi_1 = 45°$ N.W. $\phi_2 = 45°$ N.E. $\Delta v = +0.175$		$\phi_1 = 45°$ N.E. $\phi_2 = 45°$ S.E. $\Delta v = -0.024$	
	Δs	$v\phi_1 - v\phi_2$	Δs	$v\phi_1 - v\phi_2$	Δs	$v\phi_1 - v\phi_2$	Δs	$v\phi_1 - v\phi_2$
	N 149 $\frac{d\lambda}{ds}=0.8793$		N 150 $\frac{d\lambda}{ds}=0.8793$		N 151 $\frac{d\lambda}{ds}=0.8792$		N 152 $\frac{d\lambda}{ds}=0.8793$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4299·149	− 0·0336	− 2·273	− 0·0012	− 0·051	+ 0·0358	+ 2·411	− 0·0012	− 0·099
4302·085	− 338	− 2·284	− 20	− 0·101	+ 359	+ 2·415	− 16	− 0·124
4314·248	− 350	− 2·349	− 12	− 0·051	+ 364	+ 2·436	− 3	− 0·043
4315·138	− 350	− 2·348	− 6	− 0·013	+ 353	+ 2·366	− 10	− 0·086
4320·907	− 340	− 2·281	− 18	− 0·087	+ 360	+ 2·404	− 10	− 0·086
4326·923	− 353	− 2·356	− 17	− 0·081	+ 360	+ 2·399	− 13	− 0·104
4331·811	− 341	− 2·278	− 7	− 0·019	+ 342	+ 2·284	− 8	− 0·073
4337·725	− 347	− 2·310	− 12	− 0·050	+ 348	+ 2·316	− 6	− 0·061
4338·084	− 350	− 2·328	− 6	− 0·013	+ 361	+ 2·396	− 12	− 0·098
4339·882	− 328	− 2·192	− 2	+ 0·012	+ 367	+ 2·431	− 12	− 0·098
4343·861	− 341	− 2·268	− 12	− 0·050	+ 362	+ 2·397	− 16	− 0·122
4344·670	− 340	− 2·261	− 17	− 0·080	+ 352	+ 2·334	− 3	− 0·042
4346·725	− 347	− 2·302	− 13	− 0·056	+ 364	+ 2·407	− 11	− 0·091
4347·403	− 348	− 2·308	− 4	− 0·012	+ 385	+ 2·535	− 17	− 0·128
4349·107	− 336	− 2·232	− 2	+ 0·012	+ 357	+ 2·361	− 19	− 0·140
	N 145 $\frac{d\lambda}{ds}=0.8756$		N 146 $\frac{d\lambda}{ds}=0.8757$		N 147 $\frac{d\lambda}{ds}=0.8757$		N 148 $\frac{d\lambda}{ds}=0.8755$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4351·000	− 0·0330	− 2·204	− 0·0021	− 0·105	+ 0·0353	+ 2·345	− 0·0024	− 0·172
4352·908	− 347	− 2·307	− 8	− 0·025	+ 367	+ 2·429	− 8	− 0·073
4358·670	− 337	− 2·240	− 6	− 0·013	+ 350	+ 2·320	− 12	− 0·098
4366·061	− 354	− 2·339	− 6	− 0·013	+ 359	+ 2·370	− 14	− 0·110
4371·442	− 356	− 2·347	− 5	− 0·006	+ 356	+ 2·347	− 1	− 0·030
4373·415	− 343	− 2·266	− 3	+ 0·006	+ 350	+ 2·308	− 8	− 0·073
4373·727	− 330	− 2·186	− 23	− 0·116	+ 371	+ 2·435	− 12	− 0·097
4376·107	− 320	− 2·123	+ 2	+ 0·036	+ 335	+ 2·215	− 25	− 0·176
4379·396	− 335	− 2·212	− 18	− 0·085	+ 354	+ 2·328	− 1	− 0·030
4385·144	− 342	− 2·249	− 29	− 0·152	+ 354	+ 2·322	− 9	− 0·079
4388·571	− 343	− 2·253	− 4	0	+ 358	+ 2·344	− 7	− 0·066
4390·149	− 328	− 2·161	− 13	− 0·055	+ 354	+ 2·319	− 11	− 0·091
4395·201	− 340	− 2·230	+ 5	+ 0·054	+ 375	+ 2·441	− 13	− 0·103
4396·008	− 347	− 2·271	− 30	− 0·157	+ 375	+ 2·440	− 6	− 0·060
4400·555	− 339	− 2·220	− 6	− 0·012	+ 357	+ 2·328	− 15	− 0·114

TABLE VII. *Results from all plates, line for line* (*continued*)

SERIES III (*continued*)

	$\phi_1 = 60°$ S.E. $\phi_2 = 30°$ S.W. $\Delta v = -0{\cdot}165$		$\phi_1 = 30°$ S.W. $\phi_2 = 60°$ N.W. $\Delta v = +0{\cdot}075$		$\phi_1 = 60°$ N.W. $\phi_2 = 30°$ N.E. $\Delta v = +0{\cdot}165$		$\phi_1 = 30°$ N.E. $\phi_2 = 60°$ S.E. $\Delta v = -0{\cdot}075$	
λ	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$
	N 177 $\frac{d\lambda}{ds}=0{\cdot}8794$		N 178 $\frac{d\lambda}{ds}=0{\cdot}8793$		N 179 $\frac{d\lambda}{ds}=0{\cdot}8793$		N 180 $\frac{d\lambda}{ds}=0{\cdot}8792$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4299·149	− 0·0342	− 2·302	+ 0·0128	+ 0·875	+ 0·0354	+ 2·377	− 0·0126	− 0·862
4302·085	− 316	− 2·137	+ 111	+ 0·768	+ 352	+ 2·361	− 129	− 0·880
4314·248	− 318	− 2·140	+ 96	+ 0·671	+ 339	+ 2·271	− 141	− 0·951
4315·138	− 310	− 2·090	+ 106	+ 0·733	+ 352	+ 2·350	− 137	− 0·926
4320·907	− 343	− 2·289	+ 114	+ 0·781	+ 345	+ 2·302	− 131	− 0·886
4326·923	− 340	− 2·266	+ 94	+ 0·656	+ 344	+ 2·291	− 132	− 0·891
4331·811	− 326	− 2·176	+ 120	+ 0·815	+ 364	+ 2·410	− 130	− 0·877
4337·725	− 328	− 2·183	+ 116	+ 0·789	+ 353	+ 2·337	− 136	− 0·912
4338·084	− 336	− 2·232	+ 107	+ 0·733	+ 351	+ 2·325	− 130	− 0·875
4339·882	− 333	− 2·212	+ 120	+ 0·813	+ 338	+ 2·243	− 134	− 0·899
4343·861	− 330	− 2·190	+ 110	+ 0·750	+ 360	+ 2·375	− 121	− 0·818
4344·670	− 333	− 2·208	+ 100	+ 0·688	+ 351	+ 2·318	− 140	− 0·934
4346·725	− 337	− 2·231	+ 108	+ 0·737	+ 330	+ 2·188	− 121	− 0·817
4347·403	− 328	− 2·176	+ 114	+ 0·774	+ 337	+ 2·231	− 127	− 0·854
4349·107	− 335	− 2·217	+ 108	+ 0·736	+ 341	+ 2·253	− 135	− 0·902
	N 181 $\frac{d\lambda}{ds}=0{\cdot}8758$		N 182 $\frac{d\lambda}{ds}=0{\cdot}8755$		N 183 $\frac{d\lambda}{ds}=0{\cdot}8757$		N 184 $\frac{d\lambda}{ds}=0{\cdot}8757$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4351·000	− 0·0347	− 2·298	+ 0·0109	+ 0·745	+ 0·0345	+ 2·286	− 0·0123	− 0·831
4352·908	− 341	− 2·260	+ 106	+ 0·726	+ 341	+ 2·260	− 132	− 0·886
4358·670	− 330	− 2·188	+ 120	+ 0·810	+ 357	+ 2·353	− 123	− 0·829
4366·061	− 332	− 2·194	+ 111	+ 0·754	+ 342	+ 2·256	− 150	− 0·992
4371·442	− 329	− 2·172	+ 126	+ 0·844	+ 360	+ 2·361	− 132	− 0·880
4373·415	− 330	− 2·177	+ 116	+ 0·782	+ 349	+ 2·293	− 128	− 0·855
4373·727	− 321	− 2·121	+ 132	+ 0·879	+ 354	+ 2·322	− 132	− 0·880
4376·107	− 331	− 2·180	+ 115	+ 0·775	+ 352	+ 2·308	− 121	− 0·812
4379·396	− 333	− 2·190	+ 110	+ 0·744	+ 350	+ 2·293	− 130	− 0·866
4385·144	− 337	− 2·209	+ 108	+ 0·730	+ 346	+ 2·264	− 136	− 0·900
4388·571	− 335	− 2·194	+ 110	+ 0·741	+ 350	+ 2·285	− 127	− 0·844
4390·149	− 331	− 2·169	+ 110	+ 0·741	+ 350	+ 2·284	− 124	− 0·826
4395·201	− 338	− 2·208	+ 110	+ 0·740	+ 346	+ 2·256	− 128	− 0·849
4396·008	− 323	− 2·116	+ 114	+ 0·764	+ 352	+ 2·291	− 134	− 0·884
4400·555	− 325	− 2·125	+ 109	+ 0·732	+ 350	+ 2·276	− 137	− 0·901

TABLE VII. *Results from all plates, line for line (continued)*

SERIES III *(concluded)*

λ	$\phi_1 = 75°$ S.E. $\phi_2 = 15°$ S.W. $\Delta v = -0{\cdot}148$		$\phi_1 = 15°$ S.W. $\phi_2 = 75°$ N.W. $\Delta v = +0{\cdot}118$		$\phi_1 = 75°$ N.W. $\phi_2 = 15°$ N.E. $\Delta v = +0{\cdot}148$		$\phi_1 = 15°$ N.E. $\phi_2 = 75°$ S.E. $\Delta v = -0{\cdot}118$	
	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$
	N 187 $\frac{d\lambda}{ds} = 0{\cdot}8792$		N 188 $\frac{d\lambda}{ds} = 0{\cdot}8791$		N 189 $\frac{d\lambda}{ds} = 0{\cdot}8793$		N 190 $\frac{d\lambda}{ds} = 0{\cdot}8791$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4299·149	− 0·0317	− 2·128	+ 0·0200	+ 1·367	+ 0·0340	+ 2·272	− 0·0220	− 1·492
4302·085	− 322	− 2·157	+ 206	+ 1·403	+ 345	+ 2·300	− 198	− 1·353
4314·248	− 315	− 2·104	+ 205	+ 1·391	+ 333	+ 2·216	− 218	− 1·472
4315·138	− 320	− 2·135	+ 202	+ 1·372	+ 338	+ 2·246	− 210	− 1·422
4320·907	− 325	− 2·161	+ 206	+ 1·394	+ 340	+ 2·254	− 230	− 1·542
4326·923	− 315	− 2·094	+ 205	+ 1·385	+ 338	+ 2·236	− 216	− 1·453
4331·811	− 320	− 2·121	+ 201	+ 1·358	+ 338	+ 2·232	− 219	− 1·469
4337·725	− 336	− 2·215	+ 209	+ 1·404	+ 340	+ 2·240	− 220	− 1·471
4338·084	− 321	− 2·123	+ 202	+ 1·361	+ 337	+ 2·221	− 225	− 1·502
4339·882	− 319	− 2·109	+ 203	+ 1·366	+ 331	+ 2·183	− 212	− 1·421
4343·861	− 320	− 2·112	+ 197	+ 1·327	+ 335	+ 2·204	− 220	− 1·468
4344·670	− 326	− 2·148	+ 202	+ 1·357	+ 341	+ 2·239	− 218	− 1·455
4346·725	− 320	− 2·110	+ 206	+ 1·381	+ 339	+ 2·226	− 217	− 1·448
4347·403	− 327	− 2·153	+ 210	+ 1·405	+ 338	+ 2·220	− 224	− 1·491
4349·107	− 318	− 2·095	+ 202	+ 1·355	+ 333	+ 2·187	− 221	− 1·471
	N 191 $\frac{d\lambda}{ds} = 0{\cdot}8757$		N 192 $\frac{d\lambda}{ds} = 0{\cdot}8757$		N 193 $\frac{d\lambda}{ds} = 0{\cdot}8757$		N 194 $\frac{d\lambda}{ds} = 0{\cdot}8757$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4351·000	− 0·0324	− 2·140	+ 0·0211	+ 1·415	+ 0·0342	+ 2·250	− 0·0207	− 1·391
4352·908	− 326	− 2·151	+ 200	+ 1·347	+ 335	+ 2·206	− 221	− 1·476
4358·670	− 317	− 2·091	+ 207	+ 1·387	+ 339	+ 2·226	− 217	− 1·448
4366·061	− 324	− 2·129	+ 187	+ 1·261	+ 336	+ 2·202	− 208	− 1·390
4371·442	− 320	− 2·100	+ 215	+ 1·430	+ 341	+ 2·228	− 220	− 1·460
4373·415	− 323	− 2·117	+ 207	+ 1·380	+ 333	+ 2·178	− 214	− 1·423
4373·727	− 327	− 2·141	+ 207	+ 1·379	+ 344	+ 2·244	− 229	− 1·513
4376·107	− 320	− 2·097	+ 200	+ 1·336	+ 346	+ 2·255	− 231	− 1·525
4379·396	− 326	− 2·131	+ 204	+ 1·359	+ 344	+ 2·240	− 217	− 1·438
4385·144	− 328	− 2·138	+ 217	+ 1·434	+ 336	+ 2·186	− 218	− 1·441
4388·571	− 318	− 2·075	+ 191	+ 1·275	+ 335	+ 2·178	− 217	− 1·433
4390·149	− 314	− 2·049	+ 199	+ 1·323	+ 337	+ 2·189	− 208	− 1·378
4395·201	− 323	− 2·100	+ 197	+ 1·309	+ 331	+ 2·148	− 214	− 1·411
4396·008	− 323	− 2·099	+ 202	+ 1·338	+ 336	+ 2·178	− 229	− 1·501
4400·555	− 335	− 2·169	+ 205	+ 1·354	+ 334	+ 2·162	− 214	− 1·409

TABLE VII. *Results from all plates, line for line (continued)*

SERIES IV

	$\phi_1 = 0°$ E. $\phi_2 = 90°$ S. $\Delta v = -0{\cdot}150$		$\phi_1 = 90°$ S. $\phi_2 = 0°$ W. $\Delta v = -0{\cdot}116$		$\phi_1 = 0°$ W. $\phi_2 = 90°$ N. $\Delta v = +0{\cdot}150$		$\phi_1 = 90°$ N. $\phi_2 = 0°$ E. $\Delta v = +0{\cdot}116$	
λ	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$
	N 199 $\frac{d\lambda}{ds} = 0{\cdot}8792$		N 200 $\frac{d\lambda}{ds} = 0{\cdot}8792$		N 201 $\frac{d\lambda}{ds} = 0{\cdot}8791$		N 202 $\frac{d\lambda}{ds} = 0{\cdot}8792$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4299·149	− 0·0282	− 1·911	− 0·0277	− 1·846	+ 0·0275	+ 1·868	+ 0·0278	+ 1·852
4302·085	− 277	− 1·878	− 275	− 1·832	+ 273	+ 1·853	+ 275	+ 1·832
4314·248	− 277	− 1·870	− 283	− 1·874	+ 275	+ 1·858	+ 274	+ 1·818
4315·138	− 283	− 1·907	− 280	− 1·854	+ 279	+ 1·882	+ 283	+ 1·873
4320·907	− 274	− 1·847	− 277	− 1·832	+ 272	+ 1·834	+ 277	+ 1·832
4326·923	− 284	− 1·905	− 285	− 1·877	+ 274	+ 1·843	+ 277	+ 1·828
4331·811	− 278	− 1·864	− 280	− 1·843	+ 273	+ 1·834	+ 279	+ 1·837
4337·725	− 274	− 1·836	− 276	− 1·814	+ 278	+ 1·860	+ 280	+ 1·838
4338·084	− 277	− 1·854	− 277	− 1·820	+ 278	+ 1·860	+ 272	+ 1·789
4339·882	− 278	− 1·859	− 282	− 1·850	+ 273	+ 1·825	+ 273	+ 1·794
4343·861	− 280	− 1·868	− 274	− 1·798	+ 278	+ 1·856	+ 280	+ 1·834
4344·670	− 274	− 1·831	− 281	− 1·840	+ 284	+ 1·892	+ 278	+ 1·821
4346·725	− 278	− 1·854	− 282	− 1·845	+ 280	+ 1·867	+ 275	+ 1·802
4347·403	− 266	− 1·781	− 278	− 1·820	+ 278	+ 1·854	+ 280	+ 1·832
4349·107	− 268	− 1·791	− 274	− 1·794	+ 280	+ 1·865	+ 275	+ 1·800
	N 195 $\frac{d\lambda}{ds} = 0{\cdot}8757$		N 196 $\frac{d\lambda}{ds} = 0{\cdot}8756$		N 197 $\frac{d\lambda}{ds} = 0{\cdot}8757$		N 198 $\frac{d\lambda}{ds} = 0{\cdot}8756$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4351·000	− 0·0275	− 1·841	− 0·0283	− 1·856	+ 0·0275	+ 1·841	+ 0·0276	+ 1·813
4352·908	− 282	− 1·882	− 280	− 1·836	+ 281	+ 1·876	+ 273	+ 1·793
4358·670	− 277	− 1·848	− 274	− 1·795	+ 280	+ 1·866	+ 279	+ 1·826
4366·061	− 283	− 1·880	− 279	− 1·822	+ 277	+ 1·843	+ 276	+ 1·803
4371·442	− 278	− 1·846	− 276	− 1·800	+ 277	+ 1·840	+ 286	+ 1·861
4373·415	− 280	− 1·857	− 278	− 1·811	+ 274	+ 1·820	+ 275	+ 1·792
4373·727	− 280	− 1·856	− 274	− 1·785	+ 280	+ 1·856	+ 274	+ 1·785
4376·107	− 279	− 1·849	− 283	− 1·839	+ 273	+ 1·812	+ 278	+ 1·809
4379·396	− 277	− 1·834	− 278	− 1·806	+ 275	+ 1·822	+ 270	+ 1·758
4385·144	− 278	− 1·836	− 275	− 1·784	+ 280	+ 1·849	+ 282	+ 1·827
4388·571	− 276	− 1·822	− 277	− 1·794	+ 287	+ 1·889	+ 272	+ 1·764
4390·149	− 277	− 1·827	− 277	− 1·793	+ 274	+ 1·809	+ 279	+ 1·805
4395·201	− 281	− 1·848	− 274	− 1·772	+ 275	+ 1·812	+ 284	+ 1·832
4396·008	− 279	− 1·835	− 278	− 1·795	+ 279	+ 1·835	+ 277	+ 1·789
4400·555	− 281	− 1·845	− 278	− 1·793	+ 281	+ 1·845	+ 276	+ 1·781

Table VII. *Results from all plates, line for line (continued)*

SERIES IV (*continued*)

	$\phi_1=15°$ S.E. $\phi_2=75°$ S.W. $\Delta v=-0{\cdot}170$		$\phi_1=75°$ S.W. $\phi_2=15°$ N.W. $\Delta v=-0{\cdot}077$		$\phi_1=15°$ N.W. $\phi_2=75°$ N.E. $\Delta v=+0{\cdot}170$		$\phi_1=75°$ N.E. $\phi_2=15°$ S.E. $\Delta v=+0{\cdot}077$	
	Δs	$v\phi_1-v\phi_2$	Δs	$v\phi_1-v\phi_2$	Δs	$v\phi_1-v\phi_2$	Δs	$v\phi_1-v\phi_2$
λ	N 157 $\frac{d\lambda}{ds}=0{\cdot}8795$		N 158 $\frac{d\lambda}{ds}=0{\cdot}8795$		N 159 $\frac{d\lambda}{ds}=0{\cdot}8795$		N 160 $\frac{d\lambda}{ds}=0{\cdot}8795$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4299·149	− 0·0323	− 2·188	− 0·0216	− 1·427	+ 0·0334	+ 2·257	+ 0·0203	+ 1·345
4302·085	− 318	− 2·155	− 218	− 1·438	+ 330	+ 2·230	+ 204	+ 1·350
4314·248	− 323	− 2·177	− 212	− 1·394	+ 333	+ 2·239	+ 199	+ 1·313
4315·138	− 322	− 2·170	− 228	− 1·493	+ 331	+ 2·226	+ 213	+ 1·400
4320·907	− 318	− 2·140	− 211	− 1·384	+ 331	+ 2·221	+ 216	+ 1·415
4326·923	− 320	− 2·148	− 234	− 1·523	+ 335	+ 2·241	+ 200	+ 1·313
4331·811	− 319	− 2·138	− 223	− 1·453	+ 340	+ 2·267	+ 204	+ 1·335
4337·725	− 318	− 2·127	− 212	− 1·381	+ 328	+ 2·188	+ 211	+ 1·375
4338·084	− 324	− 2·164	− 232	− 1·505	+ 335	+ 2·232	+ 210	+ 1·369
4339·882	− 323	− 2·156	− 226	− 1·467	+ 331	+ 2·206	+ 205	+ 1·338
4343·861	− 324	− 2·159	− 224	− 1·452	+ 340	+ 2·257	+ 206	+ 1·342
4344·670	− 321	− 2·140	− 210	− 1·366	+ 340	+ 2·256	+ 200	+ 1·304
4346·725	− 321	− 2·139	− 216	− 1·402	+ 336	+ 2·231	+ 202	+ 1·316
4347·403	− 322	− 2·144	− 210	− 1·365	+ 342	+ 2·267	+ 210	+ 1·365
4349·107	− 320	− 2·130	− 205	− 1·333	+ 350	+ 2·314	+ 193	+ 1·259
	N 153 $\frac{d\lambda}{ds}=0{\cdot}8760$		N 154 $\frac{d\lambda}{ds}=0{\cdot}8765$		N 155 $\frac{d\lambda}{ds}=0{\cdot}8763$		N 156 $\frac{d\lambda}{ds}=0{\cdot}8760$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4351·000	− 0·0319	− 2·132	− 0·0220	− 1·430	+ 0·0345	+ 2·292	+ 0·0206	+ 1·345
4352·908	− 320	− 2·137	− 212	− 1·380	+ 310	+ 2·076	+ 200	+ 1·306
4358·670	− 323	− 2·151	− 217	− 1·408	+ 340	+ 2·255	+ 215	+ 1·396
4366·061	− 316	− 2·103	− 215	− 1·392	+ 335	+ 2·219	+ 213	+ 1·380
4371·442	− 326	− 2·160	− 217	− 1·402	+ 342	+ 2·258	+ 196	+ 1·273
4373·415	− 322	− 2·134	− 230	− 1·480	+ 340	+ 2·244	+ 207	+ 1·340
4373·727	− 324	− 2·145	− 214	− 1·382	+ 331	+ 2·188	+ 198	+ 1·284
4376·107	− 327	− 2·162	− 221	− 1·423	+ 332	+ 2·193	+ 205	+ 1·326
4379·396	− 320	− 2·117	− 221	− 1·422	+ 342	+ 2·251	+ 202	+ 1·306
4385·144	− 324	− 2·137	− 217	− 1·394	+ 337	+ 2·216	+ 219	+ 1·406
4388·571	− 319	− 2·104	− 219	− 1·405	+ 335	+ 2·201	+ 190	+ 1·229
4390·149	− 323	− 2·127	− 222	− 1·425	+ 331	+ 2·176	+ 202	+ 1·301
4395·201	− 319	− 2·099	− 216	− 1·383	+ 349	+ 2·281	+ 205	+ 1·317
4396·008	− 328	− 2·152	− 213	− 1·364	+ 340	+ 2·225	+ 199	+ 1·280
4400·555	− 325	− 2·131	− 217	− 1·387	+ 336	+ 2·198	+ 196	+ 1·260

TABLE VII. *Results from all plates, line for line* (*continued*)

SERIES IV (*continued*)

	ϕ_1 = 30° S.E. ϕ_2 = 60° S.W. $\Delta v = -0{\cdot}177$		ϕ_1 = 60° S.W. ϕ_2 = 30° N.W. $\Delta v = -0{\cdot}029$		ϕ_1 = 30° N.W. ϕ_2 = 60° N.E. $\Delta v = +0{\cdot}177$		ϕ_1 = 60° N.E. ϕ_2 = 30° S.E. $\Delta v = +0{\cdot}029$	
	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$
λ	N 219 $\frac{d\lambda}{ds}=0{\cdot}8794$		N 220 $\frac{d\lambda}{ds}=0{\cdot}8793$		N 221 $\frac{d\lambda}{ds}=0{\cdot}8792$		N 222 $\frac{d\lambda}{ds}=0{\cdot}8793$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4299·149	− 0·0324	− 2·201	− 0·0139	− 0·897	+ 0·0351	+ 2·370	+ 0·0108	+ 0·704
4302·085	− 313	− 2·130	− 140	− 0·903	+ 333	+ 2·255	+ 118	+ 0·765
4314·248	− 329	− 2·221	− 134	− 0·861	+ 350	+ 2·351	+ 122	+ 0·782
4315·138	− 329	− 2·220	− 127	− 0·818	+ 333	+ 2·244	+ 114	+ 0·737
4320·907	− 325	− 2·190	− 134	− 0·859	+ 368	+ 2·456	+ 92	+ 0·599
4326·923	− 326	− 2·192	− 135	− 0·863	+ 349	+ 2·334	+ 116	+ 0·746
4331·811	− 339	− 2·268	− 137	− 0·874	+ 358	+ 2·385	+ 110	+ 0·707
4337·725	− 338	− 2·257	− 113	− 0·724	+ 348	+ 2·318	+ 123	+ 0·786
4338·084	− 327	− 2·189	− 136	− 0·866	+ 345	+ 2·299	+ 103	+ 0·663
4339·882	− 336	− 2·243	− 123	− 0·785	+ 352	+ 2·341	+ 107	+ 0·687
4343·861	− 337	− 2·245	− 120	− 0·765	+ 350	+ 2·325	+ 109	+ 0·698
4344·670	− 329	− 2·195	− 115	− 0·734	+ 340	+ 2·263	+ 106	+ 0·679
4346·725	− 348	− 2·311	− 133	− 0·844	+ 351	+ 2·329	+ 95	+ 0·612
4347·403	− 314	− 2·102	− 121	− 0·771	+ 351	+ 2·329	+ 122	+ 0·777
4349·107	− 349	− 2·314	− 150	− 0·948	+ 354	+ 2·345	+ 110	+ 0·703
	N 215 $\frac{d\lambda}{ds}=0{\cdot}8755$		N 216 $\frac{d\lambda}{ds}=0{\cdot}8754$		N 217 $\frac{d\lambda}{ds}=0{\cdot}8754$		N 218 $\frac{d\lambda}{ds}=0{\cdot}8756$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4351·000	− 0·0334	− 2·230	− 0·0134	− 0·853	+ 0·0329	+ 2·199	+ 0·0107	+ 0·687
4352·908	− 330	− 2·204	− 129	− 0·821	+ 361	+ 2·394	+ 115	+ 0·735
4358·670	− 326	− 2·175	− 120	− 0·764	+ 348	+ 2·310	+ 111	+ 0·709
4366·061	− 341	− 2·261	− 130	− 0·824	+ 346	+ 2·292	+ 114	+ 0·726
4371·442	− 331	− 2·196	− 133	− 0·840	+ 353	+ 2·330	+ 104	+ 0·663
4373·415	− 327	− 2·170	− 136	− 0·858	+ 339	+ 2·243	+ 106	+ 0·675
4373·727	− 323	− 2·145	− 126	− 0·797	+ 348	+ 2·297	+ 106	+ 0·675
4376·107	− 324	− 2·150	− 123	− 0·778	+ 349	+ 2·302	+ 98	+ 0·626
4379·396	− 350	− 2·305	− 129	− 0·813	+ 366	+ 2·402	+ 104	+ 0·661
4385·144	− 330	− 2·178	− 134	− 0·842	+ 350	+ 2·300	+ 110	+ 0·696
4388·571	− 327	− 2·158	− 127	− 0·798	+ 352	+ 2·309	+ 109	+ 0·689
4390·149	− 332	− 2·187	− 130	− 0·816	+ 345	+ 2·266	+ 117	+ 0·737
4395·201	− 328	− 2·159	− 140	− 0·875	+ 335	+ 2·201	+ 111	+ 0·700
4396·008	− 334	− 2·194	− 146	− 0·911	+ 351	+ 2·297	+ 111	+ 0·699
4400·555	− 334	− 2·194	− 133	− 0·832	+ 365	+ 2·382	+ 120	+ 0·754

TABLE VII. *Results from all plates, line for line* (*continued*)

SERIES IV (*continued*)

λ	$\phi_1 = 45°$ S.E.; $\phi_2 = 45°$ S.W.; $\Delta v = -0·175$		$\phi_1 = 45°$ S.W.; $\phi_2 = 45°$ N.W.; $\Delta v = +0·024$		$\phi_1 = 45°$ N.W.; $\phi_2 = 45°$ N.E.; $\Delta v = +0·175$		$\phi_1 = 45°$ N.E.; $\phi_2 = 45°$ S.E.; $\Delta v = -0·024$	
	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$
	N 207, $\frac{d\lambda}{ds} = 0·8792$		N 208, $\frac{d\lambda}{ds} = 0·8792$		N 209, $\frac{d\lambda}{ds} = 0·8792$		N 210, $\frac{d\lambda}{ds} = 0·8791$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4299·149	− 0·0351	− 2·367	− 0·0019	− 0·095	+ 0·0355	+ 2·394	− 0·0015	− 0·118
4302·085	− 349	− 2·352	− 3	+ 0·005	+ 358	+ 2·409	− 20	− 0·149
4314·248	− 329	− 2·218	− 9	− 0·032	+ 356	+ 2·386	− 8	− 0·074
4315·138	− 347	− 2·329	− 8	− 0·025	+ 359	+ 2·404	− 4	− 0·049
4320·907	− 326	− 2·194	+ 2	+ 0·036	+ 357	+ 2·386	− 15	− 0·117
4326·923	− 314	− 2·115	− 14	− 0·063	+ 361	+ 2·406	− 9	− 0·080
4331·811	− 329	− 2·204	− 6	− 0·013	+ 374	+ 2·481	+ 3	− 0·006
4337·725	− 333	− 2·224	+ 1	+ 0·030	+ 354	+ 2·353	− 11	− 0·092
4338·084	− 338	− 2·254	− 20	− 0·099	+ 357	+ 2·371	− 1	− 0·030
4339·882	− 337	− 2·247	− 10	− 0·037	+ 355	+ 2·358	− 18	− 0·135
4343·861	− 344	− 2·286	− 14	− 0·062	+ 355	+ 2·354	0	− 0·024
4344·670	− 344	− 2·285	− 4	− 0·001	+ 359	+ 2·377	− 16	− 0·122
4346·725	− 342	− 2·272	− 6	− 0·013	+ 363	+ 2·401	− 8	− 0·073
4347·403	− 347	− 2·302	− 4	− 0·001	+ 362	+ 2·394	− 7	− 0·067
4349·107	− 331	− 2·202	− 7	− 0·019	+ 355	+ 2·349	− 11	− 0·091
	N 211, $\frac{d\lambda}{ds} = 0·8755$		N 212, $\frac{d\lambda}{ds} = 0·8757$		N 213, $\frac{d\lambda}{ds} = 0·8756$		N 214, $\frac{d\lambda}{ds} = 0·8756$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4351·000	− 0·0339	− 2·259	− 0·0011	− 0·044	+ 0·0360	+ 2·388	− 0·0014	− 0·110
4352·908	− 361	− 2·393	− 11	− 0·044	+ 350	+ 2·325	− 10	− 0·085
4358·670	− 325	− 2·167	− 15	− 0·068	+ 343	+ 2·277	− 7	− 0·067
4366·061	− 339	− 2·247	− 8	− 0·025	+ 359	+ 2·370	0	− 0·024
4371·442	− 341	− 2·255	− 6	− 0·013	+ 360	+ 2·371	− 8	− 0·073
4373·415	− 337	− 2·229	− 5	− 0·006	+ 365	+ 2·400	− 14	− 0·109
4373·727	− 330	− 2·186	+ 4	+ 0·048	+ 347	+ 2·289	− 12	− 0·097
4376·107	− 324	− 2·148	− 18	− 0·086	+ 346	+ 2·282	− 4	− 0·048
4379·396	− 338	− 2·230	− 2	+ 0·012	+ 367	+ 2·407	− 4	− 0·048
4385·144	− 340	− 2·238	− 15	− 0·067	+ 358	+ 2·347	− 12	− 0·097
4388·571	− 343	− 2·253	− 9	− 0·031	+ 353	+ 2·313	− 7	− 0·066
4390·149	− 340	− 2·234	0	+ 0·024	+ 361	+ 2·361	− 13	− 0·103
4395·201	− 323	− 2·127	− 7	− 0·018	+ 352	+ 2·302	− 11	− 0·090
4396·008	− 342	− 2·241	− 9	− 0·030	+ 363	+ 2·368	− 5	− 0·054
4400·555	− 335	− 2·195	− 10	− 0·036	+ 365	+ 2·376	− 14	− 0·108

Table VII. *Results from all plates, line for line* (*continued*)

SERIES IV (*continued*)

	$\phi_1 = 60°$ S.E. $\phi_2 = 30°$ S.W. $\Delta v = -0{\cdot}165$		$\phi_1 = 30°$ S.W. $\phi_2 = 60°$ N.W. $\Delta v = +0{\cdot}075$		$\phi_1 = 60°$ N.W. $\phi_2 = 30°$ N.E. $\Delta v = +0{\cdot}165$		$\phi_1 = 30°$ N.E. $\phi_2 = 60°$ S.E. $\Delta v = -0{\cdot}075$	
	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$	Δs	$v_{\phi_1} - v_{\phi_2}$
λ	N 231 $\frac{d\lambda}{ds} = 0{\cdot}8796$		N 232 $\frac{d\lambda}{ds} = 0{\cdot}8796$		N 233 $\frac{d\lambda}{ds} = 0{\cdot}8794$		N 234 $\frac{d\lambda}{ds} = 0{\cdot}8794$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4299·149	− 0·0350	− 2·352	+ 0·0106	+ 0·737	+ 0·0332	+ 2·239	− 0·0125	− 0·856
4302·085	− 325	− 2·193	+ 120	+ 0·824	+ 357	+ 2·393	− 145	− 0·980
4314·248	− 329	− 2·209	+ 103	+ 0·715	+ 345	+ 2·308	− 122	− 0·833
4315·138	− 350	− 2·339	+ 110	+ 0·758	+ 347	+ 2·320	− 134	− 0·907
4320·907	− 333	− 2·228	+ 100	+ 0·695	+ 350	+ 2·333	− 122	− 0·831
4326·923	− 334	− 2·229	+ 109	+ 0·749	+ 359	+ 2·384	− 135	− 0·909
4331·811	− 330	− 2·201	+ 108	+ 0·741	+ 354	+ 2·349	− 139	− 0·932
4337·725	− 341	− 2·264	+ 122	+ 0·826	+ 354	+ 2·344	− 130	− 0·875
4338·084	− 333	− 2·214	+ 101	+ 0·697	+ 353	+ 2·337	− 128	− 0·863
4339·882	− 342	− 2·268	+ 110	+ 0·752	+ 341	+ 2·262	− 133	− 0·893
4343·861	− 336	− 2·228	+ 101	+ 0·695	+ 347	+ 2·295	− 132	− 0·885
4344·670	− 332	− 2·202	+ 106	+ 0·725	+ 346	+ 2·288	− 133	− 0·891
4346·725	− 337	− 2·232	+ 109	+ 0·743	+ 346	+ 2·287	− 127	− 0·854
4347·403	− 336	− 2·225	+ 113	+ 0·768	+ 345	+ 2·281	− 139	− 0·927
4349·107	− 334	− 2·211	+ 113	+ 0·767	+ 353	+ 2·327	− 144	− 0·957
	N 235 $\frac{d\lambda}{ds} = 0{\cdot}8757$		N 236 $\frac{d\lambda}{ds} = 0{\cdot}8755$		N 237 $\frac{d\lambda}{ds} = 0{\cdot}8756$		N 238 $\frac{d\lambda}{ds} = 0{\cdot}8756$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4351·000	− 0·0316	− 2·108	+ 0·0120	+ 0·813	+ 0·0340	+ 2·255	− 0·0143	− 0·954
4352·908	− 315	− 2·100	+ 105	+ 0·720	+ 355	+ 2·346	− 128	− 0·861
4358·670	− 328	− 2·175	+ 107	+ 0·731	+ 353	+ 2·329	− 115	− 0·780
4366·061	− 316	− 2·096	+ 108	+ 0·735	+ 353	+ 2·323	− 132	− 0·882
4371·442	− 326	− 2·154	+ 107	+ 0·728	+ 348	+ 2·288	− 135	− 0·899
4373·415	− 334	− 2·201	+ 118	+ 0·794	+ 355	+ 2·329	− 123	− 0·825
4373·727	− 317	− 2·096	+ 118	+ 0·794	+ 352	+ 2·310	− 125	− 0·837
4376·107	− 333	− 2·193	+ 108	+ 0·733	+ 349	+ 2·290	− 130	− 0·867
4379·396	− 323	− 2·129	+ 109	+ 0·738	+ 349	+ 2·287	− 136	− 0·902
4385·144	− 319	− 2·100	+ 108	+ 0·730	+ 350	+ 2·288	− 136	− 0·900
4388·571	− 324	− 2·128	+ 104	+ 0·705	+ 354	+ 2·310	− 130	− 0·863
4390·149	− 319	− 2·097	+ 110	+ 0·741	+ 347	+ 2·266	− 133	− 0·880
4395·201	− 331	− 2·165	+ 110	+ 0·739	+ 357	+ 2·322	− 138	− 0·909
4396·008	− 340	− 2·219	+ 117	+ 0·782	+ 350	+ 2·279	− 124	− 0·824
4400·555	− 330	− 2·155	+ 103	+ 0·696	+ 350	+ 2·276	− 130	− 0·859

TABLE VII. *Results from all plates, line for line (concluded)*

SERIES IV (*concluded*)

	$\phi_1=$ 75° S.E. $\phi_2=$ 15° S.W $\Delta v=-0{\cdot}148$		$\phi_1=$ 15° S.W. $\phi_2=$ 75° N.W. $\Delta v=+0{\cdot}118$		$\phi_1=$ 75° N.W. $\phi_2=$ 15° N.E. $\Delta v=+0{\cdot}148$		$\phi_1=$ 15° N.E. $\phi_2=$ 75° S.E. $\Delta v=-0{\cdot}118$	
	Δs	$v_{\phi_1}-v_{\phi_2}$	Δs	$v_{\phi_1}-v_{\phi_2}$	Δs	$v_{\phi_1}-v_{\phi_2}$	Δs	$v_{\phi_1}-v_{\phi_2}$
λ	N 243 $\frac{d\lambda}{ds}=0{\cdot}8791$		N 244 $\frac{d\lambda}{ds}=0{\cdot}8790$		N 245 $\frac{d\lambda}{ds}=0{\cdot}8791$		N 246 $\frac{d\lambda}{ds}=0{\cdot}8789$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4299·149	− 0·0320	− 2·146	+ 0·0202	+ 1·379	+ 0·0332	+ 2·221	− 0·0218	− 1·479
4302·085	− 317	− 2·125	+ 201	+ 1·372	+ 329	+ 2·200	− 215	− 1·459
4314·248	− 330	− 2·197	+ 205	+ 1·391	+ 338	+ 2·247	− 226	− 1·521
4315·138	− 314	− 2·097	+ 201	+ 1·366	+ 334	+ 2·221	− 216	− 1·459
4320·907	− 327	− 2·173	+ 195	+ 1·325	+ 334	+ 2·216	− 222	− 1·493
4326·923	− 317	− 2·106	+ 206	+ 1·391	+ 349	+ 2·304	− 229	− 1·533
4331·811	− 326	− 2·158	+ 198	+ 1·339	+ 344	+ 2·269	− 219	− 1·468
4337·725	− 312	− 2·067	+ 203	+ 1·367	+ 345	+ 2·270	− 221	− 1·477
4338·084	− 319	− 2·110	+ 196	+ 1·324	+ 345	+ 2·270	− 214	− 1·434
4339·882	− 314	− 2·078	+ 198	+ 1·335	+ 337	+ 2·220	− 222	− 1·483
4343·861	− 321	− 2·118	+ 201	+ 1·351	+ 340	+ 2·234	− 221	− 1·474
4344·670	− 317	− 2·092	+ 207	+ 1·388	+ 340	+ 2·233	− 223	− 1·486
4346·725	− 318	− 2·097	+ 201	+ 1·350	+ 350	+ 2·294	− 225	− 1·497
4347·403	− 326	− 2·146	+ 193	+ 1·301	+ 338	+ 2·220	− 220	− 1·466
4349·107	− 323	− 2·126	+ 203	+ 1·361	+ 335	+ 2·199	− 222	− 1·477
	N 239 $\frac{d\lambda}{ds}=0{\cdot}8755$		N 240 $\frac{d\lambda}{ds}=0{\cdot}8756$		N 241 $\frac{d\lambda}{ds}=0{\cdot}8756$		N 242 $\frac{d\lambda}{ds}=0{\cdot}8758$	
	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.	mm.	km./sec.
4351·000	− 0·0321	− 2·122	+ 0·0204	+ 1·372	+ 0·0341	+ 2·244	− 0·0222	− 1·483
4352·908	− 320	− 2·114	+ 210	+ 1·408	+ 346	+ 2·273	− 213	− 1·426
4358·670	− 317	− 2·091	+ 200	+ 1·344	+ 333	+ 2·189	− 214	− 1·430
4366·061	− 313	− 2·061	+ 200	+ 1·341	+ 331	+ 2·171	− 217	− 1·445
4371·442	− 320	− 2·100	+ 201	+ 1·344	+ 346	+ 2·259	− 220	− 1·460
4373·415	− 319	− 2·093	+ 197	+ 1·319	+ 330	+ 2·160	− 220	− 1·459
4373·727	− 326	− 2·134	+ 203	+ 1·355	+ 337	+ 2·201	− 220	− 1·458
4376·107	− 318	− 2·084	+ 200	+ 1·336	+ 339	+ 2·212	− 222	− 1·470
4379·396	− 325	− 2·124	+ 205	+ 1·365	+ 340	+ 2·216	− 219	− 1·450
4385·144	− 320	− 2·089	+ 204	+ 1·356	+ 339	+ 2·204	− 212	− 1·404
4388·571	− 320	− 2·087	+ 197	+ 1·311	+ 340	+ 2·208	− 207	− 1·372
4390·149	− 327	− 2·128	+ 210	+ 1·390	+ 332	+ 2·159	− 216	− 1·426
4395·201	− 310	− 2·021	+ 198	+ 1·314	+ 355	+ 2·293	− 219	− 1·441
4396·008	− 321	− 2·087	+ 193	+ 1·284	+ 330	+ 2·141	− 210	− 1·386
4400·555	− 324	− 2·102	+ 200	+ 1·324	+ 346	+ 2·235	− 216	− 1·421

Part II. Discussion of Results derived from Lines of Different Wave Lengths

§ 8. *Comparison of results for individual lines*

It will be convenient first to discuss these results from the point of view of line to line concordance. By such a scrutiny an unexpected dependence of velocity on wave length has been brought to light which will have to be dealt with at some length before we can proceed to the consideration of the mean results, plate to plate, i.e. round the sun's limb.

As for each velocity-difference shown for a particular line on a particular plate in Series I there exist three corresponding velocity-differences in the other three Series, means from four values can at once be taken out, and a "Normal Series" thus be constructed.

For a further averaging of the plates from the point of view of line to line effect it is best to group the material in such a way that velocity-differences of about the same amount are brought together. Table VIII shows the manner of

Table VIII. *Arrangement of material in groups with approximately the same numerical velocity-difference*

−2·2 km./sec.		+2·3 km./sec.		±1·9 km./sec.		±1·4 km./sec.		±0·8 km./sec.		0·0 km./sec.	
ϕ_1	ϕ_2	ϕ_1	ϕ_2	ϕ_1	ϕ_2	ϕ_1	ϕ_2	ϕ_1	ϕ_2	ϕ_1	ϕ_2
15° S.E.	75° S.W.	15° N.W.	75° N.E.	0° E.	90° S.	75° S.W.	15° N.W.	60° S.W.	30° N.W.	45° S.W.	45° N.W.
30° S.E.	60° S.W.	30° N.W.	60° N.E.	90° S.	0° W.	15° S.W.	75° N.W.	30° S.W.	60° N.W.	45° N.E.	45° S.E.
45° S.E.	45° S.W.	45° N.W.	45° N.E.	0° W.	90° N.	75° N.E.	15° S.E.	60° N.E.	30° S.E.		
60° S.E.	30° S.W.	60° N.W.	30° N.E.	90° N.	0° E.	15° N.E.	75° S.E.	30° N.E.	60° S.E.		
75° S.E.	15° S.W.	75° N.W.	15° N.E.								

this grouping. There are five combinations of latitudes which give velocity-differences approximating to − 2·2 km./sec., and also five which give about + 2·3 km./sec. We need for the purposes of line to line comparison regard only the numerical values, disregarding the sign. Hence in the next three columns in each case two positive and two negative velocity-differences can be grouped together, just as we might have taken together the ten observations of the first two columns. The observations of the last column will give no information with regard to line to line effect, but may afford a useful check in the matter of accidental errors.

Taking means from the figures of the "Normal Series" in this way, results are obtained as shown in Table IX. The headings are the same as in the preceding table, while also the total number of plates is given for each column.

The special feature of this table is the diminution of the velocity-differences on going from shorter to longer wave length, at any rate for the larger values. This feature is even more apparent if they are plotted graphically, as is done in Fig. 4. The abscissae are there the wave lengths; the mean velocity-differences per group, from Table IX, determine the ordinates. Each division of the figure corresponds to a column in the table. The zero points on the axis of ordinates are different in each case, being always, except for the bottom figure, a long way off the page. The scale is otherwise the same for all.

TABLE IX. *Mean velocity-differences for individual lines from material grouped according to numerical value*

Mean $v_{\phi_1} - v_{\phi_2} \ldots$ / λ	−2·2 (20 plates)	+2·3 (20 plates)	±1·9 (16 plates)	±1·4 (16 plates)	±0·8 (16 plates)	0·0 (8 plates)
4299·149	2·227	2·309	1·879	1·422	0·801	0·066
4302·085	2·190	2·309	1·896	1·409	0·824	0·076
4314·248	2·221	2·320	1·848	1·411	0·791	0·044
4315·138	2·206	2·312	1·896	1·418	0·794	0·048
4320·907	2·212	2·325	1·869	1·416	0·795	0·059
4326·923	2·189	2·314	1·861	1·408	0·789	0·052
4331·811	2·189	2·306	1·840	1·390	0·804	0·043
4337·725	2·193	2·298	1·871	1·394	0·806	0·034
4338·084	2·187	2·297	1·855	1·405	0·784	0·058
4339·882	2·182	2·292	1·874	1·385	0·788	0·042
4343·861	2·195	2·297	1·837	1·395	0·780	0·071
4344·670	2·176	2·291	1·876	1·382	0·782	0·074
4346·725	2·203	2·305	1·835	1·395	0·769	0·052
4347·403	2·183	2·301	1·835	1·379	0·798	0·043
4349·107	2·191	2·302	1·837	1·385	0·814	0·068
4351·000	2·189	2·293	1·848	1·407	0·798	0·082
4352·908	2·188	2·283	1·862	1·390	0·791	0·053
4358·670	2·170	2·273	1·839	1·385	0·780	0·041
4366·061	2·167	2·289	1·841	1·389	0·807	0·034
4371·442	2·172	2·292	1·869	1·406	0·793	0·029
4373·415	2·169	2·273	1·830	1·386	0·807	0·057
4373·727	2·163	2·285	1·853	1·392	0·789	0·047
4376·107	2·155	2·268	1·840	1·381	0·773	0·056
4379·396	2·167	2·278	1·829	1·378	0·777	0·049
4385·144	2·165	2·271	1·826	1·397	0·794	0·058
4388·571	2·152	2·279	1·827	1·366	0·776	0·042
4390·149	2·150	2·252	1·823	1·372	0·780	0·030
4395·201	2·146	2·253	1·798	1·359	0·777	0·029
4396·008	2·162	2·245	1·843	1·372	0·787	0·061
4400·555	2·167	2·257	1·823	1·357	0·783	0·047

It is at once apparent that some systematic effect is present. The dots do not cluster round horizontal lines as might be expected, but round lines of downward inclination towards the right (greater wave lengths). There is no evidence of discontinuity at the central points which separate the two spectral regions.

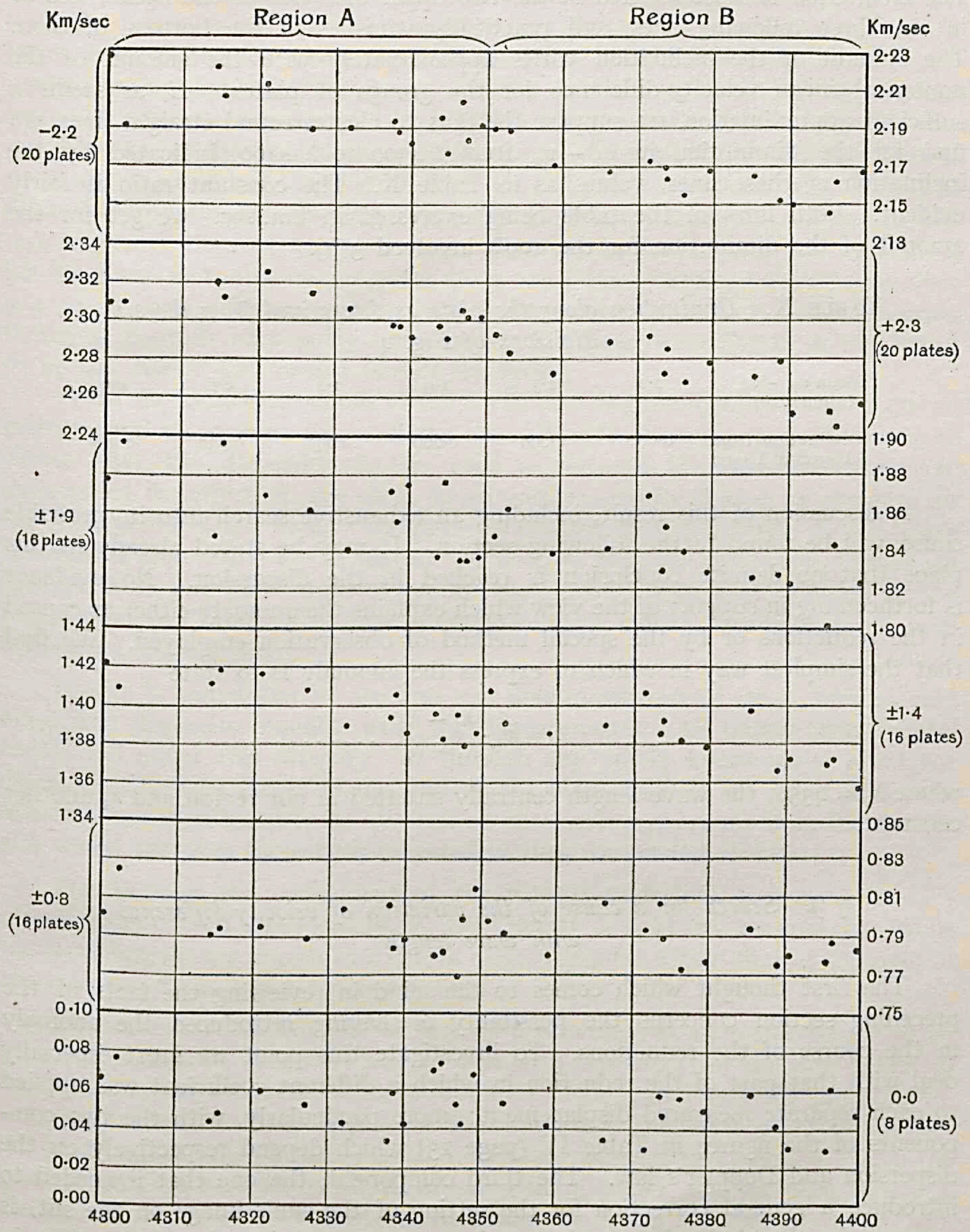

Fig. 4. Graphical representation of Table IX. Mean velocity-differences for individual lines from material grouped according to numerical value.

The inclination is most marked in the two upper divisions of the figure, less so in the three following ones, and practically vanishes in the bottom division. The amount of the inclination varies approximately with the amount of the numerical mean velocity-difference for the groups of plates. If, as seems a sufficient approximation, we suppose the dots to cluster round straight lines, we find for the diminution in $v_{\phi_1} - v_{\phi_2}$ from λ 4300 to λ 4400, indicated by the inclination of these lines, values as in Table X. The constant ratio is fairly evident. Both lines of the table being expressed in km./sec., we get for the amount of the diminution for the 100 λ involved 3 %.

TABLE X. *Diminution along the plate as determined from the six divisions of Fig.* 4

Mean $v_{\phi_1} - v_{\phi_2}$ (numerical)	2·2	2·3	1·9	1·4	0·8	0·0
Diminution from λ 4300 to λ 4400	0·060	0·066	0·060	0·048	0·030	0·006

A discussion of this result, including an exhaustive search into its probable cause, will be found in the following section. It may be stated already in this place that no definite conclusion is reached in the discussion. No evidence is forthcoming in support of the view which explains the anomaly either as caused in the reductions or by the special method of observation employed. We find that the simplest way in which to express the anomaly is to state

$$v_\lambda = v_{\lambda_0} \cdot \frac{\lambda_1 - \lambda}{\lambda_1 - \lambda_0} \quad \text{......................} (10),$$

where $\lambda_0 = 4350$, the wave length centrally situated in our region and λ_1 another constant.

§ 9. *Search for a cause of the variation of velocity-difference with wave length*

The first thought which comes to the mind in reviewing the facts of the preceding section concerns the possibility of having introduced the anomaly in the course of the reductions. To investigate this point we must especially deal with that part of the reduction in which a different coefficient was applied to each separate measured displacement; more particularly, with the two components of the figures in Table IV (page 13) which depend respectively on the dispersion and Doppler's law. The third component, the one that is needed to introduce a general correction for the setting of the sun's image on the slit, is constant for the whole of each plate and so cannot have introduced the effect in question. It is true that with regard to this latter factor, the question may be asked whether it ought not in reality to have been different for the different wave lengths. Such would have been necessary if the solar image had varied in size with the wave length. A brief consideration shows that in order to get a 3 % effect, from λ 4300 to λ 4400, the solar radius would have to differ by the same percentage for light of those wave lengths, that is, by about 2·5 mm. for our image of 172 mm. diameter; a supposition which is untenable.

That the application of the dispersion and of Doppler's law has been correct as to direction of run, is evident from the following considerations. Both the dispersion and the velocity law make the displacements at the red end of our region greater than at the violet end, allowing, in the case of the dispersion, for the jump in the factor on going from one plate (λ 4300—λ 4350) to another (λ 4350—λ 4400). Owing to both causes the coefficient given in Table IV must therefore diminish when going from smaller to greater wave length as was found to be the case in the construction of the table.

As to the numerical values of the coefficient, beginning with the part due to instrumental dispersion, we recall the example given on page 12. It was there shown that the dispersion factors used represented the observed dispersion, determined directly from the plate, to an amply accurate degree, at any rate for the two plates dealt with. Comparisons similar to those given at the place referred to, were made for 24 plates. In no case does the dispersion determined directly from the plate differ by more than 0·1 % from that adopted in the preparation of Table IV. The systematic effect cannot therefore have been introduced in this way.

It is to be noted that we are thus now able to rule out all causes which would affect the dispersion equally with the displacements. All purely instrumental causes fall under this category. If through any purely instrumental effect the displacements were larger at one end of the plate than at the other, the same influence would necessarily be at work on the mean separations from line to line and would therefore have been detected in these dispersion checks.

The Doppler law component of the velocity-coefficient, expressed as λ/V, cannot have caused the anomaly, V, the velocity of light being a constant, while the wave lengths are known to a degree of accuracy far within that of the error of observation of the present investigation.

We must now examine the method of observation as a possible source of an apparent variation. The best way to deal with this aspect of the case is first to recall the way in which the observations were made. In Fig. 5 the sun is represented in the way its image appears on the slit plate. The South pole is at the top, the North pole at the bottom. Each dotted line connects two points of which the spectra are compared in one observation (pair of plates, one for each region A and B). To avoid confusion only 16 such lines are drawn, whereas in reality there are in each series 24 observations; those relating to latitudes 30° and 60° in the four quadrants are missing in the figure. As was stated in § 3 (page 8) each plate gives a comparison between two spectra of which one was formed with a double opening in front of the slit and this latter tangential to the limb, the other with a single opening in front of the slit, with the slit radial to the limb at a point 90° away. The slit openings thus used are denoted in the figure by short, thick lines. Their distance inside the limb and their length are reproduced on a much larger scale than the solar image itself. We see that in the S.E. and N.W. quadrants the slit was always tangential, in the S.W. and N.E. quadrants always radial. Going from the sun's East point through S., W., N. back to E. the nearer point was always photographed in two half-exposures between which the continuous exposure for the spectrum of the further point was taken. Thus in observation 4—7 the exposure of the double spectrum (slit tangential) of 7 was sandwiched in between the two half-exposures on the single spectrum (slit radial) at 4. On the other

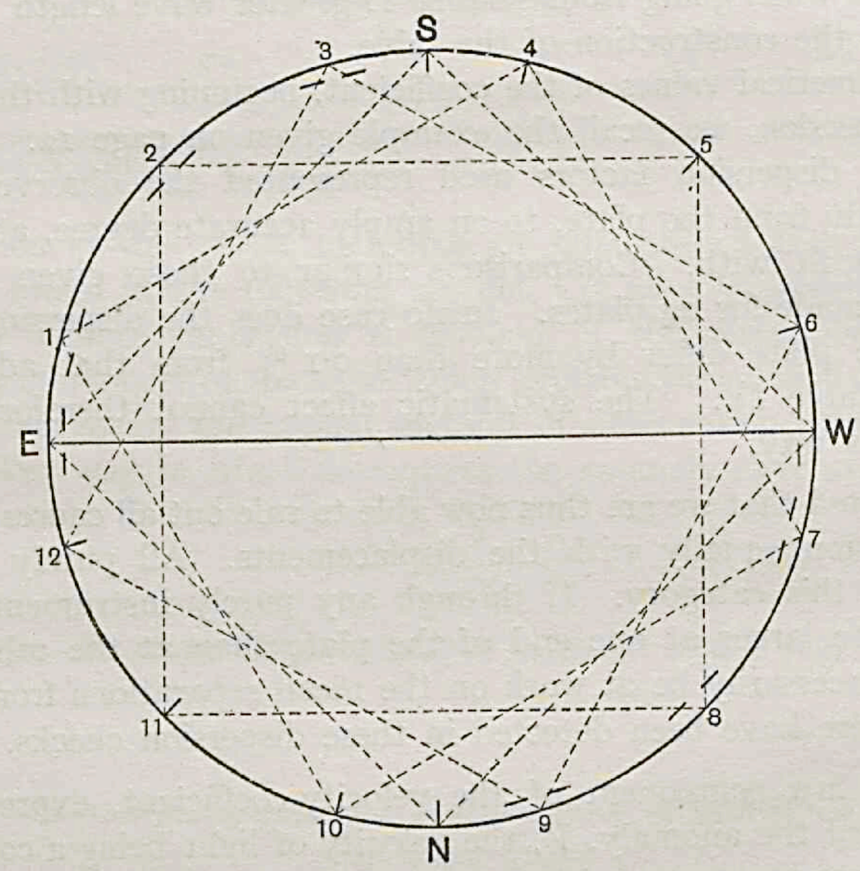

Fig. 5. Diagram showing method of observations for complete series, omitting cases involving latitudes 30° and 60° in all quadrants.

hand, in observation 7—10 two half-exposures are taken at 7 of the double spectrum, respectively before and after the continuous exposure of the single spectrum at 10.

Is it possible that this method of obtaining the material has caused the anomaly which we are investigating? To enable us to judge about this it is necessary to know the behaviour of the velocity-differences along the plate for *each* of the observations separate. So far we only dealt with this behaviour as it appeared after grouping them together in the way given in the preceding paragraph. Without giving the complete details it may be stated that if we regard the observations of the Normal Series (mean of the four series), not only is the diminution of the velocity-difference with increasing wave length always apparent, but it also occurs, as far as the accidental errors allow us to judge, in always the same ratio, amounting to about 3 % of the mean value on the plates in question. In no case is the effect either markedly smaller or markedly larger. Even in the single plates or pairs of plates of each of the original series the diminution is apparent in approximately this constant ratio, as can be judged from a survey of Table VII.

With this further evidence in mind we can at once rule out many further hypothetical sources of the anomaly, as follows.

(*a*) In the first place it is clear that there can be no question of an additive displacement, varying with the wave length, but independent of the solar latitude. All pure limb-centre influences are hence inadmissible as causes of the variation.

(*b*) Nor can an additive effect, due either to our using tangential double spectra in two of the quadrants, or to the single opening radial exposures in the other two opposite quadrants, but otherwise independent of the latitude, have existed. In such a case observations 11—2 and 2—5 would show the anomaly to the same amount, whereas it is large in the former and vanishes in the latter.

(*c*) It is not easy to imagine an influence, existing only in two opposite quadrants but now varying with the latitude, which would give the observed result. Observations 1—4, 2—5, 3—6 are all affected to about the same degree; while observation 11—2 is unaffected, whereas, as in (*b*), it should also in this case undergo the same variation as 2—5.

(*d*) A combination of two causes, one acting on the tangential spectra, and one on the radial, might be regarded as *à priori* possible, for instance, a combined effect arising from a difference of tilt in the lines. The lines in the double (tangential) spectra might be tilted one way through some one cause, those in the single (radial) spectra the other way through another cause. In the Southern hemisphere such tilts might well combine to give total relative tilts of equal amounts for observations 1—4, 2—5, 3—6 and so introduce equally large anomalies in the observed $v_{\phi_1} - v_{\phi_2}$ along the plates. But here again the observations at 45° prevent us from accepting this explanation. Whatever the cause of the "radial" tilt it will be of the same amount and in the same direction for 5 and 11. For 2 it is identical in the two observations so the relative tilt must also be the same in the observations 2—5 and 5—11. The displacements are in one case considerable, in the other approximately zero. It is highly improbable that the same relative tilt would cause a large anomaly to be introduced in the one case, and none in the other.

While dealing with tilts it may be well to mention a possible cause of their appearance. A tilt could occur, due to variation of the velocity along the length of the slit owing to different latitude, in the tangential case; also due to varying distance from the limb, in the radial case. Such tilts would vanish for the equator-pole plates. They cannot therefore be the source of the effect under discussion as these plates show it to the full amount (third graph of Fig. 4).

(*e*) The divided exposure might have introduced an error of some kind, by broadening the lines in a manner varying from one end of the spectral region to the other. But such an error would not vary from observation to observation and could therefore not cause an anomaly proportionate in amount to the mean velocity-difference.

(*f*) The observed anomaly cannot reside solely in one of the hemispheres, because observations dealing solely with the other hemisphere would in such a case not show it, whereas it exists all round the sun. Similar reasons make it impossible for a special influence solely existent in either Eastern or Western half to have been its source. Further the fact that observations 2—5 and 8—11 both show the effect fully, makes it impossible to locate the disturbance exclusively in the equatorial or exclusively in the polar regions.

Altogether it seems reasonable to conclude that the special effect in question has not been caused by the method of observation at all. Whereas Fig. 4 has enabled us to conclude that an apparently linear diminution exists for $v_{\phi_1} - v_{\phi_2}$ all along the spectral region amounting to 3 % from end to end, and which may be expressed in a formula

$$(v_{\phi_1} - v_{\phi_2})_\lambda = (v_{\phi_1} - v_{\phi_2})_{\lambda_0} \cdot \frac{\lambda_1 - \lambda}{\lambda_1 - \lambda_0} \quad \ldots\ldots\ldots\ldots\ldots\ldots (11),$$

where $\lambda_0 = 4350$, the centre of our region, and λ_1 is another constant determined by the amount of the diminution, we now conclude that if absolute determinations of the velocities had been made under otherwise similar circumstances, a similar relation

$$(v_\phi)_\lambda = (v_\phi)_{\lambda_0} \cdot \frac{\lambda_1 - \lambda}{\lambda_1 - \lambda_0} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

would have been brought to light. To the investigation of the source of this relation, which is to hold for all values of ϕ and for λ within our spectral region, the problem of this section is now reduced.

Is it possible that the measurement has been subject to a systematic error? Errors introduced by tilt or broadening of the slit, where these phenomena vary with the use of tangential and radial slit, or with divided and undivided exposure, have already been considered. A systematic error introduced by a change of temperature of the plate during measurement would have affected the mean separations between the lines just as much as the displacements for each line and would therefore have been detected in the dispersion checks (page 45). A variation of the value of a drum division of the scale microscope, during the measurement, must be ruled out unless such a variation reached a maximum at the moment of turning from "out" to "home," a most unlikely hypothesis. A change in the relation between drumhead division and scale interval, owing to a progressive variation in the latter, would have been detected by the repetition of each measurement with the plate end for end. In the dispersion checks a systematic difference between the dispersions as determined from plates "red to right" and plates "red to left" would then have occurred, whereas such was not the case. A careful search has been made for systematic differences between the measurements "going" and "returning," as well as between those "red to right" and "red to left," but none were detected. From the original measurements the mean errors were also computed as determined from first and second settings on the same line in the "single" spectra or from top and bottom settings on the same line of the "double" spectra. No difference between these appearing, the conclusions reached with regard to influence of tilt or broadening of lines are confirmed.

As to the parallelism of the wire with the lines it is true that this was not absolute. In § 4 it was stated that when the spectrum was parallel to the run of the sliding stage the micrometer wire was parallel to the spectrum lines. This would have been rigorously true for plates with λ 4350 in the centre. Owing to the dispersion in the direction parallel to the slit, caused by the small-angle separating prism, the resultant dispersion in our two regions is along contiguous parts of a slightly curved line. Parallelism of the spectrum with the run is judged to exist for each plate when a movement to and fro of the whole sliding stage brings the spectrum at either end of the run to the same position in the field of view. It is thus evident that there will be a slight angle between the direction of the absorption lines in the field for the two regions A and B. The micrometer wire was carefully set, once for all, in a direction halving this angle. It is, however, extremely unlikely that an error has been introduced by this procedure. The angle actually amounted to $0° \, 5'$ so that the micrometer wire was never more than $2'{\cdot}5$ out of its true position on this account. The sine of this latter angle being 0·0007 it is outside all probability that the 3 % effect has been caused by it. Moreover, as for the whole of each of the two plates constituting an observation this inclination between micrometer wire and spectrum line remains constant, any effect caused by it should show a discontinuity in the values on going from one plate to the other rather than a continuous diminution all along the total region. We have noted that in Fig. 4 there is no sign of such a discontinuity.

The method of reduction, the instrumental equipment, the method of observation—including the effect of regional differences on the sun—and the measurement have all been reviewed and the conclusion has been reached that it is unlikely that the source of the anomaly is to be found in any of these.

Accordingly it would appear that in the sun itself some physical cause is active in producing an effect (at all points of the limb) which is, within the limits of spectrum here examined, expressed by formula (12). Light of different wave lengths reaching the observer along a given ray may originate in different levels on the sun. This in itself would not give rise to a varying velocity in the line of sight. *A varying velocity in the line of sight would result if the rays were curved while passing through these levels.* The curvature, again, would be different for different wave lengths on account of the change of refraction with wave length. The latter cause would generally make the velocities smaller for the more refrangible rays, the former cause larger. If the former preponderates an effect of the kind observed might be the result. It appears at any rate as if the facts here discussed and first presented in § 8, may have an important bearing on the question of the true place of origin of the absorption lines in the spectrum of the limb.

§ 10. *Evidence of a similar effect in earlier investigations*

The most important confirmation of the anomaly appearing in the line-to-line comparison of the present results is found in Adams' earlier series of observations as published in his larger monograph. If we examine the table given on page 109 of that work, we see that apart from the residuals for the lines of the element lanthanum and of cyanogen, for which lines Adams finds definite evidence of special behaviour, there is a preponderance of positive residuals in the upper half of the table and of negative ones in the lower half; that is to say, there is evidence of decreasing velocity with increasing wave length, just as in our case. Looking through the records for individual plates which make up the series in question (1906—7) we find that a certain number of plates are more especially affected than others. If we pick these out, obtain velocities per line for each latitude, and express the residuals with the mean velocity per latitude in percentages, we get a result as shown in Table XI. There can be no doubt about the

TABLE XI. *Residuals from 12 selected Mount Wilson plates, 1906—07*

λ	0°	8°	15°	23°	30°	38°	Mean
	%	%	%	%	%	%	%
4203·730	+ 1·8	+ 0·8	+ 0·8	+ 0·9	+ 1·7	+ 0·4	+ 1·1
4209·144	+ 2·0	+ 0·8	+ 0·7	+ 1·0	+ 1·8	+ 0·6	+ 1·1
4220·509	+ 1·3	+ 0·6	+ 1·0	+ 0·7	+ 1·2	+ 0·9	+ 0·9
4232·887	+ 1·2	+ 0·6	+ 0·9	+ 0·4	+ 1·0	+ 0·1	+ 0·7
4257·815	+ 0·6	+ 1·1	+ 0·9	+ 1·2	+ 0·8	+ 1·4	+ 1·0
4258·477	+ 0·2	+ 0·3	− 0·1	+ 0·1	+ 0·7	0·0	+ 0·2
4265·418	− 0·3	0·0	+ 0·2	− 0·3	− 0·4	+ 0·4	− 0·1
4266·081	+ 0·3	+ 0·7	+ 0·1	+ 0·9	+ 0·5	+ 1·2	+ 0·6
4268·915	+ 0·3	0·0	+ 0·2	+ 0·3	− 0·4	− 0·1	0·0
4276·836	− 0·3	− 0·2	0·0	− 0·4	− 0·5	− 0·2	− 0·3
4284·838	− 0·3	− 0·6	− 0·4	0·0	− 1·3	− 0·7	− 0·5
4287·566	− 0·7	− 0·7	− 1·3	− 0·2	− 1·3	0·0	− 0·7
4288·310	− 0·9	− 0·6	− 0·6	− 0·4	− 0·5	− 0·4	− 0·6
4290·377	− 1·5	− 1·4	− 1·1	− 1·2	− 1·7	− 0·8	− 1·3
4290·542	− 1·3	− 0·6	− 0·6	− 0·6	− 0·5	− 0·5	− 0·7
4291·630	− 1·4	− 0·5	− 1·0	− 0·8	− 0·5	− 0·7	− 0·8
4294·936	− 1·1	− 0·4	− 0·3	− 1·0	− 0·6	− 0·5	− 0·6

systematic nature of the arrangement of these residuals in the sense of gradual diminution of velocity-differences with increasing wave lengths. It is true that a special selection has been made for the purpose of showing the effect in full strength. But it has been quite impossible to find twelve plates from which any other kind of systematic arrangement of residuals would have resulted. The plates in question were ω 3, 30, 31, 35, 36, 37, 40, 62, 87, 88, 89 and 90. They have no other special feature in common and were taken at different epochs from May 1906 to June 1907. Three of them were measured by Adams, the others by Miss Lasby. Each latitude appearing in the table occurs on six of the plates, whereas in the total 1906—7 series it thus occurs from 12 to 20 times.

Evershed and Royds found in 1911 a lower value for the equatorial velocity as determined from plates in the green region than as from plates in the violet[1], the difference amounting to about 3 %. Again Schlesinger finds a diminution of 1 % between velocities as determined from region λ 4100 and from λ 4250[2]. The possibility is suggested that the difference between the rotational velocities as found by the different observers is to some extent due to the fact of their dealing with different parts of the solar spectrum, and so, in accordance with the conclusions of the preceding paragraph, with different points or levels on or near the solar surface.

§ 11. *Conclusions as to individual lines and elements*

It remains to complete the investigation of the *special* behaviour of individual lines. We may assume formula (12) to represent the average state of things, whatever its ultimate interpretation may be. We can then see how far individual lines depart from this average. This has been done, combining all the material together. A value of 7600 for the constant λ_1 represents the

TABLE XII. *Mean residuals from systematic effect for individual lines*

λ	Element	Intensity	Residual %	λ	Element	Intensity	Residual %
4299·149	Ca	3	+ 0·2	4351·000	Ti	1	+ 0·4
4302·085	Ti	2	0·0	4352·908	Fe	4	+ 0·1
4314·248	Sc	3	− 0·1	4358·670	Fe	2	− 0·5
4315·138	Ti	3	+ 0·3	4366·061	Fe	2	+ 0·1
4320·907	Sc	3	+ 0·5	4371·442	Cr	2	+ 0·7
4326·923	Fe	2	− 0·1	4373·415	Cr	1	+ 0·2
4331·811	Ni	2	− 0·3	4373·727	Fe	2	+ 0·3
4337·725	Cr	3	+ 0·1	4376·107	Fe	6	− 0·3
4338·084	Ti	4	− 0·1	4379·396	V	4	− 0·1
4339·882	Cr	3	− 0·2	4385·144	Cr	2	+ 0·4
4343·861	Fe	2	− 0·1	4388·571	Fe	3	− 0·2
4344·670	Cr	4	− 0·1	4390·149	V	2	− 0·5
4346·725	Fe	2	0·0	4395·201	Ti	3	− 0·8
4347·403	Fe	1	− 0·2	4396·008	Ti	1	+ 0·2
4349·107	Fe	2	+ 0·3	4400·555	Sc	3	0·0

3 % ratio of diminution. With this value average figures have been calculated for each of the columns of Table IX and residuals (c—o) obtained with the observed values shown in that table. These have been expressed in percentages and then combined together for each line having due regard to weight. The result is shown in Table XII. No systematic arrangement remains in the residuals. None of

[1] *M.N.* LXXIII, p. 561. [2] *Allegheny Publications*, p. 112.

them exceeds 0·8 % which value appears with a negative sign for the Titanium line 4395. When grouped according to origin or intensity no evidence of special behaviour appears. We are thus justified in regarding the residuals as wholly due to accidental error. The mean error for one line amounts under those circumstances to 0·3 %.

Part III. Discussion of Velocity-Differences at Different Latitudes

§ 12. *Results for pairs of plates*

The conclusions drawn in Part II as a result of the line-to-line comparison of all the available material need not deter us from attaching full weight to most of the results which can be obtained from a review, plate-to-plate, of the same material. Average velocity-differences were obtained for each pair of plates (region A and region B) from the figures of Table VII. These mean values must be affected by the influence which, as we saw, has caused the velocity-differences to decrease with increasing wave lengths. But even so we found this diminution to be proportionate in amount to the mean velocity-difference on the plate and the presumption is therefore very great that these means themselves, if they have been affected at all, are changed also in the same proportion, that is by a factor constant for all. Although it is unfortunate that, on this score, the results obtained in the present investigation will carry little weight as to the *absolute* value of the sun's rotational velocity, yet the comparison of the velocities obtained at the various points all round the sun's limb may be fully carried through with the conviction that any *relative* results, such as have regard to the latitude law, the behaviour in different solar hemispheres, or the general concordance in the velocities for the epoch of observation, should carry the full weight which their internal agreement entitles them to.

Table XIII (pp. 54, 55) gives these means per observation (pair of plates) obtained from the available material. The first column gives the latitudes compared, then follow four groups of five columns each for the four series and finally a column containing the mean velocity-differences per observation from the four series and so constituting the Normal Series. For each observation plate numbers and date (or dates) are given, while the mean velocity-difference $v_{\phi_1} - v_{\phi_2}$ appears in the next column. Then follows, with the last decimal as unit (1 m./sec.), the difference between the two mean velocity-differences for regions A and B which constitute the observation in question. The last column in each group gives this amount in percentage of $v_{\phi_1} - v_{\phi_2}$. The sign in both these columns is that of *numerical* $(v_{\phi_1} - v_{\phi_2})_A$ minus *numerical* $(v_{\phi_1} - v_{\phi_2})_B$. They are included in order to confirm the conclusion drawn on page 42 (§ 8) with regard to the continuity, on passing from region A to region B, of the diminution of the observed velocity-difference with increasing wave length.

The table is seen to be further divided in six horizontal divisions. Each division contains four observations which belong together in the way which follows from the method of observation. Taking as an example the second division from the top we see that the velocity-differences involved are

$$v_{15\,\text{S.E.}} - v_{75\,\text{S.W.}}$$
$$v_{75\,\text{S.W.}} - v_{15\,\text{N.W.}}$$
$$v_{15\,\text{N.W.}} - v_{75\,\text{N.E.}}$$
$$v_{75\,\text{N.E.}} - v_{15\,\text{S.E.}}$$

and it is clear that their sum must be identically zero. This sum as it appears from the observations is given in each case in the table. It is seen that the largest error amounts to − 0·028 km./sec., while the average numerical deviation from zero amounts to 0·011 km./sec., and in the Normal Series to 0·004 km./sec. It may be claimed that these considerations give confidence in the method of observation and in the results.

Such confidence is also derived to a considerable extent from a first glance at the agreement between the figures given for the four series respectively. The greatest range which we find when comparing the values along the horizontal lines of the table amounts to 0·046 km./sec. (for $\phi_1 = 60°$ S.E.), while the mean range is not more than 0·021 km./sec., corresponding to a probable error per observation, on the supposition of accidental errors only, of

$$\pm\ 0{\cdot}006 \text{ km./sec.}$$

TABLE XIII. *Mean velocity-differences per observation, regions* A *and* B *combined*

ϕ_1	ϕ_2	Series I Plates *A*	*B*	Date June 1911	$v_{\phi_1} - v_{\phi_2}$	num. $(v_{\phi_1} - v_{\phi_2})_A$ − num. $(v_{\phi_1} - v_{\phi_2})_B$	Same in per cent.	Series II Plates *A*	*B*	Date June 1911	$v_{\phi_1} - v_{\phi_2}$	num. $(v_{\phi_1} - v_{\phi_2})_A$ − num. $(v_{\phi_1} - v_{\phi_2})_B$	Same in per cent.
					km./sec.	m./sec.	%				km./sec.	m./sec.	%
0° E.	90° S.	N 9,	6	1	− 1·874	+ 30	+ 1·6	N 56,	48	2, 1	− 1·874	+ 59	+ 3·2
90° S.	0° W.	10,	5	1	− 1·844	+ 2	+ 0·1	57,	49	2, 1	− 1·820	+ 67	+ 3·7
0° W.	90° N.	62,	7	2, 1	+ 1·877	+ 19	+ 1·0	58,	50	2, 1	+ 1·874	+ 49	+ 2·6
90° N.	0° E.	11,	8	1	+ 1·841	+ 21	+ 1·1	59,	51	2, 1	+ 1·833	+ 26	+ 1·4
					0·000						+ 0·013		
15° S.E.	75° S.W.	N 32,	36	1	− 2·135	+ 26	+ 1·2	N 40,	44	1	− 2·132	+ 22	+ 1·0
75° S.W.	15° N.W.	33,	37	1	− 1·431	+ 9	+ 0·6	41,	45	1	− 1·429	+ 9	+ 0·6
15° N.W.	75° N.E.	34,	38	1	+ 2·254	+ 41	+ 1·8	42,	46	1	+ 2·249	+ 27	+ 1·2
75° N.E.	15° S.E.	35,	39	1	+ 1·318	+ 10	+ 0·8	43,	47	1	+ 1·310	+ 14	+ 1·1
					+ 0·006						− 0·002		
30° S.E.	60° S.W.	N 20,	60	1, 2	− 2·196	+ 20	+ 0·9	N 97,	93	5	− 2·172	+ 57	+ 2·7
60° S.W.	30° N.W.	21,	61	1, 2	− 0·825	+ 15	+ 1·8	98,	94	5	− 0·822	− 2	− 0·2
30° N.W.	60° N.E.	22,	24	1	+ 2·312	+ 43	+ 1·9	99,	95	5	+ 2·303	+ 38	+ 1·7
60° N.E.	30° S.E.	23,	25	1	+ 0·717	− 3	− 0·4	100,	96	5	+ 0·714	+ 17	+ 2·4
					+ 0·008						+ 0·023		
45° S.E.	45° S.W.	N 28,	63	1, 3	− 2·264	+ 37	+ 1·6	N 85,	89	5	− 2·277	+ 24	+ 1·1
45° S.W.	45° N.W.	29,	64	1, 3	− 0·029	+ 21	—	86,	90	5	− 0·020	+ 4	—
45° N.W.	45° N.E.	30,	26	1	+ 2·368	+ 12	+ 0·5	87,	91	5	+ 2·368	+ 34	+ 1·4
45° N.E.	45° S.E.	31,	27	1	− 0·059	+ 27	—	88,	92	5	− 0·064	+ 2	—
					+ 0·016						+ 0·007		
60° S.E.	30° S.W.	N 69,	65	4	− 2·204	+ 7	+ 0·3	N 129,	131	6, 7	− 2·191	+ 21	+ 1·0
30° S.W.	60° N.W.	70,	66	4	+ 0·767	+ 3	+ 0·4	130,	132	6, 7	+ 0·757	+ 13	+ 1·7
60° N.W.	30° N.E.	71,	67	4	+ 2·302	+ 40	+ 1·7	135,	133	7	+ 2·298	+ 28	+ 1·2
30° N.E.	60° S.E.	72,	68	4	− 0·864	+ 11	+ 1·3	136,	134	7	− 0·868	+ 17	+ 2·0
					+ 0·001						− 0·004		
75° S.E.	15° S.W.	N 83,	79	5	− 2·120	+ 41	+ 1·9	N 137,	141	7	− 2·109	+ 25	+ 1·2
15° S.W.	75° N.W.	84,	80	5	+ 1·362	+ 27	+ 2·0	138,	142	7	+ 1·355	+ 9	+ 0·7
75° N.W.	15° N.E.	77,	81	5	+ 2·212	+ 41	+ 1·9	139,	143	7	+ 2·234	+ 27	+ 1·2
15° N.E.	75° S.E.	78,	82	5	− 1·460	+ 15	+ 1·0	140,	144	7	− 1·468	0	0·0
					− 0·006						+ 0·012		

TABLE XIII. *Mean velocity-differences per observation, regions* A *and* B *combined* (*concluded*)

Series III					Series IV					
Plates *A* *B*	Date June 1911	$v_{\phi_1}-v_{\phi_2}$	num. $(v_{\phi_1}-v_{\phi_2})_A$ − num. $(v_{\phi_1}-v_{\phi_2})_B$	Same in per cent.	Plates *A* *B*	Date June 1911	$v_{\phi_1}-v_{\phi_2}$	num. $(v_{\phi_1}-v_{\phi_2})_A$ − num. $(v_{\phi_1}-v_{\phi_2})_B$	Same in per cent.	Normal Series $v_{\phi_1}-v_{\phi_2}$
		km./sec.	m./sec.	%			km./sec.	m./sec.	%	km./sec.
N 117, 113	6	− 1·867	+ 9	+ 0·5	N 199, 195	8	− 1·852	+ 10	+ 0·6	− 1·867
118, 114	6	− 1·830	+ 15	+ 0·8	200, 196	8	− 1·821	+ 31	+ 1·7	− 1·829
119, 115	6	+ 1·880	− 6	− 0·3	201, 197	8	+ 1·849	+ 16	+ 0·9	+ 1·870
120, 116	6	+ 1·840	+ 1	+ 0·1	202, 198	8	+ 1·814	+ 22	+ 1·2	+ 1·832
		+ 0·023					− 0·010			+ 0·006
N 105, 109	5	− 2·129	+ 17	+ 0·8	N 157, 153	7	− 2·143	+ 19	+ 0·9	− 2·135
106, 110	5	− 1·435	+ 16	+ 1·1	158, 154	7	− 1·416	+ 21	+ 1·5	− 1·428
107, 111	5	+ 2·239	+ 43	+ 1·9	159, 155	7	+ 2·230	+ 24	+ 1·1	+ 2·243
108, 112	5	+ 1·317	+ 16	+ 1·2	160, 156	7	+ 1·330	+ 26	+ 2·0	+ 1·319
		− 0·008					+ 0·001			− 0·001
N 161, 165	7	− 2·218	+ 35	+ 1·6	N 219, 215	11	− 2·207	+ 25	+ 1·1	− 2·198
162, 166	7	− 0·814	0	0·0	220, 216	11	− 0·831	+ 6	+ 0·7	− 0·823
163, 167	7	+ 2·308	+ 36	+ 1·6	221, 217	11	+ 2·316	+ 28	+ 1·2	+ 2·310
164, 168	7	+ 0·715	− 7	− 1·0	222, 218	11	+ 0·703	+ 15	+ 2·1	+ 0·712
		− 0·009					− 0·019			+ 0·001
N 149, 145	7	− 2·266	+ 50	+ 2·2	N 207, 211	9	− 2·242	+ 30	+ 1·3	− 2·262
150, 146	7	− 0·043	− 1	—	208, 212	9	− 0·026	0	—	− 0·030
151, 147	7	+ 2·373	+ 40	+ 1·7	209, 213	9	+ 2·367	+ 43	+ 1·8	+ 2·369
152, 148	7	− 0·092	+ 2	—	210, 214	9	− 0·083	+ 4	—	− 0·074
		− 0·028					+ 0·016			+ 0·003
N 177, 181	8	− 2·195	+ 16	+ 0·7	N 231, 235	11	− 2·191	+ 99	+ 4·5	− 2·195
178, 182	8	+ 0·761	− 12	− 1·6	232, 236	11	+ 0·746	+ 1	+ 0·1	+ 0·758
179, 183	8	+ 2·301	+ 16	+ 0·7	233, 237	11	+ 2·308	+ 16	+ 0·7	+ 2·302
180, 184	8	− 0·878	+ 17	+ 1·9	234, 238	11	− 0·881	+ 24	+ 2·7	− 0·873
		− 0·011					− 0·018			− 0·008
N 187, 191	8	− 2·123	+ 16	+ 0·8	N 243, 239	12	− 2·109	+ 26	+ 1·2	− 2·115
188, 192	8	+ 1·365	+ 20	+ 1·5	244, 240	15, 12	+ 1·350	+ 12	+ 0·9	+ 1·358
189, 193	8	+ 2·219	+ 27	+ 1·2	245, 241	15, 12	+ 2·226	+ 30	+ 1·4	+ 2·223
190, 194	8	− 1·452	+ 20	+ 1·4	246, 242	15, 12	− 1·458	+ 45	+ 3·0	− 1·460
		+ 0·009					+ 0·009			+ 0·006

§ 13. *Probable errors*

It will be of interest to compare the probable error obtained in the way mentioned at the end of the last paragraph with that which we get from the internal agreement of the measured velocities on the plates.

Whether we compute this latter from the residuals of the figures in Table VII with the means as from Table XIII, or with the values for the velocity-differences according to the law expressed in formula (12), or with the means for each region *A* and *B* respectively, we obtain much the same result in each case. The probable error per line on one exposure varies from

$$\pm\ 0{\cdot}016 \text{ km./sec. to } \pm\ 0{\cdot}030 \text{ km./sec.}$$

and amounts therefore in the mean to

$$\pm\ 0{\cdot}023 \text{ km./sec.}$$

In accordance with this the probable error of the mean value on each plate separately (one region) is

$$\pm\ 0{\cdot}006 \text{ km./sec.}$$

and that of the figures of Table XIII

$$\pm\ 0{\cdot}004 \text{ km./sec.}$$

We see that the probable errors per observation as obtained from internal and external agreement are approximately equal.

As the question of the accuracy of measurements on solar plates has of late years attracted increasing attention from various investigators it may be useful to give a table of probable errors as obtained on solar rotation plates by the different measurers. In order, for the purpose of such a table, to make a fair comparison between the errors of previous observers and those just given, either the former have to be multiplied or the latter divided by 2. For in all other investigations displacements were always obtained for points at opposite ends of solar diameters; from these displacements velocities at the limb were calculated by introducing the factor $\frac{1}{2}$ in the velocity-coefficient, and so combining the reduction from displacements to velocity-differences with that from velocity-differences to velocities. The probable errors were thus obtained from these latter quantities. The procedure is not quite correct; it would only be so if the numerical velocity-difference at opposite ends of a diameter was always *identically* twice the numerical velocity at either end. It seems therefore best to convert the probable errors published in these other investigations into true probable errors of velocity-differences by doubling them. Table XIV thus gives the general comparison. Only photographic determinations are taken into account. In considering the figures of the table the velocity-coefficient must be borne in mind. It is given in the third column and determines the order of the table, the observations with largest effective dispersion appearing at the top. Also it must be remembered that the lines at the red end of the spectrum are less suitable for measurement than those in the blue. The velocity-coefficient in Evershed's case is that for the enlargement which he measured. The Kodaikanal measurements made directly on the plates by the ordinary method give a larger probable error. The Edinburgh measures were made with the plate in one direction only, while also a less sensitive instrument was used.

TABLE XIV. *Comparison of probable errors*

Measurer	Probable error per line per exposure	Velocity coefficient	Spectral region
	km./sec.		
Evershed, positive on negative*	± 0·038	26	6300
Evershed, ordinary method* ...	± 0·078	26	6300
Lasby †	± 0·016	37	5600
J. S. Plaskett †	± 0·038	37	5600
H. H. Plaskett	± 0·078	37	5600
De Lury †	± 0·090	37	5600
Edinburgh	± 0·088	37	6300
Mount Wilson 1908 ‡	± 0·018	48	4250
Mount Wilson 1906–07 §	± 0·030	50	4250
J. S. Plaskett	± 0·030	52	4250
Tunstall	± 0·023	62	4350
Allegheny ‖	± 0·096	90	4100

* These values were obtained on one special plate. See *Kodaikanal Obs. Bulletin*, No. XXXII. Evershed's average error is slightly larger.

† These values were obtained on one special plate, taken at Ottawa. See *Trans. R. S. of Canada*, Third Ser., VI. sec. 3.

‡ Measurements nearly all by Miss Lasby.

§ Measurements mostly by Miss Lasby, some by Adams.

‖ Measurements by Miss Udick.

The conclusion arrived at by Plaskett and De Lury about the variety found in the achievement of the different measurers is fully borne out.

§ 14. *Symmetry with respect to the solar axis*

We have, so far, made no assumption about the distribution with respect to the solar equator and the solar axis of the velocities themselves, having up to the present dealt solely with velocity-differences. It will be convenient first to see whether there is any evidence of symmetrical arrangement or not with respect to the axis. Referring to Fig. 5 (p. 46) it may be recalled that in case of such a symmetry velocity-differences $v_{15\text{S.E.}} - v_{75\text{S.W.}}$ and $v_{75\text{S.E.}} - v_{15\text{S.W.}}$ should be equal. Thus there should be pairs of equal velocity-differences all through the series, except for the two observations 2—5 and 8—11 (Fig. 5) which deal with the Northern and Southern 45° parallels and form, in each case, their own counterpart. Table XV gives the normal velocity-differences, arranged in such a way that observations made symmetrically appear on the same line. It is seen at once that not only is the expected equality absent, but that also the values in the left hand column are consistently smaller, taking the sign into account, than those in the right hand column. The mean difference amounts to

0·031 km./sec., the difference being only 0·003 and 0·008 km./sec. for the two pairs next to the top and bottom values and reaching its maximum values for the three central pairs. These same features are all present if we regard the figures of the original four series in the same way, the mean differences being in the four cases

Series I − 0·029 km./sec.
Series II − 0·030 km./sec.
Series III − 0·032 km./sec.
Series IV − 0·031 km./sec.

TABLE XV. *Normal values compared for symmetry round axis*

ϕ_1	ϕ_2	$v\phi_1 - v\phi_2$	$v\phi_1 - v\phi_2$	ϕ_1	ϕ_2
45° S.E.	45° S.W.	− 2·262		45° S.E.	45° S.W.
30° S.E.	60° S.W.	− 2·198	− 2·195	60° S.E.	30° S.W.
15° S.E.	75° S.W.	− 2·135	− 2·115	75° S.E.	15° S.W.
0° E.	90° S.	− 1·867	− 1·829	90° S.	0° W.
15° N.E.	75° S.E.	− 1·460	− 1·428	75° S.W.	15° N.W.
30° N.E.	60° S.E.	− 0·873	− 0·823	60° S.W.	30° N.W.
45° N.E.	45° S.E.	− 0·074	− 0·030	45° S.W.	45° N.W.
60° N.E.	30° S.E.	+ 0·712	+ 0·758	30° S.W.	60° N.W.
75° N.E.	15° S.E.	+ 1·319	+ 1·358	15° S.W.	75° N.W.
90° N.	0° E.	+ 1·832	+ 1·870	0° W.	90° N.
75° N.W.	15° N.E.	+ 2·223	+ 2·243	15° N.W.	75° N.E.
60° N.W.	30° N.E.	+ 2·302	+ 2·310	30° N.W.	60° N.E.
45° N.W.	45° N.E.	+ 2·369		45° N.W.	45° N.E.

One is inclined, at first sight, to attribute the effect so found to a difference, possibly only apparent, in the velocities of approach at the East limb as compared with those of recession at the West limb. A simple consideration shows, however, that this explanation cannot hold. If such a difference existed it should certainly be possible to express it either (i) by a change, for one half of the sun, in the constants of the formula which gives the relation between velocity and latitude, or (ii) by the introduction for that half of a factor $1 + \epsilon$ where ϵ represents a small fraction, or again (iii) simply by an additive term for the velocities on one side of the limb. The last case (iii) must at once be ruled out; for any constant additive effect, existing, say, on the Eastern limb, would vanish in velocity-differences like $v_{15^\circ \text{N.E.}} - v_{75^\circ \text{S.E.}}$ where two points are compared which are both situated on the Eastern half of the sun. But also in the two other cases, (i) and (ii), $v_{45^\circ \text{N.E.}} - v_{45^\circ \text{S.E.}}$ at least should not show a difference from $v_{45^\circ \text{S.W.}} - v_{45^\circ \text{N.W.}}$, whereas it does so to a considerable extent. In fact, in these two other cases there should be a minimum approaching to zero for the difference between the two columns about the centre of the table, whereas we have found there approximately a maximum.

A little reflexion shows that the effect can have been caused by the addition to the velocities of, for the Northern solar hemisphere, a small negative velocity, for the Southern a small positive one, these additive velocities reaching their respective absolute maxima at the poles and vanishing at the equator. They may have been only apparent. Some peculiar phenomenon may have caused special displacements, largest one way at one pole of the sun, the other way at the other pole and having regular intermediate values on both the intermediate branches of the solar limb. But it is far more plausible to assume at once that they are real and that we are dealing with an added rotation round an axis in the solar equator, i.e. with either a change of or an error in the axis of rotation. Regarded in this way it is found, by a simple graphical method which need not be detailed, that a shift of the solar axis amounting to

$$0^\circ\ 45'$$

in the direction from N. to W. is entirely sufficient to account for the peculiar differences in question. This shift may have been caused by an error in the method of setting the points of required latitude on the centre of the slit. Such an error should then have been constant and therefore purely instrumental; it can have resided in the angle between the lines drawn on the slit plate, which angle might have been different from 90° by the above amount. Careful measures, instituted to elucidate this point, reveal indeed a small error in the required direction, but amounting only to 0° 15′. The remaining

$$0^\circ\ 30'$$

the author concludes to be the amount either of a real shift of the axis, from N. to W., for the epoch of observation, or of a correction to be applied on account of some undiscovered constant instrumental error.

If a real shift has occurred we must remember that the present investigation extends over only one fortnight of the sun's life and therefore may have brought to light a temporary change in the solar axis, caused by some unknown oscillation or periodic variation of short period. The recent Greenwich investigation of the position of the solar axis from sunspot movements by Dyson and Maunder[1] contains no evidence which definitely excludes the possibility of such a change. No determination of the axis based on material obtained in so small an interval of time has hitherto been made.

Some information may be gleaned from earlier spectroscopic work on the rotation. All such work has been done by comparing points on the limb at opposite ends of solar diameters. Evidence about the position of the axis can with that method only be forthcoming if observations have been made for diameters traversing both pairs of diagonally opposite quadrants. From what is published

[1] *Greenwich Observations*, 1913.

in Adams' larger memoir[1] we gather that from May 3 to June 16, 1906, plates had been taken for quadrants N.W.—S.E., while the series Oct. 19—Dec. 18 of that year had dealt with points N.E.—S.W. Comparing the mean velocities at latitudes 0°, 15° up to 75° for these two sets of plates (about ten velocities for each latitude in either set) we find them generally larger for the second series, to an amount considerably greater than is warranted by the probable errors. The fact, however, that also the velocities at 0° differ, points rather to a variation in the general rate of rotation being here the cause of the difference. The 1908 Mount Wilson plates seem to have been taken in only one pair of quadrants. None of the other papers dealing with similar researches afford sufficient data about the pairs of quadrants for which the plates were taken. The results discussed suggest the desirability of generally giving this information.

It may yet be that what we have explained as a velocity effect due to error in or change of axis, and what appeared as an additive displacement varying regularly from N. to S. pole along the two branches of the intervening limb, is really due to some other physical influence on the position of the lines. Be this as it may, the systematic nature of the non-occurrence of symmetry found in the first instance allows us to conclude about a certain correction to be applied *and at the same time about the existence for these observations of close symmetry with respect to the real* (*changed or corrected*) *axis*. It is this latter conclusion which should be specially borne in mind.

§ 15. *Symmetry with respect to the solar equator*

Table XVI gives the figures of Table XV corrected for the empirically determined error in or change of axis dealt with in the preceding section. The corrections are found by the graphical method already referred to which gave the amount of the error or change.

If symmetry with respect to the equator existed it is clear that the values of the table ought to be grouped symmetrically, except in regard to sign, with respect to the middle horizontal line of the table. We see that such is far from being the case. Supposing a distribution of velocities had occurred as is shown in the accompanying figure, where all velocities in the Northern hemisphere are 0·1 km./sec. greater than the corresponding ones in the Southern hemisphere, we should then have found for the velocity-differences amounts as given in square brackets in Table XVI. We see that the nature of the asymmetry with respect to the central line for these figures is the same as for the figures which relate to our actual observations, the numerical values being larger or smaller than the corresponding values on the other side of this line in the same cases throughout.

We are thus necessarily led to the view that for the period of observation all velocities in the Northern hemisphere were greater than the corresponding

[1] Adams and Lasby, pp. 7—10.

ones in the Southern. Owing to the method of observation we are, however, unable to make a positive statement of this kind which is at the same time quite

TABLE XVI. *Normal values corrected for change of axis*

ϕ_1	ϕ_2	$v_{\phi_1} - v_{\phi_2}$	$v_{\phi_1} - v_{\phi_2}$	ϕ_1	ϕ_2
45° S.E.	45° S.W.	− 2·262 [− 3·0]		45° S.E.	45° S.W.
30° S.E.	60° S.W.	− 2·195 [−2·9]	− 2·198 [−2·9]	60° S.E.	30° S.W.
15° S.E.	75° S.W.	− 2·125 [−2·5]	− 2·125 [−2·5]	75° S.E.	15° S.W.
0° E.	90° S.	− 1·854 [−2·0]	− 1·842 [−2·0]	90° S.	0° W.
15° N.E.	75° S.E.	− 1·441 [−1·2]	− 1·447 [−1·2]	75° S.W.	15° N.W.
30° N.E.	60° S.E.	− 0·847 [−0·6]	− 0·849 [−0·6]	60° S.W.	30° N.W.
45° N.E.	45° S.E.	− 0·044 [−0·1]	− 0·060 [−0·1]	45° S.W.	45° N.W.
60° N.E.	30° S.E.	+ 0·738 [+0·4]	+ 0·732 [+0·4]	30° S.W.	60° N.W.
75° N.E.	15° S.E.	+ 1·341 [+1·0]	+ 1·336 [+1·0]	15° S.W.	75° N.W.
90° N.	0° E.	+ 1·849 [+2·0]	+ 1·852 [+2·0]	0° W.	90° N.
75° N.W.	15° N.E.	+ 2·231 [+2·7]	+ 2·235 [+2·7]	15° N.W.	75° N.E.
60° N.W.	30° N.E.	+ 2·304 [+3·1]	+ 2·307 [+3·1]	30° N.W.	60° N.E.
45° N.W.	45° N.E.	+ 2·369 [+3·2]		45° N.W.	45° N.E.

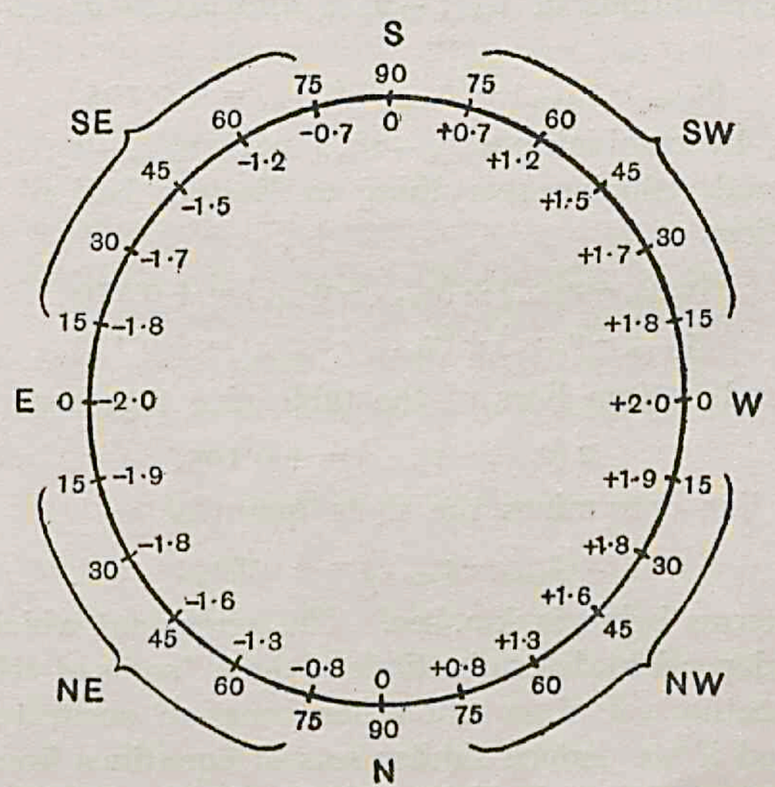

Fig. 6. Ideal distribution of velocities to compare with observed velocity-differences.

general. We can, however, go a little further in disentangling the velocities in the two hemispheres in the following way.

If we remember that there *is* symmetry with regard to the new (corrected or changed) axis, and if therefore we now put

$$v_{\phi\,\text{N.E.}} = -v_{\phi\,\text{N.W.}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (13)$$

and

$$v_{\phi\,\text{S.E.}} = -v_{\phi\,\text{S.W.}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

we shall be able to write down three pairs of identical equations, of which the known terms are in each case derived from entirely independent observations, in the following manner. A first consequence of relations (13) and (14) is that we may convert the two columns of Table XVI into one by taking means. We then have

$$v_{15\,\text{S.E.}} - v_{75\,\text{S.W.}} = -2{\cdot}125$$

which we can write

$$v_{15\,\text{S.E.}} + v_{75\,\text{S.E.}} = -2{\cdot}125.$$

Similarly lower in the table we find

$$v_{75\,\text{N.W.}} - v_{15\,\text{N.E.}} = +2{\cdot}233$$

from which follows

$$v_{15\,\text{N.E.}} + v_{75\,\text{N.E.}} = -2{\cdot}233.$$

By subtracting the second from the first we find

$$(v_{15\,\text{S.E.}} - v_{15\,\text{N.E.}}) + (v_{75\,\text{S.E.}} - v_{75\,\text{N.E.}}) = +0{\cdot}108.$$

Now it is clear that an equation identical as regards the left-hand term, can be got from the determinations of $v_{15\,\text{N.E.}} - v_{75\,\text{S.E.}}$ and $v_{75\,\text{N.E.}} - v_{15\,\text{S.E.}}$. These, suitably combined, give

$$(v_{15\,\text{S.E.}} - v_{15\,\text{N.E.}}) + (v_{75\,\text{S.E.}} - v_{75\,\text{N.E.}}) = +0{\cdot}105.$$

In the same way, by combining $v_{30\,\text{S.E.}} - v_{60\,\text{S.W.}}$ with $v_{60\,\text{N.W.}} - v_{30\,\text{N.E.}}$, and $v_{30\,\text{N.E.}} - v_{60\,\text{S.E.}}$ with $v_{60\,\text{N.E.}} - v_{30\,\text{S.E.}}$ and reducing everything to Eastern half of the sun only we get the two equations

$$(v_{30\,\text{S.E.}} - v_{30\,\text{N.E.}}) + (v_{60\,\text{S.E.}} - v_{60\,\text{N.E.}}) = +0{\cdot}110$$

and

$$(v_{30\,\text{S.E.}} - v_{30\,\text{N.E.}}) + (v_{60\,\text{S.E.}} - v_{60\,\text{N.E.}}) = +0{\cdot}113.$$

Finally, the top and bottom lines of the table give together

$$2\,(v_{45\,\text{S.E.}} - v_{45\,\text{N.E.}}) = +0{\cdot}105,$$

while the central line determines the same quantity

$$2\,(v_{45\,\text{S.E.}} - v_{45\,\text{N.E.}}) = +0{\cdot}104;$$

all the numerical terms being in km./sec. The agreement which we find in each case for the two independent determinations of these "sums of velocity-differences" shows that the method of observation has been an accurate one. This conclusion is confirmed if we deduce similar sets of equations from the four original series, when we get results as in Table XVII. In the headings of the columns expressions like $v_{15\,\text{N.}} - v_{15\,\text{S.}}$ are used instead of $v_{15\,\text{N.E.}} - v_{15\,\text{S.E.}}$ without causing confusion, on account of the symmetry with respect to the axis. For each series two sets of values are given, one set, designated by *a*, determined from the observations which would occupy the three top and the three bottom lines, if given in tables similar to Table XVI, the other set b from the observations which would be thus tabulated in the central five lines.

TABLE XVII. *Comparison of Northern with Southern hemisphere*

	$(v_{15^\circ N.} - v_{15^\circ S.}) + (v_{75^\circ N.} - v_{75^\circ S.})$	$(v_{30^\circ N.} - v_{30^\circ S.}) + (v_{60^\circ N.} - v_{60^\circ S.})$	$(v_{45^\circ N.} - v_{45^\circ S.})$	$(v_{15^\circ N.} + \ldots + v_{75^\circ N.}) - (v_{15^\circ S.} + \ldots + v_{75^\circ S.})$
Series I a	+ 0·105	+ 0·107	+ 0·052	+ 0·264
Series I b	+ 0·105	+ 0·103	+ 0·044	+ 0·252
Series II a	+ 0·122	+ 0·118	+ 0·045	+ 0·285
Series II b	+ 0·116	+ 0·110	+ 0·042	+ 0·268
Series III a	+ 0·103	+ 0·098	+ 0·054	+ 0·255
Series III b	+ 0·103	+ 0·108	+ 0·067	+ 0·278
Series IV a	+ 0·102	+ 0·113	+ 0·062	+ 0·277
Series IV b	+ 0·097	+ 0·131	+ 0·055	+ 0·283
Final means	+ 0·107	+ 0·111	+ 0·052	+ 0·270

The final column is obtained by adding together the figures of the three other columns. It obviously affords a comparison between the sum of the velocities in one hemisphere and that in the other. The column gives therefore the values, as found in the present investigation, for the quantity E of the author's former publication[1]. The marked consistency of the figures in Table XVII, together with the smallness of the probable error of Mr Tunstall's measurements compared with those of the author's, justify the course of allowing their full weight to the present results and of disregarding altogether the conclusions drawn in the 1912 publication.

That the values in Table XVII are all positive does not necessarily mean that *all* the velocities in the Northern hemisphere are larger than the corresponding ones in the Southern. In either or both of the two first columns one of the two terms making up the observed total might be zero or even negative. The observations in themselves afford no evidence in this respect, owing to the method by which they were made. Some hypotheses may seem more likely than others; we may leave their discussion to a later section.

§ 16. *Reduction to one quadrant*

As has been stated already, it is impossible to obtain, without further assumptions, from the corrected velocity-differences as given on page 61 (Table XVI) the actual velocities for the different points. The adopted method of observation is, however, in no way inferior in this respect to the usual method. From the available material it is possible to infer by simple additions from each four velocity-differences which together complete a closed circle round the limb, four velocity-differences between points at the ends of two diameters, perpendicular to one another, and so to convert the material into such as is usually obtained. Then,

[1] *M.N.* LXVIII, p. 24, 1912.

making the assumption of symmetry with respect to the corrected axis as determined in § 14, from a corresponding but different set of four observations, we can deduce four velocity-differences at the ends of two diameters symmetrically situated; so that, *in toto*, we have four determinations of $v_{\phi N.} + v_{\phi S.}$ in each case, except in the cases of equator and pole where we have only two. The values in this way obtained from the figures of Table XVI are given in Table XVIII. The

TABLE XVIII. $v_{\phi N.} + v_{\phi S.}$ *for the Normal Series, corrected for axis*

$2v_0$	$v_{15^\circ N.} + v_{15^\circ S.}$	$v_{30^\circ N.} + v_{30^\circ S.}$	$v_{45^\circ N.} + v_{45^\circ S.}$	$v_{60^\circ N.} + v_{60^\circ S.}$	$v_{75^\circ N.} + v_{75^\circ S.}$	$v_{90^\circ N.} - v_{90^\circ S.}$
3·696	3·572	3·044	2·322	1·466	0·789	(− 0·010)
3·701	3·576	3·045	2·325	1·457	0·790	(− 0·005)
....	3·566	3·045	2·306	1·457	0·784	....
....	3·567	3·036	2·309	1·458	0·788	....
3·699	3·570	3·042	2·315	1·459	0·788	(− 0·007)

agreement is again very satisfactory, and though it is partly due to the change of axis for reasons of symmetry, still in each column the agreement between the first two and that between the next two values is wholly independent of that change. The last column serves more especially as a check. It is to be noted that the mean values, given in the bottom line, would come out unaltered, except for the last one, if we had calculated the values from the figures of Table XV instead of from those of Table XVI, assuming symmetry with respect to the uncorrected axis. For each of the four series, the values of $v_{\phi N.} + v_{\phi S.}$ have actually been computed without taking into account the correction with respect to axis. The mean values thus obtained are given in Table XIX. The bottom

TABLE XIX. *Mean* $v_{\phi N.} + v_{\phi S.}$ *for the four original series, uncorrected for axis*

	$2v_0$	$v_{15^\circ N.} + v_{15^\circ S.}$	$v_{30^\circ N.} + v_{30^\circ S.}$	$v_{45^\circ N.} + v_{45^\circ S.}$	$v_{60^\circ N.} + v_{60^\circ S.}$	$v_{75^\circ N.} + v_{75^\circ S.}$	$v_{90^\circ N.} - v_{90^\circ S.}$
Series I	3·718	3·573	3·047	2·316	1·460	0·788	− 0·033
Series II	3·701	3·572	3·031	2·322	1·451	0·790	− 0·048
Series III	3·708	3·570	3·047	2·320	1·464	0·785	− 0·038
Series IV	3·668	3·565	3·046	2·305	1·465	0·789	− 0·033
Means	3·699	3·570	3·043	2·313	1·460	0·788	− 0·038

line gives the total means from the four series and is seen to be practically identical with that of Table XVIII. The exception is the figure of the last column. In Table XIX $v_{90N.} - v_{90S.}$ comes out as considerably different from zero, indicating the necessity of a correction, which only for the poles is not eliminated when taking means from the four quadrants.

It is important, especially with a view to the discussion about the latitude law, to note the close agreement between the velocity-sums as found from the four series. This agreement shows that within the interval covered by the investigation neither did any change occur in the general rate of rotation, nor did any local effects appear. An exception as to the latter conclusion must perhaps be made for the equatorial velocity of Series IV. It is smaller than the mean to a greater extent than is warranted by the general agreement of the table. The observations from which the velocity-sum in question was obtained were all made on June 8, 1911. Observations at other latitudes were made on the same day which do not give diminished velocities for those latitudes. We probably have to do, in this case, with the effect of a local disturbance on the sun's limb either at 0° E. or at 0° W., or else with a disturbance affecting the velocity all round the equator, and so appearing at both these points.

The latter hypothesis, though at first sight the more unlikely one, fits in best with the general results of the present work. We have already seen how strong the evidence is for complete symmetry with respect to the axis. We shall find in the next section that great deviations from the usually assumed velocity-law occur, which deviations remain constant for epochs like our period of observation, while they affect the velocities on solar parallels as a whole.

§ 17. *Rotation law for the epoch of observation*

If, even with the differences which we have found between the Northern and Southern hemispheres, the *mean* velocities from both ranged themselves in the usual way according to Faye's law, it should be possible to determine from the bottom line of figures of Table XIX (or Table XVIII) the two constants a and b of the formula expressing the law. It is unnecessary to give the details of the efforts made in this direction. It was at once apparent that it is impossible to represent the figures of the table by a formula

$$v_{\phi\,\text{N.}} + v_{\phi\,\text{S.}} = (2a - 2b \sin^2 \phi) \cos \phi \quad \ldots\ldots\ldots\ldots\ldots (15)$$

of the kind required. The best way to demonstrate this is by showing the graph which represents the *angular* velocities corresponding to the mean velocity-sums of the table, as well as that given by a representative formula of the above kind. This is done in Fig. 7 where the continuous line is given by the formula

$$\xi = 14^\circ{\cdot}54 - 3^\circ{\cdot}50 \sin^2 \phi,$$

and is taken from Adams' Carnegie Institute publication[1], while the broken curve connects points determined directly from the figures of Table XIX by reducing to angular velocities. The diameter of the dots representing the observations corresponds in scale exactly to the mean range in angular velocities found when

[1] Adams and Lasby, p. 129.

comparing the four series. This range varies from 0°·03 (for 15° latitude) to 0°·11 (for 60°) as can be seen from Table XX which gives the angular velocities for

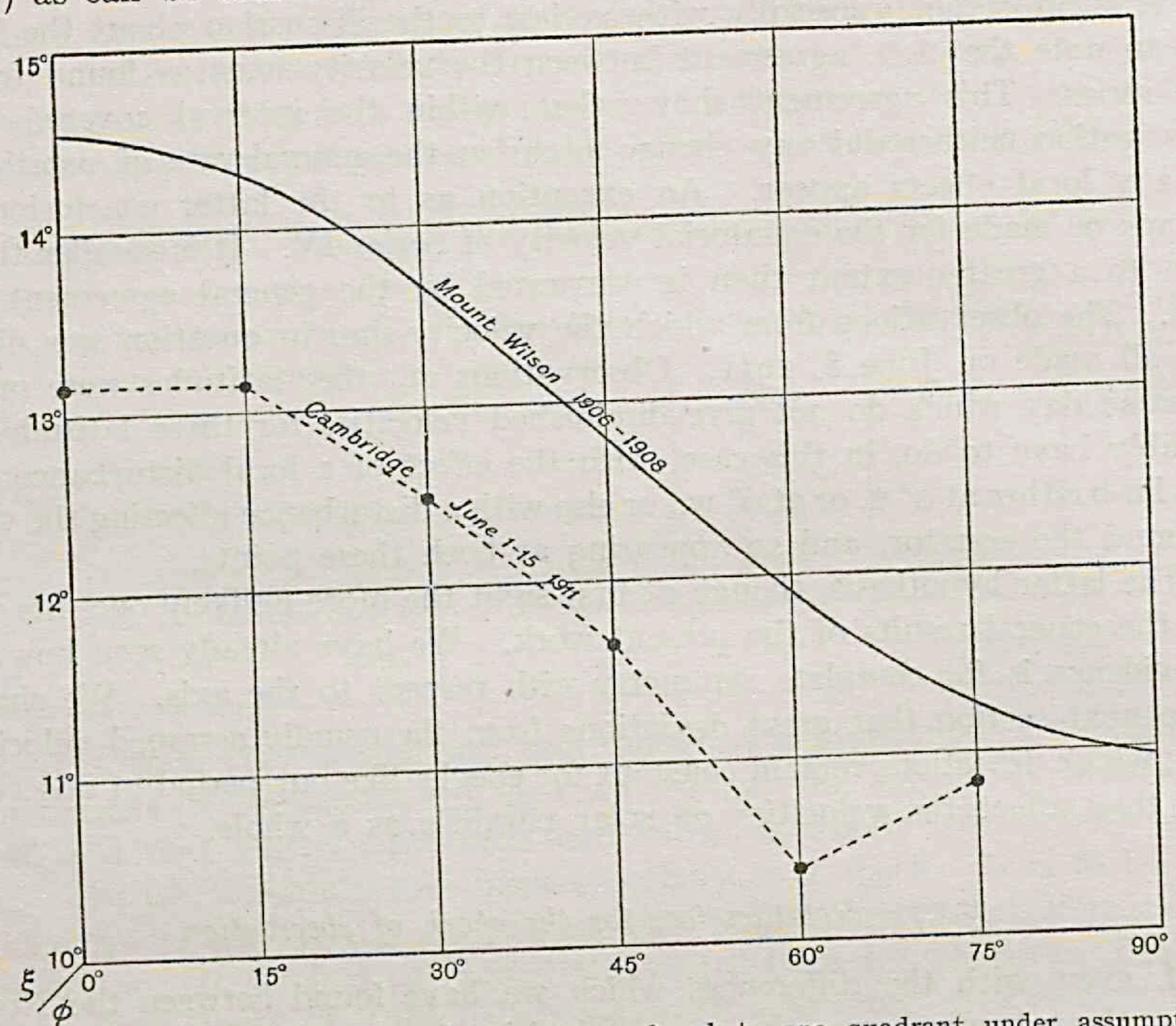

Fig. 7. Mean angular velocities from four series, reduced to one quadrant under assumptions of symmetry with respect to axis and, for the purpose of this reduction, also with respect to equator. Comparison with typical earlier results. The size of the dots is a measure of the range of variation found between the results of the four individual series.

TABLE XX. *Angular velocities, averaged over the two hemispheres, computed from the figures in Table XIX*

	0°	15°	30°	45°	60°	75°
Series I	13°·22	13°·16	12°·51	11°·65	10°·39	10°·82
Series II	13 ·16	13 ·15	12 ·45	11 ·68	10 ·31	10 ·86
Series III	13 ·19	13 ·15	12 ·52	11 ·67	10 ·41	10 ·79
Series IV	13 ·05	13 ·13	12 ·51	11 ·59	10 ·42	10 ·84
Means	13°·16	13°·15	12°·50	11°·65	10°·38	10°·83

the four series[1]. In both curve and table we have for the moment neglected the difference between the Northern and Southern hemispheres and are dealing with average results from the two.

[1] A more complete table giving all the angular velocities deduced directly from the observations is given on page 75.

From Fig. 7 we see that the two curves differ entirely in character. It is abundantly evident, if we also keep in mind the good agreement between the four series, that the Faye formula cannot be applied to the present observations. The author has, in fact, been unable to discover any simple formula with few constants to which the observations approximate. It is unnecessary to detain the reader with an enumeration of the forms which have been tried. It is sufficient to say that all the more obvious combinations of trigonometrical terms have been tested.

The task is naturally less hopeful, when instead of combining the hemispheres account is taken of the asymmetry with respect to the equator. We have seen in § 15 that the present observations do not afford means of definitively determining the velocities at the various latitudes in the Northern and Southern hemispheres, even under the adopted assumption of the existence of symmetry about the axis. Only for the latitudes 45°, for which both $v_{45\,\text{N.}} + v_{45\,\text{S.}}$ and $v_{45\,\text{N.}} - v_{45\,\text{S.}}$ are known, can we assign definitive velocities, viz.,

$$v_{45\,\text{N.}} = 1{\cdot}183 \text{ km./sec.}$$

$$v_{45\,\text{S.}} = 1{\cdot}131 \text{ km./sec.}$$

The equatorial velocity can also be directly deduced from the first column of Table XIX, viz.,

$$v_0 = 1{\cdot}850 \text{ km./sec.}$$

For the other latitudes 15° N., 15° S., 75° N., 75° S., and 30° N., 30° S., 60° N., 60° S., two sums of velocity-difference and four velocity sums are given in the bottom lines of Tables XVII and XIX. If, for the velocities at two of these latitudes (one in each group of four), arbitrary values are assumed, those at the remaining six latitudes follow from the observations. For five pairs of such arbitrary values, linear velocities have been deduced, and the corresponding angular velocities are plotted in the graphs given in Fig. 8, which accordingly represents five alternative interpretations of the results of the observations.

Certain features are bound to appear in all of them. The three angular velocities at 15° S., 0° and 15° N. must lie on a straight line, whilst towards at least one of the poles there must be an increase in angular velocity over that at the corresponding neighbouring latitude 75°—requirements which are obvious when we recall that the graph in Fig. 7 represents the mean of the Northern and Southern parts of each one of the complete graphs of Fig. 8.

For selection between the latter we can only make use of *à priori* considerations. But even these do not point convincingly to one of the alternatives as the most probable. It seems as plausible to suppose that the three angular velocities at 15° S., 0° and 15° N. were equal, so that a broad equatorial belt was at the time of observation rotating at a uniform rate, as to assume a maximum on one side of the equator or the other. It may further seem necessary to eliminate those curves which contain portions where the gradient is too steep, because in the observations involving such points the deviations from the mean value would certainly have come out much larger, when comparing the four series, than in the other observations. Table XIX shows that there is no case of an outstanding range of values for one latitude compared with the mean range for all, if we except the

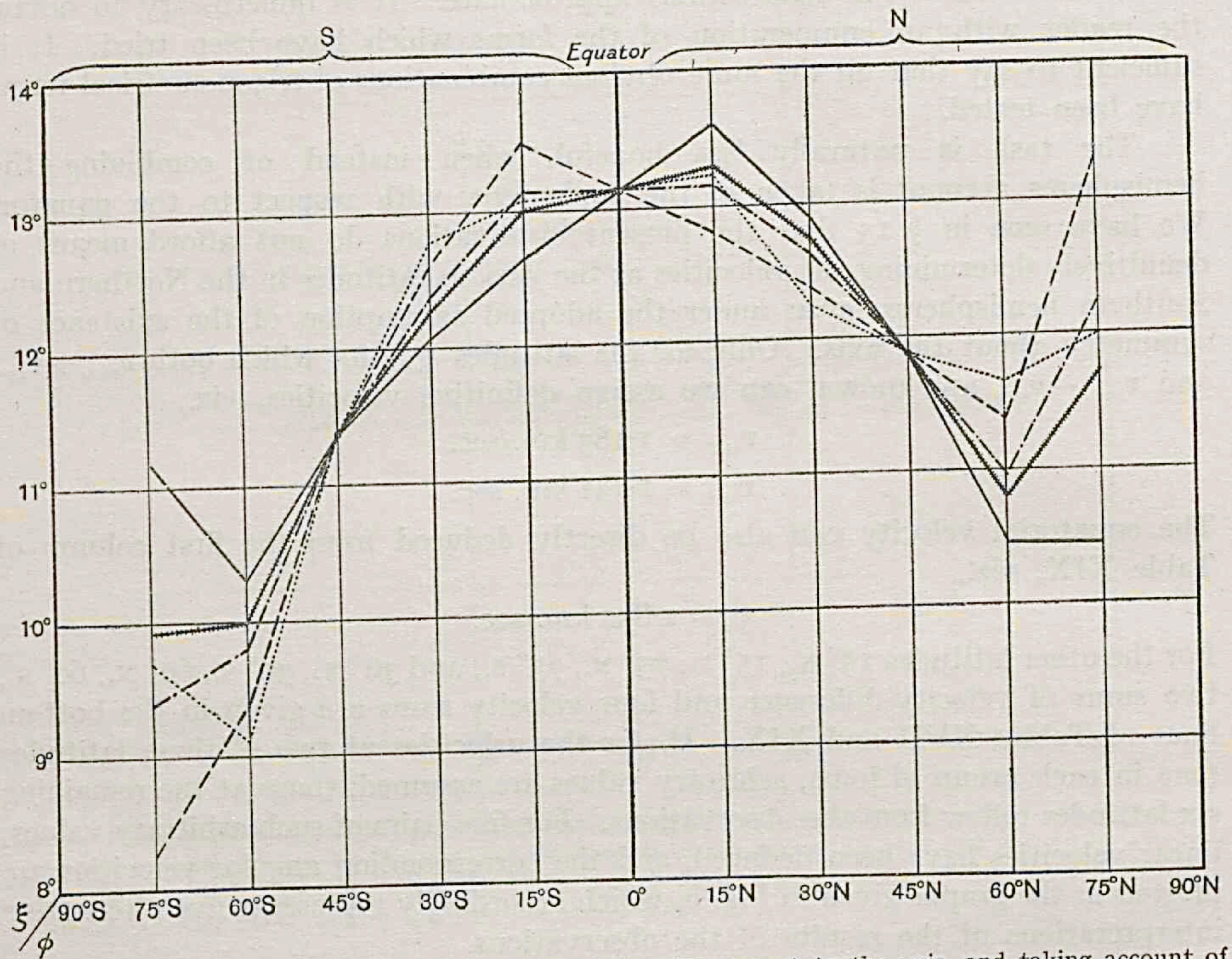

Fig. 8. Angular velocities, assuming symmetry only with respect to the axis, and taking account of difference between hemispheres as evident from Table XVII. The velocities for the epoch of observation must lie on a graph approximating to one of the five given.

one low value of v_0 for Series IV, where there can be no question of maximum gradient. We have, however, no right to reject curves with steep portions, as these portions may after all stand for parts of the curve where there had been sudden jumps and then again normal gradients in the sense required by the solar theory of Emden.

§ 18. *Tentative explanation of plate-to-plate results*

It is Emden's theory which perhaps affords the best clue towards an explanation of most of these results. It will be remembered that Emden finds[1] that in a rotating gaseous sphere under what he calls polytropic equilibrium surfaces of discontinuity must occur which are surfaces of revolution having the solar axis for their axis and which intersect a meridian plane by lines as shown in the figure. A layer of the solar mass between two such surfaces has, besides a constant "polytropic temperature," also a constant moment of rotation, i.e. the angular velocity within such a layer varies inversely as the square of the radius. Passing through such a surface of discontinuity, outwards from the axis, we pass from a layer with smaller to one with larger moment of rotation[2]. The result is that when plotting the angular velocities from 90° S. to 90° N. we should get, according to this theory, a curve approximating to that given in Fig. 10. At the points

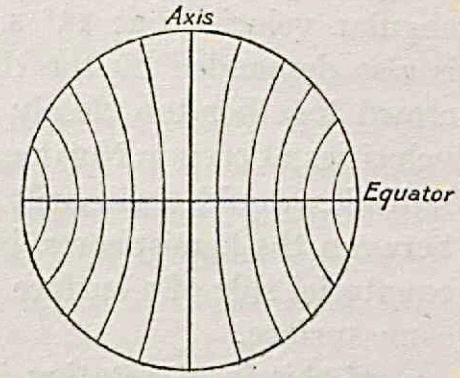

Fig. 9. Section through sun to show where planes of discontinuity of Emden's theory intersect a meridian plane.

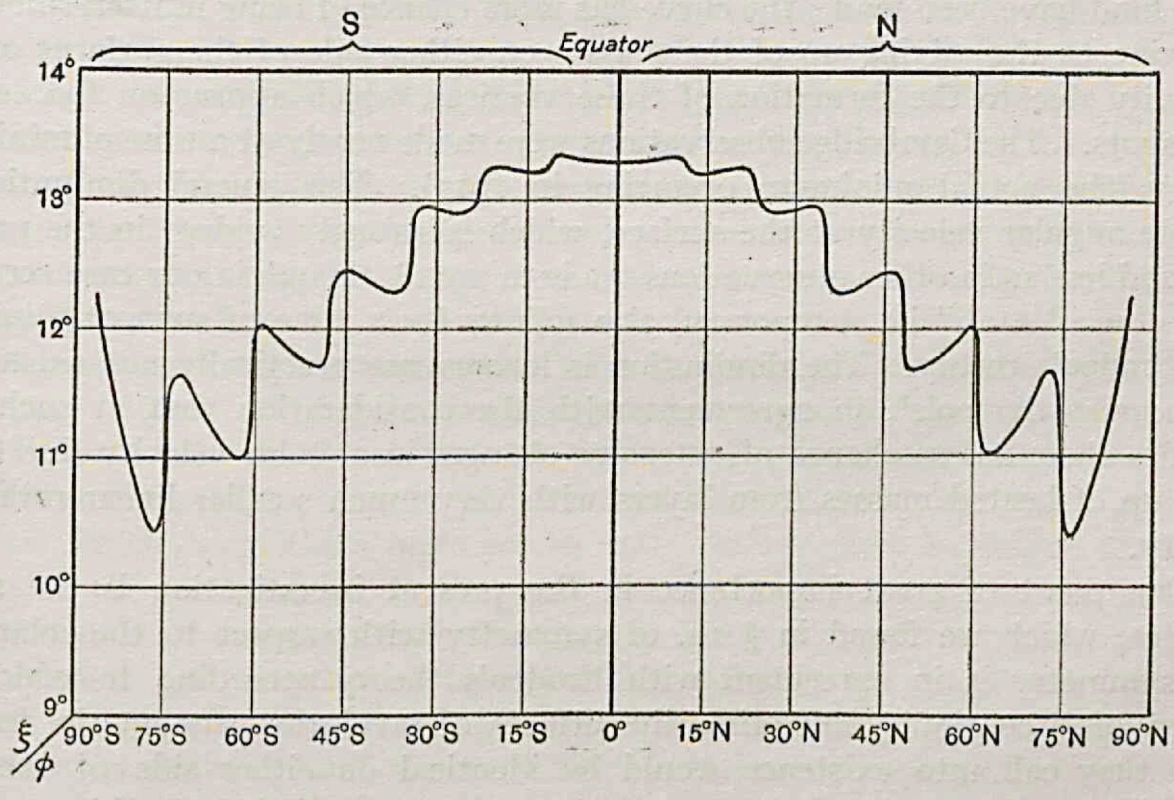

Fig. 10. Distribution of angular velocities following from Emden's theory of the sun.

where the surfaces of discontinuity intersect the limb there would be a sudden drop in the angular velocity, while between these points it would *increase* with the latitude in the ratio required by the theory. We see from Fig. 8 that the observations

[1] R. Emden, *Gaskugeln*, p. 429 *sqq.*

[2] *loc. cit.* p. 440.

may indeed be represented by a curve of this character. All we need assume is that, at the time, the planes of discontinuity were on the whole few and the jumps fairly large. The increase in angular velocity which we then would have to find on getting close to the pole is a special feature of our results. Equality of angular velocities at 15° S., 0° and 15° N., a possible solution of our equations, is also demanded by the theory so long as the surfaces of discontinuity do not crowd together too closely near the equator. A considerable difference between velocities at certain Northern latitudes compared with those at the similar Southern latitudes would necessarily be found if, on account of only a slight asymmetry between the hemispheres, in one case the point in question were situated on the equatorial side of a surface of discontinuity, in the other on the polar side of the same surface.

If this interpretation is correct, it may be that the reason why such results have not been obtained before is because no previous observer has discussed data taken so closely together in time[1]. In work extending over a considerable interval of the order of one year it is evident that many of the features of a curve like that of Fig. 10 will become smoothed out by the effect of the probable "accidental" changes and shifts of the positions of the surfaces of discontinuity. Possibly also at periods of maximum solar activity, during which most previous investigations of this kind have been made, the curve has more chance of being in itself smoothed out owing to the mixing up of the masses on either side of the surfaces of discontinuity due to the formation of those vortices, which appear on the surface as sunspots. The Cambridge observations were made nearly at a time of minimum activity (the actual minimum occurring in 1913). The general diminution of absolute angular velocity at the surface, which is strongly evident in the present work and less so in other observations made in 1911[2], though in our case certainly partly "accidental," i.e. temporary, also follows for a time of sunspot minimum from Emden's theory. The diminution is in our case practically non-existent at 75°, nearest the pole[3], in agreement with the consideration that at such high latitudes there is less chance of extensive changes in angular velocity due to the rising up of heated masses from layers with very much smaller linear rotational velocity.

One point of great importance in the present investigation is the strong evidence, which we found in § 14, of symmetry with respect to the solar axis. This symmetry is in agreement with Emden's theory according to which the surfaces of discontinuity are primarily surfaces of revolution so that the features which they call into existence would be identical on either side of the axis. Especially would this be the case at a time when very little smoothing out was done by their rolling up through the formation of vortices, i.e. at sunspot minimum. The arrangement of velocities in zones along parallels, giving an

[1] An exception is H. H. Plaskett's investigation which ranges over an interval of only six days, and which is referred to on p. 73.

[2] See also p. 72.

[3] See Fig. 7.

otherwise irregular retardation towards the poles, recalls the conditions found on Jupiter, a planet which is supposed to resemble the sun in more than one feature.

§ 19. *Comparison with earlier investigations*

Although probably, as has been stated, owing to the spreading out of the observations over considerable lengths of time, effects such as have been dealt with in the last sections do not come out clearly in hitherto published spectroscopic investigations of the solar rotation, yet it is possible to find in these some confirmation of the present results. We must now see where this confirmation is to be found, more especially with regard to deviations from Faye's law.

Taking first the Mount Wilson researches, if we divide Adams' observations into groups each taken within approximately one fortnight and plot the angular velocities, the curves so obtained show in several cases a very different character from that of the curves given by the formula

$$\xi = \alpha - \beta \sin^2 \phi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (16).$$

Only for three epochs, viz. for the observations of June 12—16, 1906 (8 plates), those of Nov. 11, 1906 (5 plates), and those made on Dec. 18 of the same year (5 plates), do the curves approximate to the ideal one[1]. In all the other cases the difference is very marked, and of such a character as to suggest that it is not due to accidental observational causes. Moreover the divergences for the individual latitudes from the ideal curve are frequently greater than the probable error which for such latitude at the special epoch of observation can be inferred from the agreement between the plates. On several occasions, notably for the observations May 26—June 11, 1908 (10 plates), there is some evidence of a regular waviness in the curve, on some we find an actual increase of angular velocity with increasing latitude. These latter cases are presented as follows in tabulated form (Table XXI). It is seen that the agreement between the plates, or between the several observations on one plate, is such that considerable colour is lent to the view which takes these increases as real. Adams does so regard the observations of the last division in the table, which were especially taken on a day when a couple of sunspots were nearing the West limb of the sun.

Evershed and Royds, at Kodaikanal, find[2] for the equatorial velocities evidence of a diminution occurring between observations made in January 1911 and others in February and March of the same year[3]. Their mean velocities for the equator for each fortnightly period are deduced from observations at latitudes ranging from 0° to 15°, on the assumption of Faye's law with Adams' constants.

[1] We have already noted, on page 60, the change which even in these observations occurs between the spring and autumn of that year.

[2] *M.N.* LXXIII, p. 561.

[3] A further diminution may have been due to the change to a different part of the spectrum and was referred to on p. 51.

Within each period there are not enough observations at latitudes near enough to one another to afford trustworthy evidence of deviation from the assumed law. The total diminution may, therefore, have been caused by some such deviation. Supposing an increase of angular velocity from 0° to 15° had been the true state of affairs for January—March, 1911, the low value which Evershed and Royds find for the equatorial velocity would still be higher than the true one of the epoch, and their observations would then in this respect tend even more to confirm those obtained at Cambridge in June of the same year[1].

TABLE XXI. *Cases of ξ increasing with increase of ϕ in Mount Wilson observations*

Date	Plate No.	ϕ	ξ	Date	Plate No.	ϕ	ξ
1907				1907			
Feb. 28	ω 61	59°·5	11°·69	Feb. 15	ω 56	69°·5	12°·41
,, 28	ω 61	59 ·5	11 ·69	,, 28	ω 61	69 ·5	11 ·53
				,, 28	ω 61	69 ·5	11 ·53
				,, 28	ω 61	69 ·5	12 ·30
				,, 28	ω 61	69 ·5	12 ·27
	Means	59°·5	11°·69		Means	69°·5	12°·01
1907				1907			
May 10	ω 83	63°·5	11°·14	May 10	ω 83	74°·4	12°·28
,, 10	ω 83	63 ·5	11 ·45	,, 10	ω 83	74 ·4	11 ·51
,, 30	ω 85	63 ·8	11 ·74	,, 30	ω 85	74 ·8	12 ·30
,, 30	ω 85	63 ·8	11 ·62	,, 30	ω 85	74 ·8	12 ·52
,, 30	ω 85	63 ·8	12 ·58	,, 30	ω 85	74 ·8	12 ·82
,, 30	ω 85	63 ·8	12 ·75	,, 30	ω 85	74 ·8	12 ·56
	Means	63°·7	11°·88		Means	74°·7	12°·33
1908				1908			
June 9	ω 128	44°·5	12°·54	June 10	ω 132	49°·4	12°·75
,, 11	ω 135$_1$	44 ·5	12 ·39	,, 11	ω 134	49 ·5	12 ·74
,, 11	ω 135$_2$	44 ·5	12 ·31	,, 11	ω 136	49 ·5	12 ·66
	Means	44°·5	12°·41		Means	49°·5	12°·72
1908				1908			
Sep. 15	ω 173	0°·0	13°·63	Sep. 15	ω 173	14°·9	13°·93
,, 15	ω 174	0 ·0	13 ·48	,, 15	ω 174	14 ·9	13 ·83
,, 15	ω 175	0 ·0	13 ·88	,, 15	ω 175	14 ·9	14 ·05
,, 15	ω 176	0 ·0	13 ·84	,, 15	ω 176	14 ·9	14 ·00
	Means	0°·0	13°·71		Means	14°·9	13°·95

The observations of J. S. Plaskett and De Lury began on the date on which the author's left off, June 15, 1911, and continued till the middle of the following October. They find a small diminution in the velocities, amounting to not quite 2 % when compared with Adams' values[2]; this diminution is, however, no greater for their first epoch, the last fortnight of June 1911, for which period there are eight observations all measured by J. S. Plaskett, than for the rest of their material,

[1] The mean linear equatorial velocity found by them for Jan.—March, 1911, is 1·961 km./sec., while that of the present work is 1·850 km./sec., respectively 13°·95 and 13°·16 per day.

[2] *Trans. R.S. of Canada*, 6, 3, p. 35.

obtained at subsequent dates. It should be noted that these June plates were taken in a part of the spectrum (λ 5600) very different from that of the present investigation and so other causes may have come into play to account for this discordance. In De Lury's observations there is one clear case of increase of angular velocity with increasing latitude, as shown in Table XXII. For the rest, each of J. S. Plaskett's series of observations, one dealing with the period June 15—Aug. 1, 1911, the other with Oct. 3—9, 1911, shows its own special characteristics as in the case of the Mount Wilson investigation; characteristics which again look as if they cannot be attributed to accidental instrumental causes and which show deviations from the simple latitude law larger than are warranted by the agreement between the plates.

TABLE XXII. *Case of ξ increasing with increase of φ in Ottawa observations*

Date	Plate No.	φ	ξ	Date	Plate No.	φ	ξ
1911				1911			
Aug. 10	833	14°·9	13°·08	Aug. 10	833	29°·8	13°·23
„ 10	834	14 ·9	13 ·08	„ 10	834	29 ·8	13 ·31
„ 30	836	14 ·9	13 ·24	„ 30	836	29 ·7	13 ·20
„ 30	837	14 ·9	12 ·21	„ 30	837	29 ·7	13 ·75
„ 30	838	14 ·9	12 ·64	„ 30	838	29 ·7	13 ·27
„ 30	839	14 ·9	13 ·20	„ 30	839	29 ·7	12 ·66
	Means	14°·9	12°·91		Means	29°·7	13°·24

At the same observatory, that of Ottawa, the observations measured and discussed by H. H. Plaskett were made[1]. The dates covered are June 6—15, 1913. Here again the mean angular velocities from the 23 plates when studied graphically at once reveal a great deviation from Faye's law. There is a big drop from 14°·12 for the equatorial velocity to 13°·48 for latitude 15°. Both in these observations and in those of J. S. Plaskett's Series I, there is an increase in angular velocity on going from 80° to 85°. But at such high latitudes ξ becomes very uncertain.

TABLE XXIII. *Case of ξ increasing with increase of φ in Allegheny observations*

Date	Plate No.	φ	ξ	Date	Plate No.	φ	ξ
1912				1912			
Sep. 30	252	2°·6	13°·5	Sep. 30	254	10°·3	14°·6
Oct. 1	258	3 ·4	14 ·4	Oct. 1	260	10 ·8	14 ·6
„ 1	259	3 ·4	14 ·2				
„ 4	263	2 ·2	13 ·8	„ 4	264	11 ·4	14 ·0
„ 14	268	1 ·8	14 ·3	„ 14	269	11 ·8	14 ·2
„ 15	273	1 ·6	14 ·5	„ 15	274	11 ·2	14 ·0
	Means	2°·5	14°·1		Means	11°·1	14°·3

Schlesinger's investigation[2] relating to material obtained between October 1911 and October 1912 comprises one series of observations sufficiently numerous within a short space of time to afford evidence on the matter in question, viz. the series Sept. 30—Oct. 15, 1912. The curve of observed velocities is again very different from the ideal one, while an increase with increasing latitude also occurs, in the zone near the equator. Particulars are given in Table XXIII.

[1] *Journal R.A.S. of Canada*, 8, p. 307.
[2] *Publ. Allegheny Obs.*, 3, 13.

Finally, there are the cases, given by Adams, of the calcium line λ 4227 and the first hydrogen line (Hα), where we are dealing with the solar atmosphere rather

TABLE XXIV. *Mount Wilson case of ξ increasing with increase of ϕ for* λ 4227

Date 1908	Plate No.	ϕ	ξ	Date 1908	Plate No.	ϕ	ξ
Aug. 5	ω 149	60°·8	12°·2	Aug. 5	ω 149	75°·5	13°·6
,, 5	ω 150	60 ·8	11 ·9	,, 5	ω 150	75 ·5	13 ·0
,, 6	ω 152	60 ·4	12 ·4	,, 6	ω 152	75 ·4	12 ·7
,, 6	ω 153	60 ·4	12 ·1	,, 6	ω 153	75 ·4	12 ·1
,, 6	ω 154	60 ·4	11 ·6	,, 6	ω 154	75 ·4	11 ·8
,, 13	ω 157	58 ·4	12 ·0	,, 13	ω 157	72 ·0	10 ·8
,, 13	ω 158	58 ·4	12 ·0	,, 13	ω 158	72 ·0	12 ·2
,, 27	ω 167	60 ·0	13 ·1	,, 27	ω 167	74 ·8	12 ·5
,, 27	ω 168	60 ·0	13 ·1	,, 27	ω 168	74 ·8	15 ·7
,, 27	ω 169	60 ·0	12 ·6	,, 27	ω 169	74 ·8	15 ·4
,, 27	ω 170	60 ·0	13 ·6	,, 27	ω 170	74 ·8	14 ·9
Oct. 22	ω 188	60 ·0	12 ·4	Oct. 22	ω 188	75 ·9	14 ·3
,, 22	ω 189	60 ·2	13 ·3	,, 22	ω 189	75 ·9	14 ·0
	Means	60°·0	12°·5		Means	74°·8	13°·3

TABLE XXV. *Mount Wilson case of ξ increasing with increase of ϕ for* Hα

	Date 1908	Plate No.	ϕ	ξ	Date 1908	Plate No.	ϕ	ξ
At Sun's limb	Mar. 24	ω 110	60°·4	13°·8				
	,, 24	ω 110	65 ·3	13 ·9	Mar. 24	ω 110	75°·2	15°·0
	May 15	ω 115	60 ·5	13 ·6	May 15	ω 115	75 ·9	14 ·0
	June 1	ω 118_1	60 ·4	13 ·6	June 1	ω 118_1	75 ·9	14 ·3
	,, 1	ω 118_2	60 ·4	13 ·8	,, 1	ω 118_2	75 ·9	15 ·2
	,, 9	ω 122	59 ·5	13 ·4	,, 9	ω 122	75 ·0	13 ·2
	,, 9	ω 123	59 ·5	13 ·0	,, 9	ω 123	75 ·0	13 ·4
	,, 9	ω 124_1	59 ·5	13 ·8	,, 9	ω 124_1	75 ·0	14 ·3
	,, 9	ω 124_2	59 ·5	13 ·6	,, 9	ω 124_2	75 ·0	14 ·3
	,, 9	ω 125_1	59 ·5	12 ·9	,, 9	ω 125_1	75 ·0	13 ·7
	,, 9	ω 125_2	59 ·5	13 ·4	,, 9	ω 125_2	75 ·0	13 ·2
	,, 9	ω 126_1	59 ·5	13 ·1	,, 9	ω 126_1	75 ·0	13 ·7
	,, 9	ω 126_2	59 ·5	13 ·6	,, 9	ω 126_2	75 ·0	14 ·5
	,, 9	ω 127_1	59 ·5	13 ·1	,, 9	ω 127_1	75 ·0	14 ·3
	,, 9	ω 127_2	59 ·5	13 ·7	,, 9	ω 127_2	75 ·0	14 ·0
	,, 10	ω 129	59 ·5	13 ·4	,, 10	ω 129	74 ·5	13 ·5
	,, 10	ω 130_1	59 ·5	14 ·0	,, 10	ω 130_1	74 ·5	13 ·8
	,, 10	ω 130_2	59 ·5	13 ·1	,, 10	ω 130_2	74 ·5	14 ·3
	,, 10	ω 131_1	59 ·5	13 ·6	,, 10	ω 131_1	74 ·5	13 ·5
	,, 10	ω 131_2	59 ·5	12 ·6	,, 10	ω 131_2	74 ·5	13 ·3
	Aug. 5	ω 141	59 ·9	13 ·9	Aug. 5	ω 141	74 ·9	15 ·3
	,, 5	ω 144	59 ·9	14 ·3	,, 5	ω 144	74 ·9	15 ·5
	,, 27	ω 171	60 ·2	14 ·0	,, 27	ω 171	75 ·0	16 ·4
		Means	59°·89	13°·53		Means	75°·00	14°·20
	1908				1908			
Within Sun's limb	May 15	ω 116	60°·8	13°·4	May 15	ω 116	76°·2	14°·0
	June 1	ω 119_1	60 ·4	12 ·8	June 1	ω 119_1	75 ·9	12 ·8
	,, 1	ω 119_2	60 ·4	12 ·5	,, 1	ω 119_2	75 ·9	12 ·5
	Aug. 4	ω 137	60 ·6	12 ·6	Aug. 4	ω 137	75 ·7	12 ·9
	,, 4	ω 138	60 ·6	12 ·6	,, 4	ω 138	75 ·7	12 ·9
	,, 5	ω 142	59 ·9	13 ·3	,, 5	ω 142	74 ·9	13 ·1
	,, 5	ω 143	59 ·9	13 ·2	,, 5	ω 143	74 ·9	13 ·9
	,, 27	ω 172	60 ·2	13 ·3	,, 27	ω 172	75 ·0	14 ·3
		Means	60°·4	12°·96		Means	75°·5	13°·30

than with the reversing layer. Both these show a distinct increase in angular velocity on going from 60° to 75°, the latter for observations both at the limb and some distance inside it. Tables XXIV and XXV give the details[1]. The

[1] Adams and Lasby, pp. 104–108.

observations are sufficiently numerous within a short time to suggest the reality of the increase, even though for each plate the velocities depend on measurements of only one line.

In the cases brought forward in detail (except the last two which probably deal with velocities at high levels), there are no other observations available for the times and latitudes specified. There is thus no reason, apart from that of belief in the constant validity of Faye's law, to doubt the reality, in earlier investigations, of local deviations at certain epochs from the average law, so that even if the interpretation suggested in § 18 of the results of the present investigation is not accepted, yet the desirability of making observations in groups close together is clearly indicated.

In order, finally, to give facilities of comparing the particular cases given in the last five tables with the results of the present investigation, the latter are completely presented in terms of angular velocities, in Table XXVI. These angular

TABLE XXVI. *Angular velocities determined from the Cambridge observations on the usual assumptions as to symmetry both about the uncorrected axis and about the equator*

	0°	15°		30°		45°		60°		75°	
		S.E.–N.W.	S.W.–N.E.	S.E.–N.W.	S.W.–N.E.	S.E.–N.W.	S.W.–N.E.	S.E.–N.W.	S.W.–N.E.	S.E.–N.W.	S.W.–N.E.
Series I June 1–5 1911	13°·22 13 ·23	13°·13 13 ·15	13°·16 13 ·18	12°·41 12 ·44	12°·60 12 ·60	11°·54 11 ·61	11°·68 11 ·77	10°·22 10 ·23	10°·58 10 ·52	10°·42 10 ·33	11°·31 11 ·23
Series II June 1–7 1911	13 ·14 13 ·18	13 ·11 13 ·11	13 ·22 13 ·17	12 ·30 12 ·39	12 ·55 12 ·57	11 ·55 11 ·59	11 ·81 11 ·78	10 ·20 10 ·17	10 ·37 10 ·52	10 ·36 10 ·53	11 ·27 11 ·30
Series III June 5–8 1911	13 ·15 13 ·23	13 ·13 13 ·09	13 ·20 13 ·17	12 ·45 12 ·41	12 ·58 12 ·62	11 ·61 11 ·47	11 ·72 11 ·86	10 ·20 10 ·12	10 ·63 10 ·69	10 ·42 10 ·54	11 ·05 11 ·16
Series IV June 7–15 1911	13 ·07 13 ·03	13 ·11 13 ·11	13 ·17 13 ·14	12 ·47 12 ·40	12 ·55 12 ·62	11 ·41 11 ·49	11 ·77 11 ·69	10 ·28 10 ·15	10 ·56 10 ·70	10 ·43 10 ·56	11 ·18 11 ·17
Means	13°·16	13°·15		12°·50		11°·65		10°·38		10°·83	

velocities have been computed from all the linear velocities obtained, each in turn got by combination of two correlated observations, i.e. from four sets of figures similar to Table XVIII, one for each of the series of observations. We thus get

16 determinations for each latitude except for the equator, for which there are only 8 values, while the 8 corresponding values relating to the velocities at the pole are, for obvious reasons, not given in the table.

The figures given are uncorrected for change of axis, and thus the table must show the effects which led to the conclusions about the axis. Except again for the equator, the angular velocities are given for each latitude in two columns, the left one containing those for the given latitude S.E.—N.W., the right one those S.W.—N.E. The latter are seen to be always greater, progressively so towards higher latitudes. The conclusions that, where we meant to observe at latitude ϕ, we really observed at latitudes $\phi + \alpha$ and $\phi - \alpha$ in the two cases, and that we ought therefore in the reduction to angular velocities to have applied the cosines of these angles instead of $\cos \phi$ for both, or that in other words the axis was to be shifted owing to an instrumental error or a real physical change by the small angle α from N. to W., seem amply justified.

The agreement of the figures apart from this is very satisfactory, even at high latitudes. The impossibility of applying Faye's law is apparent. While hitherto laws varying from

$$\xi = 14^{\circ}{\cdot}81 - 4^{\circ}{\cdot}2 \sin^2 \phi \text{ (Dunér)}$$

to

$$\xi = 14^{\circ}{\cdot}17 - 3^{\circ}{\cdot}4 \sin^2 \phi \text{ (Schlesinger)}$$

have been found for the *mean* rotation at the sun's surface, the present series of observations show that large and comparatively persistent deviations from such average laws occur which require further investigation.

§ 20. *Summary*

Four series of observations were made in the first fortnight of June 1911 at Cambridge, of which each contains the material, consisting of 48 plates, from which velocity-differences have been derived between pairs of points separated by 90° at intervals of 15° all round the sun's limb.

The comparison of results derived from different lines in the spectral region examined has brought out the result that the velocity-differences observed, and probably the velocities themselves, vary regularly from one end of the spectral region to the other, becoming smaller on proceeding towards the red. An exhaustive discussion of the anomaly leaves the presumption that its cause must be looked for on the sun. Clear traces of a similar effect have been found to exist in the work of other observers.

Apart from this effect no special departure from the average has been found to be characteristic of any one line or any one element.

The results deduced from discussion of the mean velocity-differences derived from the various photographs may, as far as they are relative, be assumed to be unaffected by the above, and can be summarised under three heads.

1. The velocities appear to be arranged with perfect symmetry with respect to a diameter forming an angle of $0° 30'$ with the assumed axis, which diameter presumably indicates the effective axis of rotation for the epoch of observation; the difference being due either to systematic instrumental error or to true physical change.

2. With respect to the equator symmetry is conspicuously absent. The sum of the velocities in the Northern hemisphere is considerably greater than that in the Southern, the total difference (for the five latitudes 15°, 30°, up to 75°) amounting to 0·270 km./sec. For latitude 45° the individual difference N.—S. is deduced without ambiguity; it there amounts to 0·052 km./sec.

3. When averaged together to one quadrant and reduced to angular velocities the results are shown to be inconsistent with Faye's law or any other simple law. This remains true if, on various hypotheses, the difference between the Northern and Southern hemispheres is allowed for. The conclusion is reached that large deviations from the usual average law occur which are—to account for what was found under 1—constant all along the respective parallels, and which persist during periods of observation like that of this investigation. The deviations occur especially at very low and at high latitudes. For these zones the angular velocity is found to remain constant or even to increase with increasing latitude.

All these results, inclusive of the difference between the Northern and Southern hemispheres, are consistent with Emden's theory of the sun. But even if no stress is put upon this interpretation they merit attention on account of the agreement between the four series of observations. For those given under 3 a considerable amount of confirmation is found in work by other investigators. Evidence with regard to the conclusions under 1 and 2 cannot be got from other work owing to the hitherto employed method of observation together with the tacit assumptions made in the reductions.

Cambridge:
PRINTED BY JOHN CLAY, M.A.
AT THE UNIVERSITY PRESS

STELLINGEN

(Revisie)

I

De formule $v = (a - b \sin^2 \Phi) \cos \Phi$ voor de omwentelingssnelheid op de zon drukt slechts uit het over een geruim tijdsverloop en over de vier quadranten van den zonnerand gemiddelde van den toestand.

II

In Juni 1911 was op de zon de verdeeling der omwentelingssnelheden sterk asymmetrisch ten opzichte van den zonne-equator. Het mag aangenomen worden dat een zoodanige asymmetrie eerder den normalen toestand voorstelt.

III

Op hetzelfde tijdstip was de verdeeling daarentegen symmetrisch ten opzichte van de zonne-as; ook dit is waarschijnlijk meesttijds geldig.

IV

De theorie van EMDEN sluit zich, in de toepassing op het omwentelings-vraagstuk, van alle zonnetheorieën het beste bij de waarnemingen aan.

V

Er zijn gronden om aan te nemen dat de zonne-as periodieke schommelingen om een gemiddelden stand uitvoert.

VI

De absorptielijnen in het zonnespectrum hebben hunnen oorsprong des te dieper binnen de zon naarmate zij van kortere golflengte zijn.

VII

De waarnemingen hebben tot nog toe weinig feiten aan het licht gebracht die numeriek ter bevestiging van de zonnetheorieën van JULIUS kunnen dienen.

VIII

In de evolutie van ons zonnestelsel heeft deeling een belangrijkere rol gespeeld dan „capture."

IX

Het bestaan van de twee klassen der zoogenaamde reuzesterren en der dwergsterren kan als vastgesteld worden beschouwd.

X

Er is een belangrijke systematieke fout in de rechte klimmingen van de fundamenteele sterrencatalogi.

XI

Lijnenreeksen in spectra worden het beste verklaard door de theorie van BOHR.

XII

De ontvanger in een telephoon (zwakstroom-installatie) kan vervangen worden door een rechtstreeks ingeschakelden dunnen platinadraad (z.g. thermo-telephoon van GWODZ en DE LANGE). De voortreffelijke geluidswedergave van dezen ontvanger kan niet door eenvoudige temperatuurwisselingen verklaard worden.

XIII

Ten onrechte elimineert ABENDANON alle tangentieele drukking bij zijne theorie over het ontstaan der plooiingen in den aardkorst.

XIV

De symbolische logica vormt den grondslag van alle wiskunde.

XV

De tegenstrijdigheid tusschen logica en ervaring wat betreft het begrip continuiteit kan alleen verdwijnen met behulp eener mystieke natuurbeschouwing zooals die van BERGSON.

XVI

Het is wenschelijk dat in Nederland een internationaal embryologisch instituut worde gesticht.

STELLINGEN

I

De formule $v = (a - b \sin^2 \phi) \cos \phi$ voor de lineaire omwentelingssnelheid op de zon drukt niet meer dan eene benadering van de werkelijkheid uit, gemiddeld over een geruim tijdsverloop en over de vier quadranten der zonnerand.

II

In Juni 1911 was op de zon de verdeeling der omwentelingssnelheden sterk asymmetrisch ten opzichte van de zonne-equator. Het mag aangenomen worden dat een zoodanige asymmetrie eerder de normale toestand voorstelt.

III

Op hetzelfde tijdstip was de verdeeling wel symmetrisch ten opzichte van de zonne-as; ook dit is waarschijnlijk over het algemeen geldig.

IV

De theorie van Emden sluit zich, in de toepassing op het rotatie-vraagstuk, van alle zonnetheorieën het beste bij de waarnemingen aan.

V

Er zijn gronden om aan te nemen dat de zonne-as periodieke schommelingen om een gemiddelde stand uitvoert.

VI

De absorptielijnen in het zonnespectrum hebben hunne oorsprong des te dieper binnen de zon naarmate zij van kortere golflengte zijn.

VII

De waarnemingen hebben tot nog toe weinig feiten aan het licht gebracht die numeriek ter bevestiging van de theorieën van Julius kunnen dienen.

VIII

In de evolutie van ons zonnestelsel heeft deeling een belangrijkere rol gespeeld dan „capture."

IX

Het bestaan van de twee klassen der zoogenaamde reuzesterren en der dwergsterren kan als vastgesteld worden beschouwd.

X

Er is een belangrijke periodieke fout in de rechte klimmingen van de fundamenteele sterrencatalogi.

XI

Lijnenserieën in spectra worden het beste verklaard door de quantumtheorie (Bohr).

XII

De symbolische logica vormt de grondslag van alle wiskunde.

XIII

De tegenstrijdigheid tusschen logica en ervaring wat betreft het begrip continuiteit kan alleen verdwijnen met behulp eener mystieke natuurbeschouwing zooals die van Bergson.

XIV

Het is wenschelijk dat in Nederland een internationaal embryologisch instituut worde gesticht.