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DEPARTMENT OF THE INTERIOR

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PUBLICATIONS

OF THE

Dominion Observatory

OTTAWA

OTTO KLOTZ, LL.D., D. Sc., *Director*

Vol. VI

Spectroscopic Investigations of the Sun

PART I

GENERAL OUTLINE OF OBSERVATIONS, INSTRUMENTS, AND
METHODS—SECTIONS 1-4

BY

RALPH E. DELURY, M.A., Ph.D.

OTTAWA

GOVERNMENT PRINTING BUREAU

1922

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GENERAL OUTLINE OF OBSERVATIONS, INSTRUMENTS AND METHODS

SECTION 1—INTRODUCTION.

BY

RALPH E. DELURY

Following the installation of the coelostat and solar spectrograph, preliminary adjustments, tests and observations were made in the autumn of 1908. Later, the spectrograph was dismounted during the course of certain constructions within the main building. In 1909 spectrum observations were resumed under the handicaps of an exceedingly poor grating and of difficulties in having necessary observing conveniences constructed. Some observations of the spectra of sun-spots and of the solar limbs recording the displacements of the spectrum lines due to the Sun's rotation were however made. After delays, better gratings became available in 1910 and 1911 and it was then possible to secure photographs of spectra of fine quality in relatively short times of exposure.

As the determination of the solar rotation had been chosen as the investigation in solar spectroscopy to be immediately attacked, several series of observations were made in 1910, 1911, 1912 and 1913 recording simultaneously spectra from opposite limbs (one strip from one limb between two from the opposite limb). It might be expected that the measurements of the differences of the positions of the spectrum lines in these observations would yield determinations of the speed of the solar rotation at different latitudes of a high degree of accuracy. However, it appeared to the writer desirable to secure along with the photographs of limb spectra,—(a) observations for the investigation of errors of measurement; (b) observations for determining the effects of blending of spectra such as occurs in the case of the overlapping of sky or haze spectrum on the spectrum from a point on the solar disc; and (c) observations of the spectra of the centre of the Sun and of terrestrial comparisons so that any peculiarities or variations observed could be more definitely interpreted. Consequently, observations covering (a) and (b) were made in 1911 and 1912; the apparatus to secure (c) was installed in 1913 and later, making possible also the determination of solar wave-lengths, and as a by-product the measurement of the solar distance by a new method dependent on the eccentricity of the Earth's orbit.

While details of the measured plates will be given later, a brief outline of the spectroscopic observations which have been obtained is desirable here:

Observations of 1908.—Plates, L 1 to L 282, from August 11 to November 30. Over 1000 observations of focal tests, grating tests and some spot spectra,—all of poor quality owing to the grating.

Observations of 1909.—Plates, L 283 to L 419, from February 12 to October 8. Over 600 observations of tests, spots and limbs to record displacements due to the solar rotation,—all of poor quality due to the grating.

Observations of 1910.—Plates, L 420 to L 641, from May 5 to December 25. About 1000 observations of tests and of limb spectra (in blue and yellow, $\lambda 4500$ and $\lambda 5600$) at various latitudes for determining the solar rotation. The spectrum photographs are of good quality owing to the employment of satisfactory gratings.

Observations of 1911.—Plates, L 642 to L 874, from January 4 to October 9. Over 1200 observations of tests and limb spectra, $\lambda 4250$ and $\lambda 5600$, at various latitudes for obtaining measurements of the solar rotation; and also a series of observations recording mechanical displacements of the spectrum lines for the investigation of errors of measurement.

Observations of 1912.—Plates, L 875 to L 974, from January 26 to October 21. About 1500 observations of tests and limb spectra at various latitudes at $\lambda 4250$ and $\lambda 5600$, for measuring the solar rotation; and also a series of photographs of blended spectra of centre and limbs.

Observations of 1913.—Plates, L 975 to L 1185, from January 5 to December 31. About 1500 observations of tests and limb spectra mainly at $\lambda 4250$ and $\lambda 5600$ at various latitudes recording displacements of the spectrum lines caused by the Sun's rotation. The observations up to September (L 1100) recorded the usual three strips of limb spectra; after this time the observations consisted of seven strips of spectra,—two strips from each of the opposite limbs, one strip from the centre of the solar disc and two strips of iodine absorption spectra.

Observations of 1914.—Plates, L 1186 to L 1562, from January 1 to December 23. Nearly 2500 observations, mainly at $\lambda 4250$ and $\lambda 5600$, of centre, limbs (at various latitudes) and iodine absorption spectra, as well as a large series of spectra of sun-spots recording the penumbral displacements ($\lambda 3800$ to $\lambda 6600$).

Observations of 1915.—Plates, L 1563 to L 1859, from January 3 to December 31. About 2000 observations, mainly at $\lambda 4300$, $\lambda 5600$ and $\lambda 5900$, of centre, limb and iodine spectra, and also some spectra of sun-spots.

Observations of 1916.—Plates, L 1860 to L 2209, from January 6 to December 29. About 2400 observations, at $\lambda 4300$, $\lambda 5200$ and $\lambda 5600$ of spectra of centre, midway points and limbs of the solar disc, along with the spectra of iodine and some of electric arcs of iron and other metals.

Observations of 1917.—Plates, L 2210 to L 2429, from January 2 to December 7. About 1100 observations at $\lambda 4300$, $\lambda 5200$ and $\lambda 5600$, of spectra of centre, midway points and limbs, with iodine and electric arcs. In June, with considerable interruption of the observations, a new and very convenient guide-plate was mounted on the front of the spectrograph which made possible the simultaneous photography of nine strips of spectra (from Plate L 2297 on) four of which are limb spectra from the four quadrants, one centre spectrum, two iodine spectra, and two strips of spectra from either midway points on the solar disc or from electric arcs.

Observations of 1918.—Plates, L 2430 to L 2700, from January 3 to December 19. Over 900 observations at $\lambda 3900$, $\lambda 4250$, $\lambda 5200$ and $\lambda 5600$, and other regions of the spectrum, practically all of which include nine strips of limb, centre, midway, iodine and arc spectra.

Observations of 1919.—Plates, L 2701 to L 2896, from January 4 to December 15. About 950 observations mainly at $\lambda 4300$, $\lambda 5200$ and $\lambda 5600$, recording nine strips of limb, centre, midway, iodine and electric arc spectra at the same time.

Observations of 1920.—Plates, L 2897 to L 3225, from January 3 to December 31. About 1500 observations mainly at $\lambda 5200$ and $\lambda 5600$, recording nine strips of spectra as usual.

Observations of 1921.—Plates, L 3226 to L 3489, from January 6 to December 13. Over 1100 observations mainly at $\lambda 3850$ and $\lambda 5600$, recording nine strips of spectra.

Measurements of these observations are far from being completed. However, the three-strip observations of 1911 to 1913 have all been measured on the 300 mm. Toepfer measuring machine, while selected plates from all of the remaining years have been measured in relation to certain problems such as (a) the effect of blended spectrum on the determinations of the solar rotation and the changes of this effect accompanying meteorological variations; (b) the difference in rotation of the north and south solar hemispheres; (c) the differences in wave-length of the spectrum lines from various points on the solar disc which have been explained here by a "pore theory" based in turn on the measures of the penumbral displacements in spots at various positions on the solar disc. Outlines of the results obtained have been published from time to time in various Journals, and references to these will be made in the later reports. Since the various investigations are inter-dependent, it seems advisable to publish the reports of the solar spectroscopic work concurrently under the four headings: Part I, General Outline of Observations, Instruments and Methods; Part II, Solar Rotation; Part III, Sunspots; Part IV, Wave-Lengths. Certain errors of measurement detected by the writer when beginning the work have recently been traced to their instrumental cause and eliminated, so that publication may now proceed with confidence in the accuracy of the measurements.

The writer here wishes to thank the Director, Dr. Otto Klotz, for his kind interest in the work and for his readiness to have every need and facility supplied. He also desires to acknowledge the coöperation of Dr. J. S. Plaskett who supervised the work to 1913. Thanks are due to other members of the staff who at various times assisted in ways which will be indicated, and notably to Mr. John L. O'Connor who has assisted faithfully in all phases of the work of the Solar Physics division since 1919. In the earlier years kind help and encouragement were received from the late Director, Dr. W. F. King.

DOMINION OBSERVATORY,

OTTAWA,

March 15, 1922.

GENERAL OUTLINE OF OBSERVATIONS, INSTRUMENTS AND METHODS**SECTION 2—METEOROLOGICAL CONDITIONS.**

BY

RALPH E. DELURY.

Photographic observations of the spectrum of the Sun should be of the finest quality for the exact measurement of those minute displacements of the spectral lines, a knowledge of which is needed for the solution of solar problems. For making such observations the best meteorological conditions are required. In Ottawa there are each year a considerable number of sufficiently bright days for this purpose though troublesome cirrus haze is frequently present. The possibilities for taking continuous series of observations may be inferred from the following tables of monthly means of Visibility and Cloudiness for the years 1919, 1920 and 1921, from estimations on a scale of 0 to 10 made each morning and afternoon:

VISIBILITY.

—	1919		1920		1921		Means	
	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.
January.....	(6.2)	(6.5)	4.4	4.8	5.2	5.9	5.3	5.7
February.....	4.9	5.8	4.9	5.0	4.9	5.3	4.9	5.4
March.....	4.3	4.5	4.4	5.8	4.8	4.9	4.5	5.0
April.....	5.4	6.3	5.6	5.9	5.7	5.6	5.5	5.9
May.....	5.5	5.6	5.3	5.4	6.3	6.1	5.7	5.7
June.....	4.2	5.6	4.2	4.2	6.3	6.6	4.9	5.4
July.....	4.4	5.0	4.7	5.1	3.1	3.2	4.1	4.5
August.....	4.7	5.2	4.1	5.0	5.7	5.9	4.9	5.4
September.....	3.8	5.2	3.4	4.5	5.4	6.3	4.2	5.3
October.....	4.0	4.5	4.2	4.8	5.2	5.7	4.5	5.0
November.....	3.9	3.9	4.7	4.8	5.9	5.9	4.8	4.9
December.....	4.4	4.9	4.2	4.6	6.7	6.5	5.1	5.3
Means.....	4.6	5.3	4.5	5.0	5.4	5.7	4.9	5.3

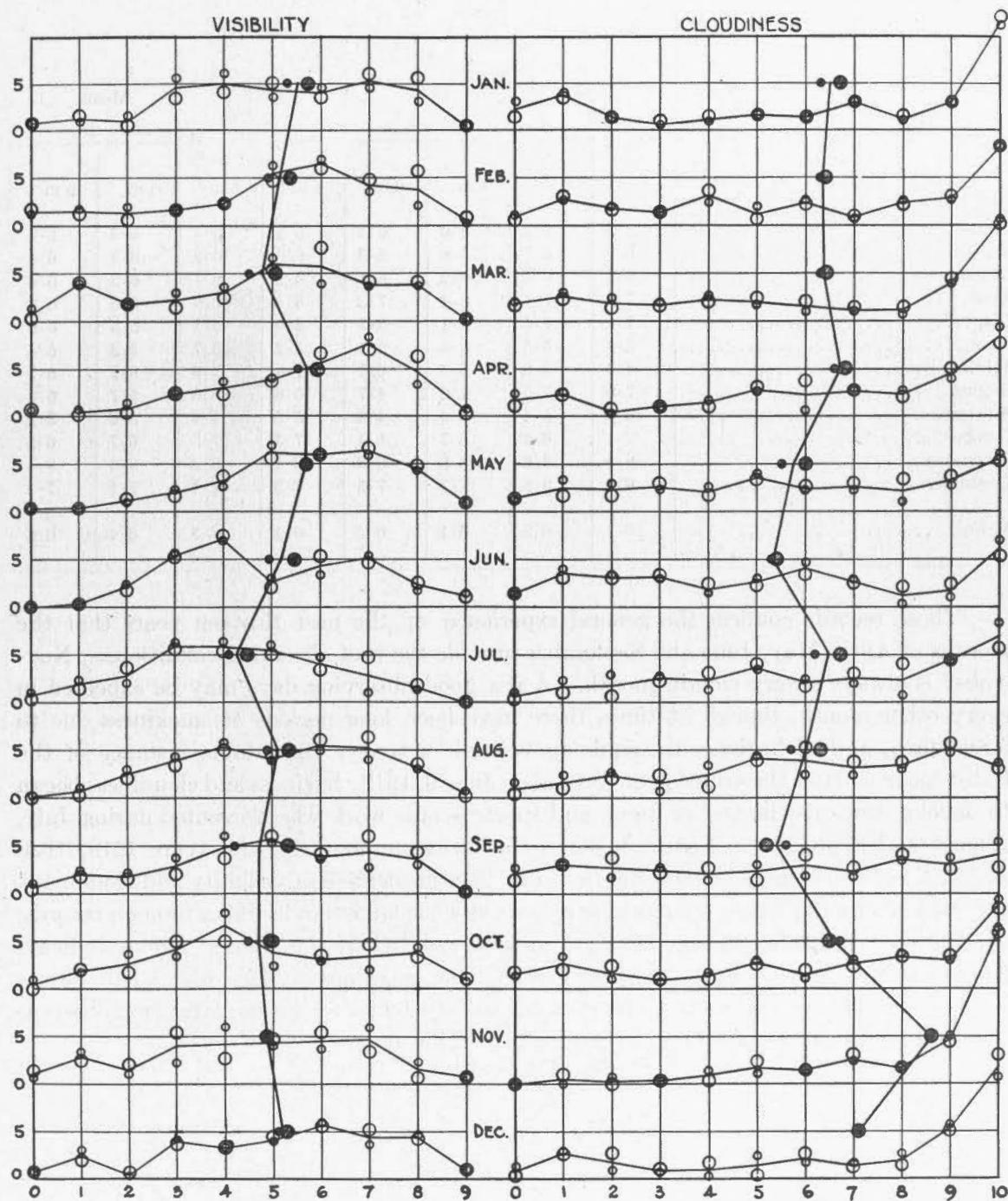


FIGURE 1. GRAPHS OF VISIBILITY AND CLOUDINESS.

The small and large circles, respectively, indicate the monthly means of morning and afternoon observations for 1919, 1920, and 1921, the graphs passing through their means. The vertical graphs show the means in the tables of visibility and cloudiness, while the horizontal graphs show the mean number of occurrences each month of the different degrees of visibility and cloudiness, the scales being 0 to 10; no records of visibility 10 were made.

CLOUDINESS

—	1919		1920		1921		Means	
	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.
January.....	7.3	7.3	6.0	6.3	5.6	6.4	6.3	6.7
February.....	6.8	6.7	5.6	5.9	6.6	6.8	6.3	6.4
March.....	6.3	6.4	6.2	6.5	6.2	6.1	6.3	6.4
April.....	7.4	7.4	6.4	7.2	6.1	5.9	6.6	6.8
May.....	7.4	7.5	5.1	5.5	3.9	5.1	5.5	6.0
June.....	5.4	5.5	5.4	5.1	5.2	5.7	5.3	5.4
July.....	4.7	5.6	6.4	6.7	7.4	7.9	6.2	6.7
August.....	7.0	7.5	4.6	4.7	5.6	6.6	5.7	6.3
September.....	6.0	5.4	5.4	4.8	5.5	5.4	5.6	5.2
October.....	7.1	6.8	5.7	5.4	7.3	7.3	6.7	6.5
November.....	8.9	8.6	8.8	8.3	8.1	8.2	8.6	8.4
December.....	6.4	6.8	7.7	7.5	7.3	7.1	7.1	7.1
Means.....	6.7	6.8	6.1	6.2	6.2	6.5	6.4	6.5

These records confirm the general experience of the past thirteen years that the months of April, May, June and September provide the best observing conditions. November is always a very cloudy month. A few good observing days may be expected in every other month, though at times there have been long periods of smokiness due to forest fires, and of haziness traceable to volcanic activity. A notable instance of the latter occurred after the eruption of Katmai on June 6, 1912: haziness and cloudiness began to develop towards the end of June, and spectroscopic work was prevented during July, August and September. Figure 1 shows the mean number (for the years 1919, 1920 and 1921) of occurrences in each month of the different degrees of visibility and cloudiness, the small circles indicating the morning records and the larger circles the afternoon records, the horizontal graphs passing through their means, while the shaded circles indicate the monthly means of the three years given in the preceding tables,—the small circles indicating as before the morning observations and the larger circles the afternoon observations, the vertical graphs passing through their means.

DOMINION OBSERVATORY,

OTTAWA,

March 15, 1922.



FIGURE 2. COELOSTAT HOUSE.

(Between pages 10 and 11.)

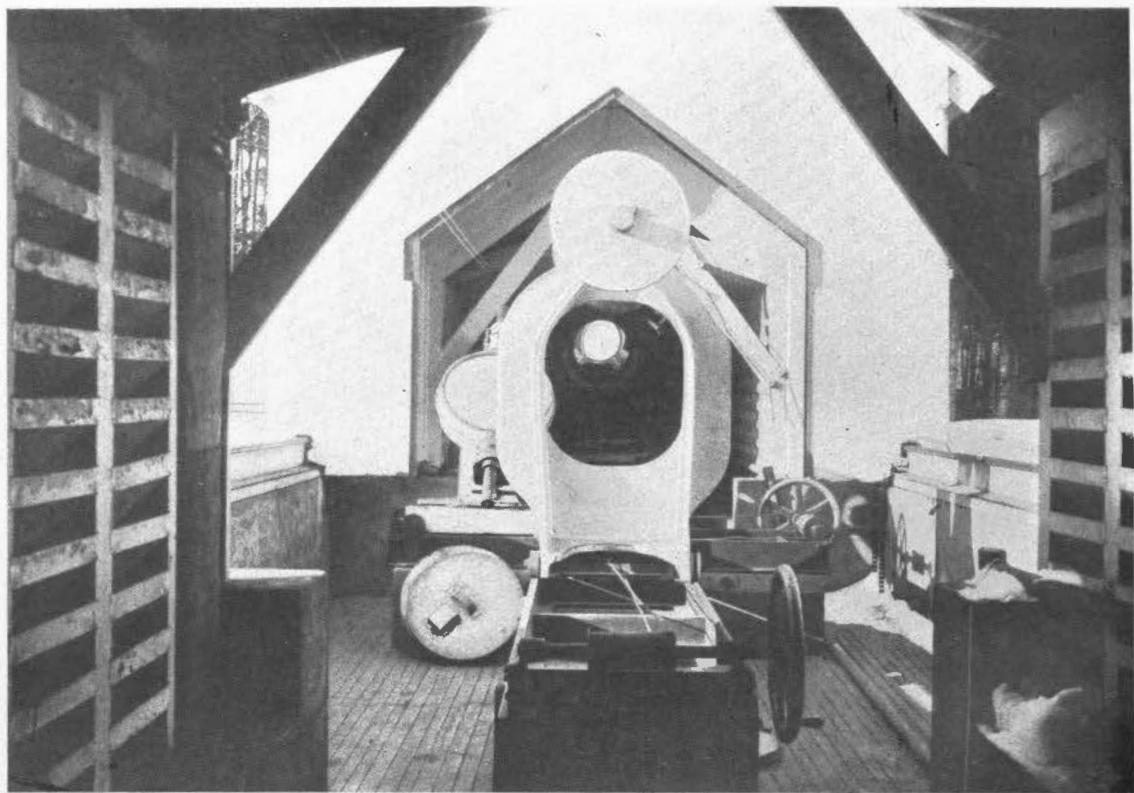


FIGURE 3. VIEW NORTH IN COELOSTAT HOUSE.

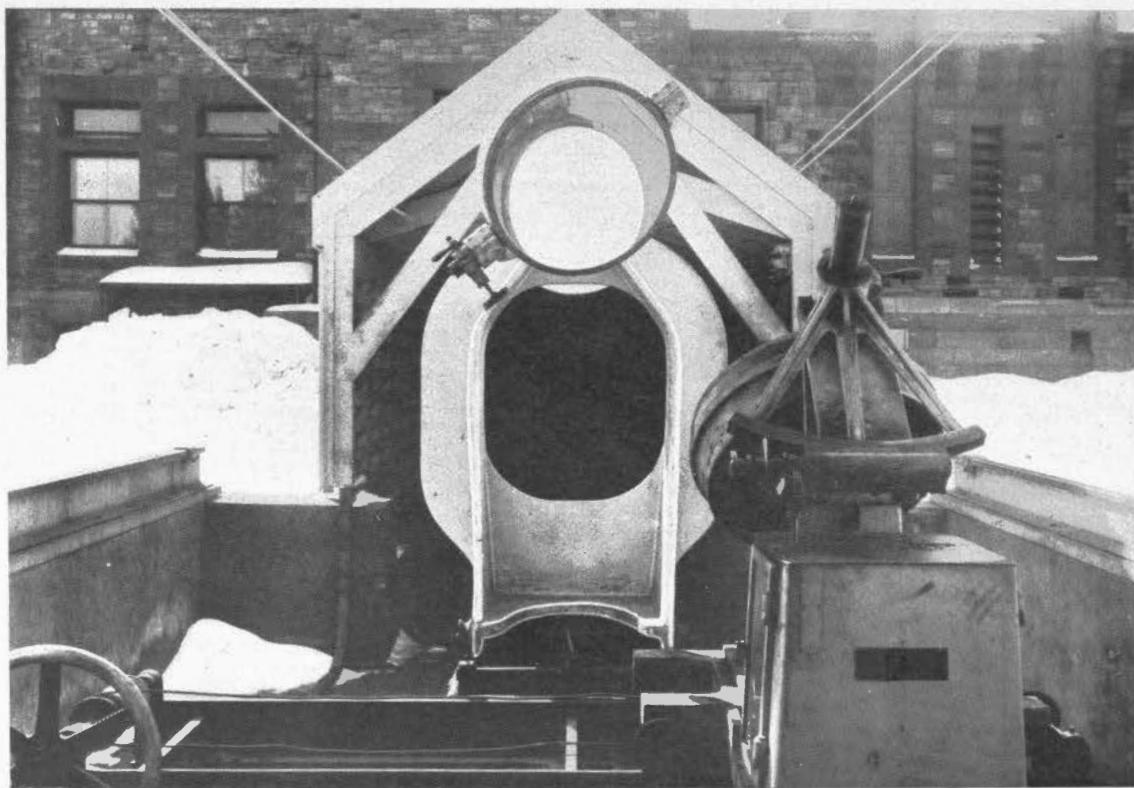


FIGURE 4. VIEW SOUTH IN COELOSTAT HOUSE.

(Between pages 10 and 11.)

GENERAL OUTLINE OF OBSERVATIONS, INSTRUMENTS AND METHODS**SECTION 3—INSTRUMENTS.**

BY

RALPH E. DELURY

Descriptions of the coelostat and solar spectrograph have already been given¹, but it is necessary to describe them here briefly together with a detailed account of the later additions to the solar equipment.

Coelostat.—The coelostat consists of a surface-silvered plane glass mirror 20 in. (51 cm.) in diameter, which is turned on an axis parallel to the Earth's axis of rotation by a weight-driven clock mechanism. This when accurately adjusted by its governor will exactly compensate for the rotation of the Earth and will direct the light from the Sun continuously to a second similar plane mirror whence it proceeds to the third, a concave mirror which reflects the light back nearly normally to a focal plane 80 ft. (24.4 m.) distant. The concave mirror has a clear aperture of 18 in. (46 cm.) and is of the same thickness as the two plane mirrors, namely, 3.5 in. (9 cm.). The three reflectors and the clock-driving mechanism were manufactured by the John A. Brashear Co., and they were first employed in 1905 on the Canadian Eclipse Expedition to Labrador. They were mounted in the coelostat house, in their present position, in 1908.

The coelostat house extends north from the main building of the Observatory, and as the photograph (Fig. 2) shows, it connects through a tunnel under the road with the basement of the building. The roof covering the first and second mirrors is rolled back on steel rails in order to admit sunlight to the mirrors. The sides of the house are louvred to promote circulation of the air, thus preventing the effects of stratification on the solar image. Canvas covers are placed over the louvres in winter to prevent the entry of snow during storms. One of the louvred sections is shown uncovered in the photograph. In the photograph may be seen part of the dome, the anemograph tower and the connection to it of the wireless aerial which extends to the steel pole appearing in the background. The Director's house is seen to the east of the main building. It is evident that at certain hours of the day and seasons of the year the shadows of the dome, the anemograph tower and even the main building will strike the coelostat. The definition of the solar image is at times impaired by the rays passing closely over the building.

Figures 3 and 4 show, respectively, views north and south in the coelostat house, in which the three mirrors, their mountings and the mechanisms for their movements and adjustments are readily seen. The primary mirror and clock-drive may be rolled

¹Report of the Chief Astronomer for 1909, pp. 207-9 and 251-4.

to the west or to the east side of the coelostat house in order to secure more nearly normal incidence and reflection of the sunlight in morning and afternoon respectively. In winter, however, the secondary mirror is so near the primary mirror that its shadow would strike the latter and in consequence the first mirror must be to the west in the afternoon and to the east in the morning. For the highest declination of the Sun in the summer, the truck supporting the second mirror is rolled southward to the limit of the 9-foot rails. The upright casting of the second mirror replaced an earlier less sturdy one. The concave mirror may be moved north and south on rails 18 ft. (5.5 m.) long, so that the solar image may be focussed where desired in the tunnel or farther within the basement of the building. This adjustment is used daily in response to the changing focal length of the mirror system brought about by the heating of the mirrors, an effect which has been lessened by the use of blinds between exposures or by an electric fan driving air against the primary mirror. The tilting of the concave mirror in vertical and horizontal directions is done by slow-motion screws operated by tightly-stretched cords from drums situated near the solar image so that the latter may be placed in any desired position or guided very steadily during observations. The rails on which the truck of the concave mirror rolls are inclined $3^{\circ}.5$ to the horizontal line, the direction in which the beam of light reflected from the concave mirror enters the basement at a suitable elevation.

In the plan, Figure 5, are shown the relative positions of the three mirrors for making observations on winter afternoons. Lines depict the directions of a ray of light from the first to the second and third mirrors and thence to the spectrograph.

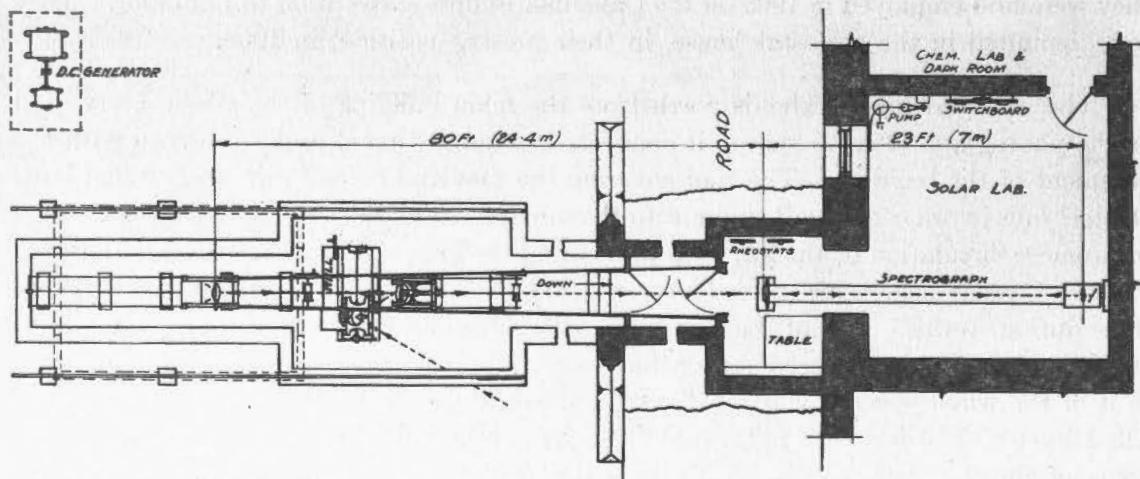


FIGURE 5. PLAN OF COELOSTAT HOUSE AND SOLAR LABORATORY.

Spectrograph.—The head of the spectrograph is mounted on a concrete pier in the tunnel under the roadway, while the foot rests on a pier built against the brick wall on the south side of the solar laboratory. The axis of the spectrograph passes through the centres of the grating, lens, and slit and, projected northward, strikes the centre of the concave mirror in the coelostat house (See Figure 5). This axis is inclined $3^{\circ}.5$ to the floor of the

laboratory. A diagram of a section of the spectrograph is given in Figure 6. In this the positions of the grating, lens, slit and photographic plate may be seen. The grating rests on a plate with a vertical pivot about which it may be turned to bring any desired part of the spectrum to the photographic plate or eye-piece where it may be observed while turning the grating with a handle extended to near the front of the spectrograph. The grating is held against a plate which has a bearing at its centre in another plate, thus providing for adjusting the lines of the grating parallel to the slit by means of screws. Another screw adjusts the tilt of the plate so that the spectrum may be thrown below the slit to a suitable place on the photographic plate. The lens may be moved towards or from the photographic plate for focussing the spectrum sharply. A rectangular mask is placed in front of the lens to mask all but the most satisfactory part of the grating and to keep directly reflected light from striking the photographic plate.

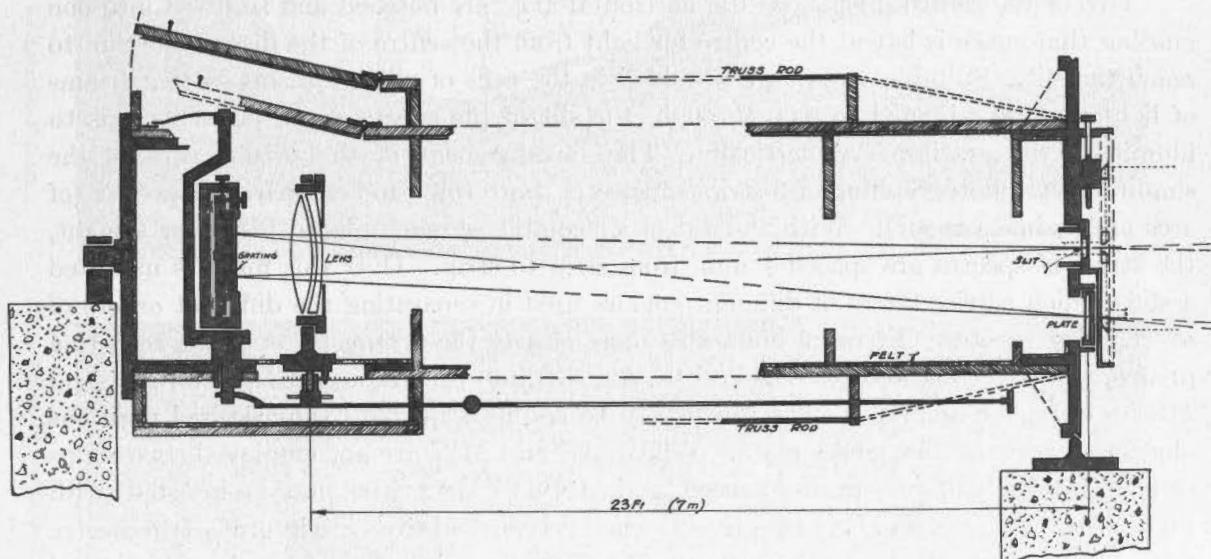


FIGURE 6. DIAGRAM OF SOLAR SPECTROGRAPH.

The head and foot of the spectrograph consist of heavy castings which are connected by a wooden box provided with truss rods to lessen bending. The box is lined with felt to prevent sudden changes of temperature within, while double walls surround the grating end for the same purpose. Ribs and the dark felt hinder scattered light from reaching the sensitive plate. The front casting is of brass, turned with a circular V-bearing which rests on a semicircular cast-iron bearing supported on the pier. The foot casting is of iron with a cylindrical horizontal bearing at its end. The spectrograph may be rotated on its axis as it rests on these bearings. The circular front is geared at the back to receive, and be operated by, a pinion mounted in the casting which supports the head of the spectrograph.

Figure 7 shows the front of the spectrograph resting on its semicircular bearing. In the photograph may be seen: the guide-plate (which was accurately milled from a carefully designed casting) mounted on the centre of the spectrograph; the focal-plane camera above; the plate-holder partially withdrawn from its mounting which may be run up and down in bevelled slides which are also shown; the electric arc mountings hanging from their wires; the iodine-tube hanging from its rubber tubing connection which leads off to the vacuum pump; the graduations to degrees on the circular front with vernier (to lower left) for reading to tenths of a degree; below the vernier, the handle by means of which the spectrograph is rotated; the slides of the guide-plate withdrawn just enough to show the four quadrantal limb prisms and their mountings; and the four prisms mounted over the slit at the centre to receive the light from the four limb prisms and also from the two prisms shown on the horizontal axis midway between limb and centre.

Two of the centre prisms, on the horizontal axis, are notched and so fitted into one another that space is left at the centre for light from the centre of the disc of the Sun to reach the slit. Suitable screws are provided in the cells of all the prisms so that beams of light may be adjusted to pass through the slit of the spectrograph down its axis to illuminate the grating symmetrically. The arrangement of the prisms permits the simultaneous photographing of 9 strips of spectra, both solar and comparison spectra (of arcs and iodine vapour). With the aid of a "comb" or mask placed just over the slit, the strips of spectra are spaced 1 mm. from strip to strip. Over this mask is mounted a slide which carries filters of different colours used in separating the different orders of overlapping spectra. Figure 9 illustrates more clearly the arrangement of the reflecting prisms, which are marked N, E, S and W, for the limb prisms, and ME, MW, MN and MS for intermediate prisms all of which may be readily adjusted to any desired positions along the axes of the guide plate. When ME and MW are not employed, two strips of E and of W limb spectra are secured, and MN and MS prisms may be inserted (with two others above CN and CS respectively) when it is desired to secure intermediate spectra from points on the N-S axis nearer the limbs than the points 3 mm. north and south of the centre supplied by the direct beam (which may be passed through the tube of iodine vapour). The feet of the arc mountings are of the same size and they fit the bevelled slides about the E-W and N-S axes of the guide-plate. It is an easy matter by this arrangement to replace any of the limb or intermediate spectra by those of electric arcs.

For investigating the solar rotation, simultaneous observations of the four quadrantal limb spectra set at any desired angles ($0^\circ + \phi$, $90^\circ + \phi$, $180^\circ + \phi$ and $270^\circ + \phi$), are obtained along with centre and comparison spectra; while for determining wave-lengths of the spectrum lines observations from five points along the projected axis of rotation (N, centre, S and two intermediate points), are desirable along with spectra from metallic arcs and E and W limbs,—or in place of the latter an additional pair of arcs at different pressures from the other pair.

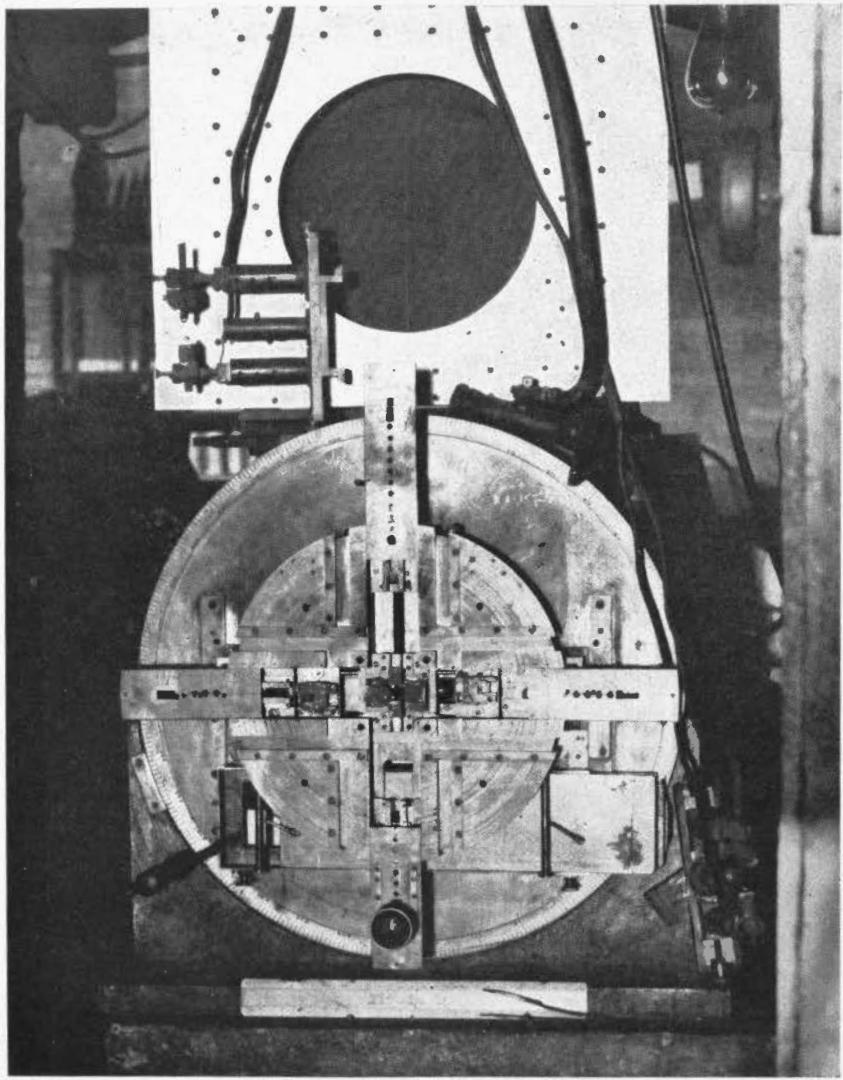


FIGURE 7. HEAD OF SOLAR SPECTROGRAPH SHOWING REFLECTING PRISMS.

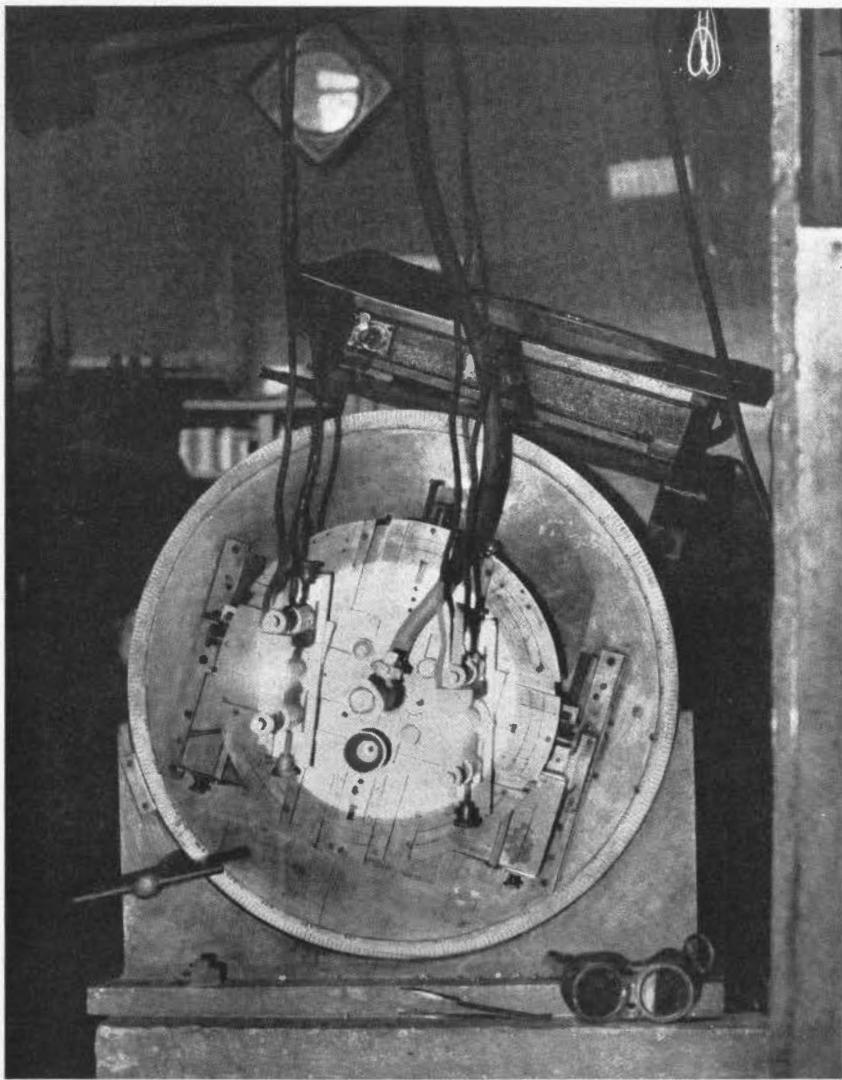


FIGURE 8. HEAD OF SOLAR SPECTROGRAPH SHOWING THE SOLAR IMAGE, IODINE-TUBE,
AND ELECTRIC ARCS, AS EMPLOYED IN OBSERVING.
(Facing page 14.)

Figure 8 shows the front of the spectrograph with the electric arcs and the iodine-tube in position to produce comparison spectra, and with the solar image (23 cm. in diameter) centred as in observations. In making the photograph, the solar image (much weakened) was exposed for a second and the arcs flashed on for a small fraction of a second (in actual observations the arcs are covered by asbestos hoods). They are seen here

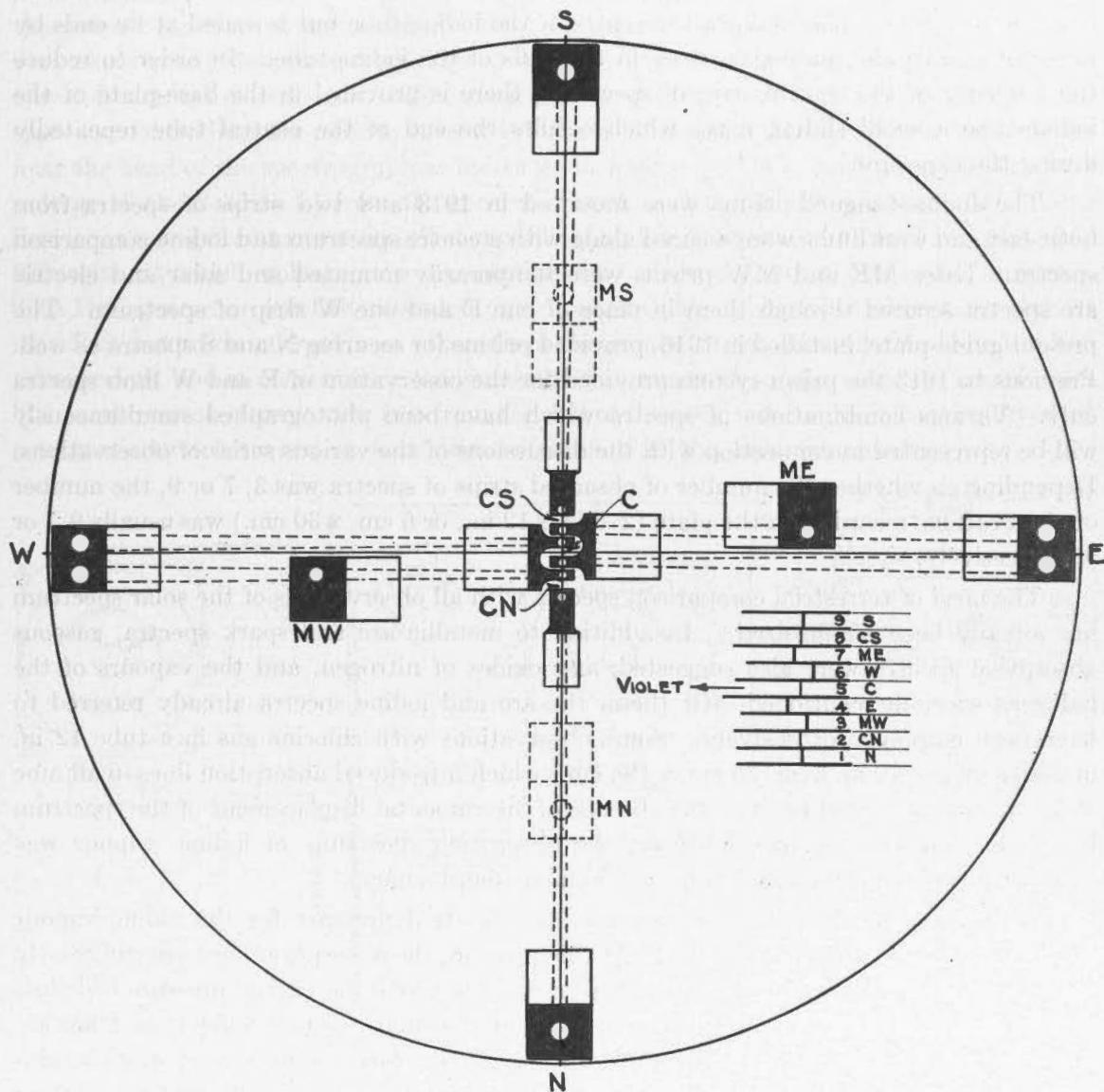


FIGURE 9. DIAGRAM OF THE ARRANGEMENT OF THE REFLECTING PRISMS.

mounted over the ME and MW prisms. The spectrograph is turned slightly from the "horizontal" position but the plates on which the arcs are mounted on insulating blocks are rotated so as to keep the arcs in a vertical position. The tubes about which the arcs are rotated contain the lenses which focus the images of the arcs on the slit of the spectrograph.

By shadows projected by the sunlight from the concave mirror, the positions of the metal electrodes of the arcs may be adjusted so as to use the exact centres of the arcs for the comparison spectra. When desired solar and arc spectra may be photographed overlapping,—a glance at such photographs revealing the relative positions of the spectrum lines of sun and arc. While the iodine-tube introduces absorption in the strips of spectra 3 mm. N. and S. of the central strip, yet the latter is protected from the vapour by means of a fine tube which passes down the centre of the iodine-tube but is sealed at its ends by pressure against the plate-glass discs in the ends of the iodine-tube. In order to reduce the intensity of the central strip of spectrum, there is provided in the base-plate of the iodine-tube a small sliding mask which occults the end of the central tube repeatedly during the exposure.

The double-tongued prisms were mounted in 1913 and two strips of spectra from both east and west limbs were secured along with a centre spectrum and iodine comparison spectra. Later ME and MW prisms were temporarily mounted and solar and electric arc spectra secured through them in place of one E and one W strip of spectrum. The present guide-plate, installed in 1916, provided prisms for securing N and S spectra as well. Previous to 1913 the prism system provided for the observation of E and W limb spectra only. Various combinations of spectra which have been photographed simultaneously will be represented in connection with the discussions of the various series of observations. Depending on whether the number of observed strips of spectra was 3, 7 or 9, the number of observations recorded on the plate (2·5 in. x 12 in., or 6 cm. x 30 cm.) was usually 9, 7 or 5, respectively.

The need of terrestrial comparison spectra with all observations of the solar spectrum has already been emphasized.¹ In addition to metallic arc and spark spectra, gaseous absorption spectra were also suggested, and oxides of nitrogen, and the vapours of the halogens specially mentioned. Of these, the arc and iodine spectra already referred to have been employed extensively. Some observations with chlorine gas in a tube 12 in. in diameter and 72 in. long (30 cm. x 183 cm.) which introduced absorption lines in all nine strips of spectra served to show the absence of instrumental displacement of the spectrum lines. For obvious reasons, however, the absorption spectrum of iodine vapour was adopted as a comparison spectrum for regular employment.

A pressure of 250 mm. has been used as standard pressure for the iodine vapour producing the comparison spectrum. At this pressure the absorption lines are sufficiently sharp for accurate measurement, and this pressure is above the partial pressure of iodine at the temperatures used. A lower pressure than 250 mm. is more difficult to maintain in a tube where metal and glass are used with wax to seal their junctions. A wax containing resin and shellac was found to serve in sealing the tube and to withstand the heating required to vapourize the iodine sufficiently to produce absorption spectra of the required intensity. The pressure was controlled at first with a hand-operated air-pump supplied with a small chamber and barometer tube. A stroke of the pump from time to time kept the pressure close to standard. Later, when arc spectra were used as well, it became more desirable to control the pressure in the iodine-tube automatically. An oil-pump

¹Reports of the Chief Astronomer, 1910, p. 168, and 1911, p. 123.

was installed which is run continuously during the observations, and when the pressure of 250 mm. is reached the rise of the mercury in the lower arm of a manometer makes electrical contact by means of two platinum wires sealed into the manometer and an electro-magnet pulls an iron plate from the end of a leak-tube connected to a tank (used as "ballast") and air leaks in until the pressure of the system rises enough to cause the mercury to drop from contact with the upper platinum wire. The pump again reduces the pressure, and the process is repeated, maintaining the pressure in the iodine-tube, manometer and tank very close to any desired value. The contrivance may also be used for controlling pressures of enclosed electric arcs. This apparatus is illustrated in Figure 10, where the rheostats for controlling the electric currents of the arcs are also shown. These controls are near the head of the spectrograph as indicated in Figure 5. After preliminary work with a voltage of about 85 to 95 from the generator used in charging the batteries of the Time Service, a new generator was installed capable of giving 350 volts, but usually employed at 220 volts, at which voltage it will maintain four electric arcs at five or six amperes. This D.C. generator was first mounted on a concrete pier in the solar laboratory with its axis N-S, but when current was taken from the generator records were made on the N-S seismograph, and in consequence the generator was removed to the concrete transformer hut in the terrace twenty-five feet from the end of the coelostat house, it being started by a magnetic switch turned on from the switchboard in the solar laboratory.

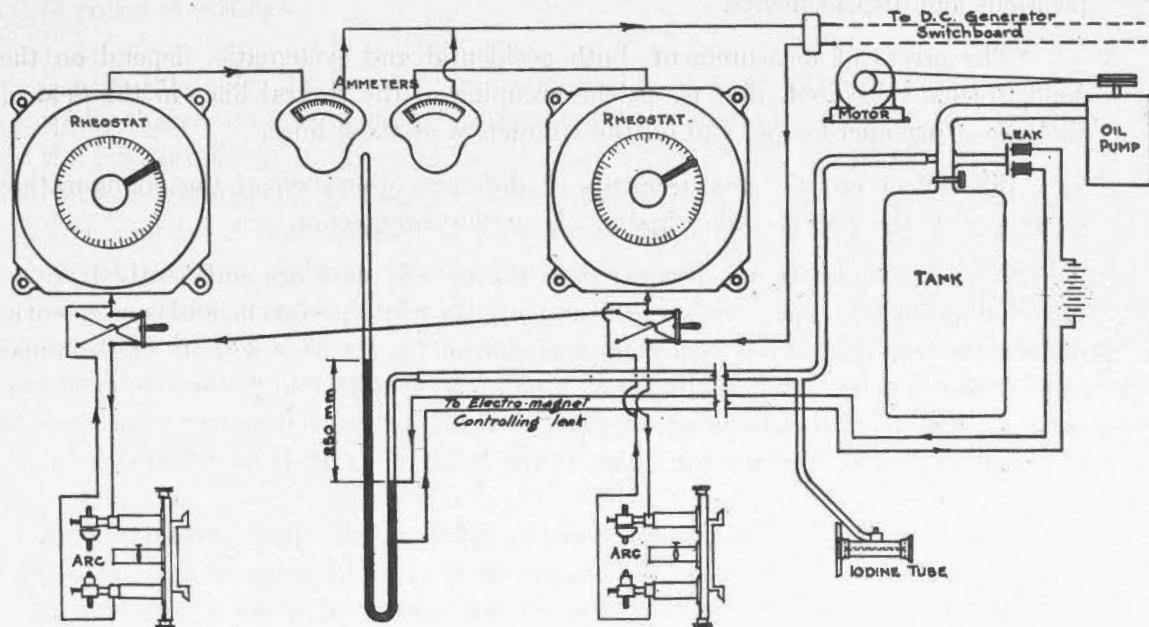


FIGURE 10. DIAGRAM OF THE CONTROLS OF THE PRESSURE IN THE IODINE-TUBE AND OF THE CURRENTS IN THE ELECTRIC ARCS.

The above general descriptions will be supplemented with further details where needed with the discussions of the observations.

DOMINION OBSERVATORY,

OTTAWA,

March 15, 1922.

GENERAL OUTLINE OF OBSERVATIONS, INSTRUMENTS AND METHODS

SECTION 4—ERRORS IN MICROMETER MEASUREMENTS OF SPECTRUM LINES.

BY

RALPH E. DELURY.

Errors in the measurement of spectrum line displacements were investigated by the writer in 1911, and certain peculiar systematic effects were found¹. To reduce the problem to its simplest form the spectrum lines in adjacent strips of solar spectra were displaced relatively by mechanical means, the lines in a central strip being shifted from those in the two strips on either side of it, in imitation of the displacements due to the solar rotation in spectra from the east and west limbs of the Sun. The findings of that investigation may be quoted:—

“There are systematic personal errors in the measurements of spectral line positions and displacements.

“The errors of measurement, both accidental and systematic, depend on the configuration measured, that is, on the grouping of the several lines in the field of the measuring microscope, and on the characters of these lines.

“The effect on the measurements of different observers, of the configuration employed in the present investigation, is in the same sense.

“The systematic errors discovered in the present case are sufficiently large to introduce grave errors into one’s results and into their interpretation, and consequently one’s measurements cannot be accepted as sufficiently accurate without the elimination of these errors. Systematic errors ranging from 0·13 km. per sec. to 0·02 km. per sec. were found in measurements such as made for the determination of the rate of the solar rotation, the value for which at the equator is a little over 2 km. per sec.”

In view of the possibility that the observer’s knowledge of the configuration in the field of the microscope or of the direction and magnitude of the displacements being measured might influence his measures, a slotted mask was employed which could be moved from strip to strip of spectrum allowing only one strip to be visible at a time, and thereby insuring against any effect of prejudice. While this method proved of very great value also in making measurement easier by eliminating extraneous light, yet it did not eliminate the systematic errors, and it seemed probable, therefore, that the errors were in some way

¹Journal of the Royal Astronomical Society of Canada, V. 334-407, 1911; also Report of the Chief Astronomer, 1911, 264-281.

due to the measuring instrument, in which case the disconcerting systematic differences in the measures made by various observers would be explained by their different methods of using the machine. Finally, some series of measures in which the order of measuring the various strips of spectrum was varied, showed a change in certain of the systematic errors, and the idea arose that the settings on a spectrum line varied with the interval of time which elapsed after turning the micrometer screw a few turns in bringing the spectrum line to be measured into the field of the microscope. A few settings made in rapid succession immediately after bringing a spectrum line under the microscope revealed quite definitely the fact that a shifting of the spectrum line relatively to the spider thread of the microscope amounting to about 0.005 mm. took place, and while the settings were being made reached completion within three minutes. This could only be interpreted as due to a movement of the nut (and with it the carriage bearing the photograph of the spectrum) and not of the micrometer screw, for on the Toepfer 300 mm. measuring machine the ball on the end of the screw is kept immovably pressed against the flat thrust plate by a weight supported over a pulley by a cord attached to the nut. The lubricating oil on screw and nut was at once blamed. No doubt, it was worked from the sides of the threads (of screw and of nut) nearest the weight during the rapid turning and then, while the settings were being made, settled to capillary equilibrium, moving the nut away from the weight by a distance of about 0.005 mm. as indicated in the following table of means of series of settings.

In the table, the first column contains the intervals in seconds when settings of the spider thread were made on the image of a sharp spectrum line after it was brought under the microscope by five turns of the micrometer screw into or out of the nut. The other columns contain the averages of ten settings to four places of decimals of a millimeter. The second and third columns and the fourth and fifth contain duplicate sets of pairs of settings made on different days with the customary oil on the screw and loose nut. In these, eighteen settings extending over three minutes were made after turning the screw five turns into the nut (a) in bringing the spectrum line under the microscope; then followed a similar set after five turns of the screw out of the nut (b), and these measurements were alternated until ten series of each were made,—the means of which are given in the table. The sixth and seventh columns contain means of similar sets of readings after the oil had been cleaned from screw and nut by gasoline, while the eighth and ninth columns give similar results with the split nut tightened and the usual lubricating oil employed. In Figure 11 are plotted, to a suitable base, the means of the second and fourth columns in the upper continuous curve; means of the third and fifth columns in the upper broken curve; means of sixth and eighth columns about the lower continuous straight line; while about the lower broken straight line are plotted the means of the seventh and ninth columns. In other words, the upper pair of curves show the error due to the capillary action of oil in a loose nut after turning the screw into and out of the nut, while the lower lines show this effect removed by using no oil, or by using oil in a tightened nut, the two latter being averaged as they both showed the absence of the capillary effect.

Sec.	Oil in loose nut		Oil in loose nut		No oil in loose nut		Oil in tight nut	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
5.....	.0119	.0114	.0137	.0117	.0138	.0129	.0094	.0088
15.....	.0103	.0092	.0120	.0110	.0136	.0124	.0083	.0094
25.....	.0093	.0070	.0109	.0104	.0129	.0125	.0090	.0081
35.....	.0078	.0065	.0102	.0093	.0135	.0124	.0088	.0088
45.....	.0076	.0063	.0092	.0091	.0130	.0129	.0101	.0086
55.....	.0067	.0055	.0087	.0088	.0136	.0127	.0090	.0089
65.....	.0059	.0059	.0095	.0089	.0124	.0131	.0090	.0094
75.....	.0059	.0051	.0096	.0096	.0119	.0129	.0096	.0084
85.....	.0056	.0056	.0091	.0083	.0128	.0135	.0094	.0096
95.....	.0055	.0059	.0095	.0092	.0129	.0131	.0090	.0076
105.....	.0056	.0053	.0084	.0091	.0127	.0125	.0087	.0090
115.....	.0060	.0049	.0086	.0096	.0137	.0125	.0088	.0084
125.....	.0063	.0061	.0095	.0088	.0134	.0120	.0084	.0082
135.....	.0055	.0064	.0087	.0096	.0122	.0129	.0081	.0084
145.....	.0059	.0062	.0086	.0095	.0126	.0122	.0086	.0086
155.....	.0055	.0052	.0092	.0086	.0125	.0126	.0090	.0079
165.....	.0059	.0058	.0090	.0082	.0130	.0123	.0090	.0090
175.....	.0053	.0056	.0090	.0086	.0126	.0117	.0089	.0090

The effects of the capillary behaviour of the oil depend on the quality or freshness of the oil, the temperature, the cleanliness of the screw and nut and the looseness of the nut on the screw. The errors introduced into measurements are dependent on the speed of the measurements and the order in measuring the various strips of spectrum. The errors therefore vary from time to time and are different for various observers. Such effects are undoubtedly present in all past measurements made here with the Toepfer machine, and as the effects are of varying degree careful inspection will be necessary to eliminate any errors that may have been introduced by this peculiar effect.

It is impossible to state to what extent such an effect may have been present in the measurements at other observatories, but probably it plays some part in differences found in the measurements of the same spectrum lines on the same plates by different observers, with the same measuring machine or employing different machines. If the effect is present in a measuring machine it is almost certain to introduce serious errors in measurements made with the plate in only one position, both in comparing the positions of spectrum lines in adjacent strips and also in comparing results from lines of different character if varying times are required in the measurement of lines of different intensities or widths. Even the means of measurements made of spectrum plates with "violet left" and "violet right" will not necessarily be correct, since the rate at which capillary equilibrium is reached in the oil is dependent on whether the lines are approached by screwing the micrometer into the nut or out of it (See the difference between the continuous line and the broken line in the upper part of Figure 11).

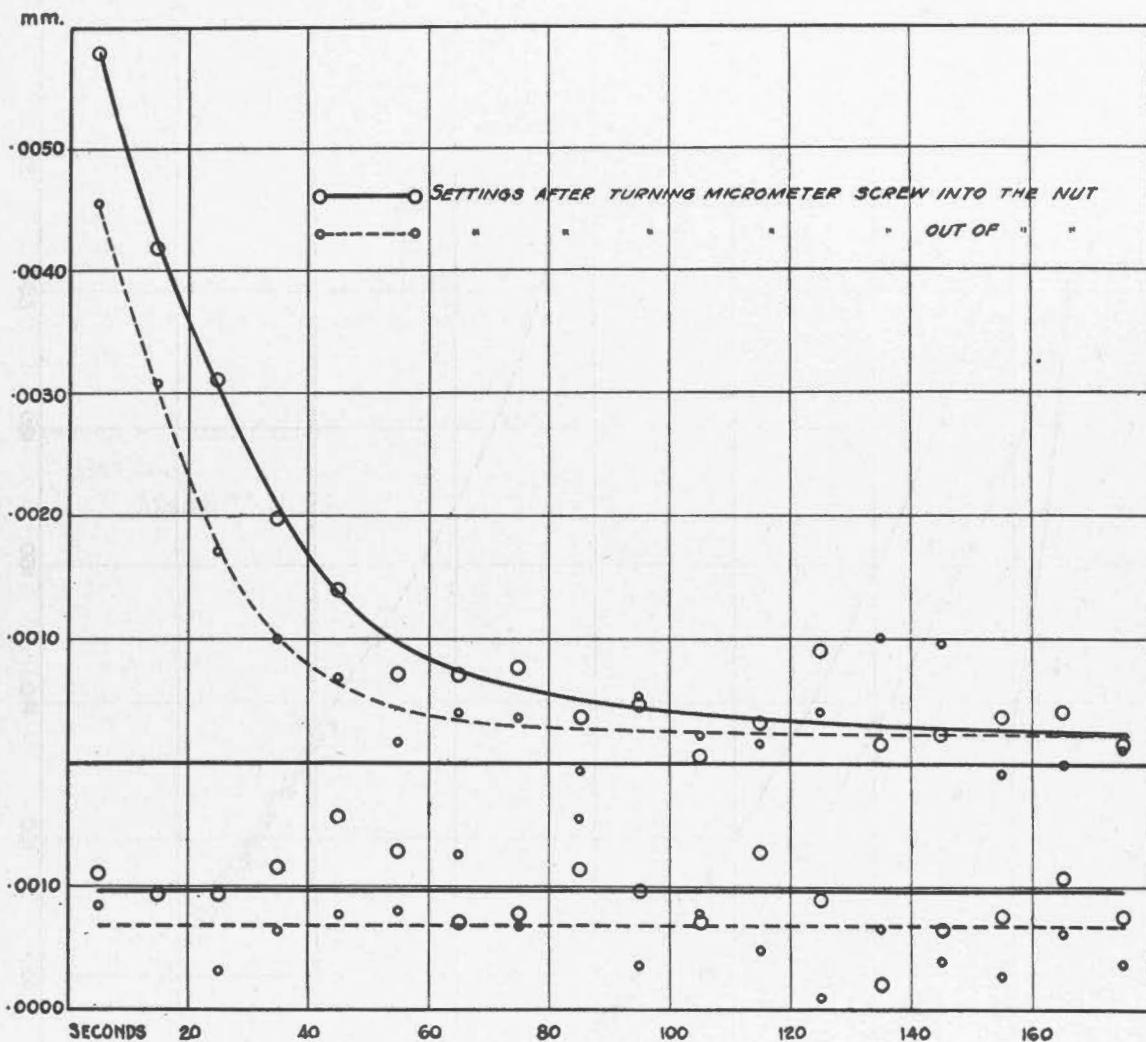


FIGURE 11. GRAPHS ILLUSTRATING THE EFFECTS ON MICROMETER READINGS OF OIL IN A LOOSE NUT (UPPER CURVES), AND THE REMOVAL OF THE EFFECTS (LOWER CURVES).

While the long series of settings was being made it was noticed that all readings were gradually increasing, the whole increase amounting to about 0.005 mm. in 80 minutes. This was attributed to the local heating by the electric bulb used in lighting the negatives for measurement. The measuring machine is in a steel case with glass door, and the light from the powerful bulb is reflected from the back up through the photograph and the microscope. An increase of six or eight degrees centigrade takes place during a morning's measuring. The local heating of the back of the large casting of the machine causes it to expand and press away the thrust plate from the end of the screw thus necessitating progressive turning of the latter into the nut to keep the spectrum line under the microscope. The extent of this error is shown in Figure 12 together with graphs of other readings made with a glass screen between the light and the machine. The glass screen

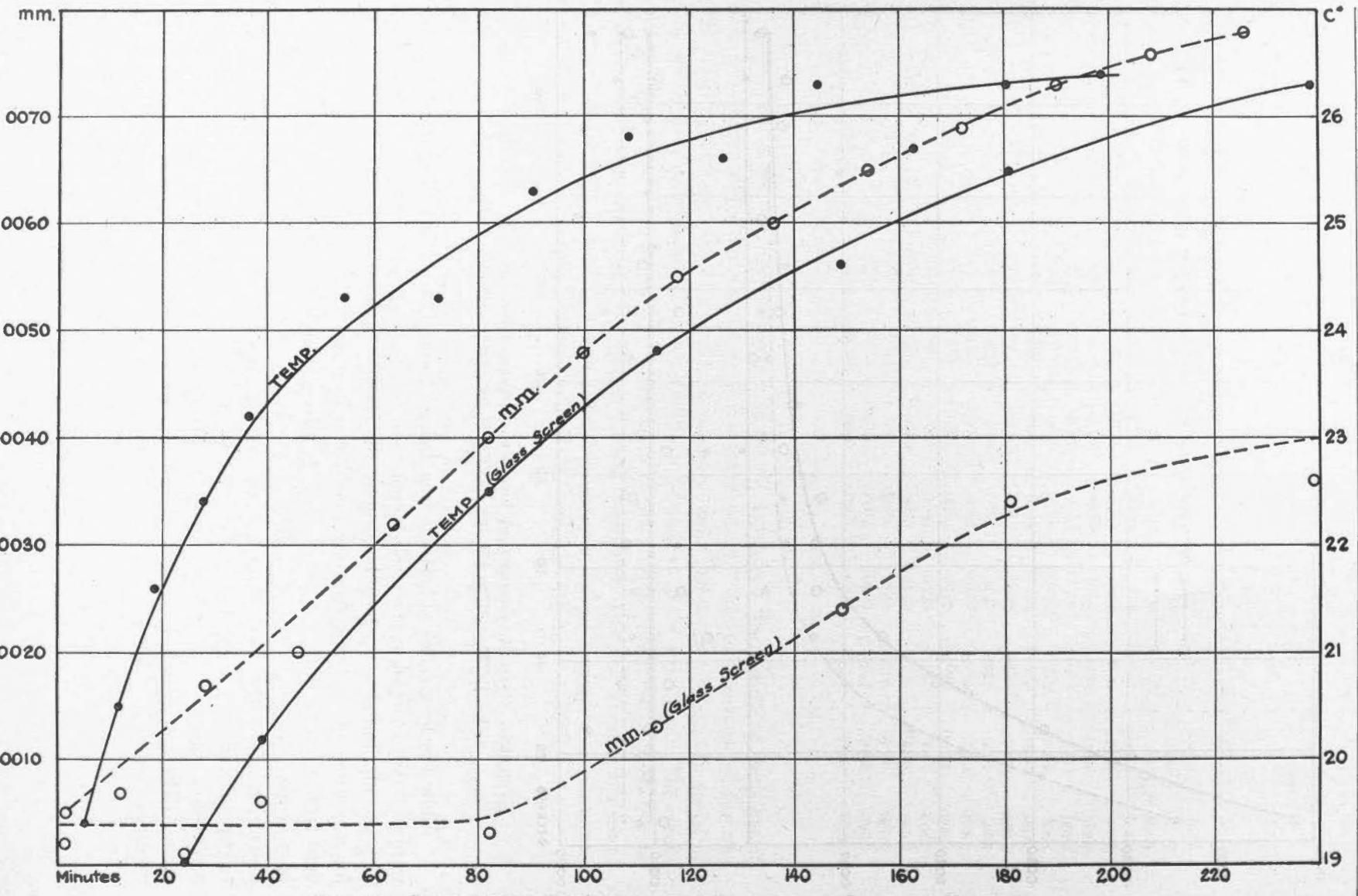


FIGURE 12. GRAPHS SHOWING EFFECTS OF CHANGE OF TEMPERATURE ON READINGS OF MICROMETER.

lessens the change considerably, so that no error need be feared in the measurements of any spectrum line in several strips of spectrum; but for the measurements of many lines along a strip of spectrum the variations due to temperature would have to be considered in fine wave-length determinations.

The part played by the oil error in the various series of measurements which have been made here during the past thirteen years will be discussed when the results of each series are presented; a considerable number of repeated measurements will have to be made in each series to ensure the elimination of any such errors which may have been present.

DOMINION OBSERVATORY,

OTTAWA,

March 15, 1922.

DEPARTMENT OF THE INTERIOR
CANADA

HON. CHARLES STEWART, *Minister*

W. W. CORY, C.M.G., *Deputy Minister*

PUBLICATIONS

OF THE

Dominion Observatory
OTTAWA

OTTO KLOTZ, LL.D., D. Sc., *Director*

Vol. VI

Spectroscopic Investigations of the Sun

PART I

GENERAL OUTLINE OF OBSERVATIONS, INSTRUMENTS, AND
METHODS—SECTION 5

BY

RALPH E. DELURY, M.A., Ph.D.

OTTAWA
F. A. CLAND
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
1924

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GENERAL OUTLINE OF OBSERVATIONS, INSTRUMENTS AND METHODS

SECTION 5—THE DOUBLE SPECTROCOMPARATOR.

BY

RALPH E. DELURY

A measuring instrument has been recently completed in the machine-shop of the Observatory, in accordance with suggestions made a few years ago¹ of using two microscopes and a semi-transparent plane reflector so arranged that images of two photographic plates are produced in each of two focal planes where they can be measured or compared, overlapping or side by side. The machine is intended primarily for measuring the negatives of solar spectra with positive copies of them, or with one another, but it is also adapted for measuring single plates in the usual way.

General Description.—The optical parts are arranged in the simple symmetrical plan indicated in Figure 13. The plates, P,P , which are to be compared are illuminated by

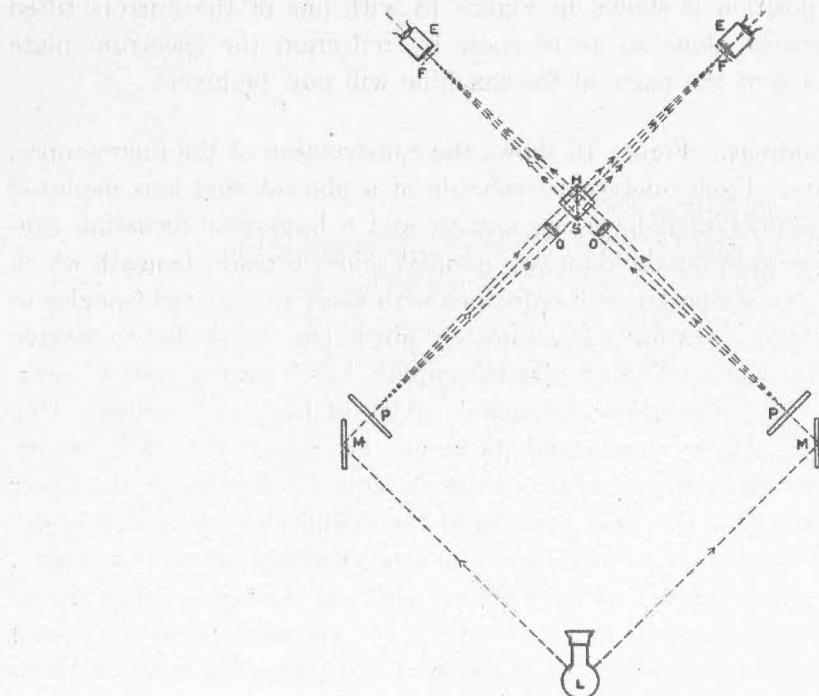


Figure 13.—Plan of Optical Parts.

light from L , reflected by mirrors, M,M . Images of P,P , are focussed by lenses, O,O , in focal planes, F,F , where they may be observed through eye-pieces, E,E . The half-silvered surface, HS , lying between two cemented prisms, divides the light from both lenses so that images of both plates are produced in both focal planes.

¹Astrophysical Journal, Vol. XLVI, 219–225, 1917.

The plates are held in adjustable frames mounted on carriages which are driven by micrometer screws passing through split nuts on their under sides. The carriages travel on ball and roller bearings along surfaces ground parallel to the direction of the micrometer screws on the heavy base of the instrument. The planes of the plates are inclined 90° to one another and 45° to the horizontal plane.

The microscopes are mounted with their axes intersecting at 90° , and each at 90° to one of the plates. They are supported in a heavy casting which may be moved on a bevelled slide on the base in a direction parallel to the axes of the micrometer screws. The instrument may be rotated on a pivot on the surface of a specially constructed table having two openings for admitting light to the plates. The measuring machine, rotated from its normal position, is pictured in Figure 14, showing its parts arranged in accordance with the plan of Figure 13. The plates may be seen held in their adjustable frames on carriages resting on the base; mirrors, pivoted on the sides of the base, reflect light to the plates from the incandescent bulb shown beneath the table; the intersecting microscopes with their focussing lenses and eye-pieces are seen mounted on their heavy stand, the half-silvered surface being placed at their intersection in a vertical plane. The instrument in its normal position is shown in Figure 15 with one of the mirrors tilted down from its regular vertical plane so as to show by reflection the spectrum plate mounted above. The details of the parts of the machine will now be given.

Micropscopes and Mountings.—Figure 16 shows the construction of the microscopes, mountings and attachments. Each microscope consists of a photo-visual lens mounted in a brass tube with rack and pinion focussing device, and a large field-focussing eye-piece mounted over an adjustable ring holding two parallel spider threads, beneath which lies the focal plane mask. To support the microscopes with their axes at right-angles to one another, a cylindrical bronze casting was accurately machined and drilled to receive four stout tubes normal to its axis. The circular cover-plate has been removed to show this microscope block set within the upper octagonal cavity of the main casting. One of the four tubes from which the eye-piece and its mount have been removed may be seen projecting to the upper right in the figure, while the inner extremity of the lower right lens-tube may be seen within the axial opening of the cylindrical microscope block. Into this axial opening, the case containing the Lummer-Brodhun prism fits snugly. This case and its double prism appears at the extreme right of the figure. The prisms forming the glass cube with its diagonal half-silvered surface are held in place by hard rubber stops. The case may be rotated about the axis of the central microscope block to adjust this semi-transparent surface to a vertical position. The block itself is mounted within the large casting on a horizontal axis at right-angles to its own axis, and a pair of opposing screws provide adjustment which places the half-silvered surface directly above the intersection of the planes of the photographic plates to be measured. Another pair of adjusting screws makes possible the placing of the plane containing the axes of the microscopes exactly at right-angles to the direction of the axes of the micrometer screws.

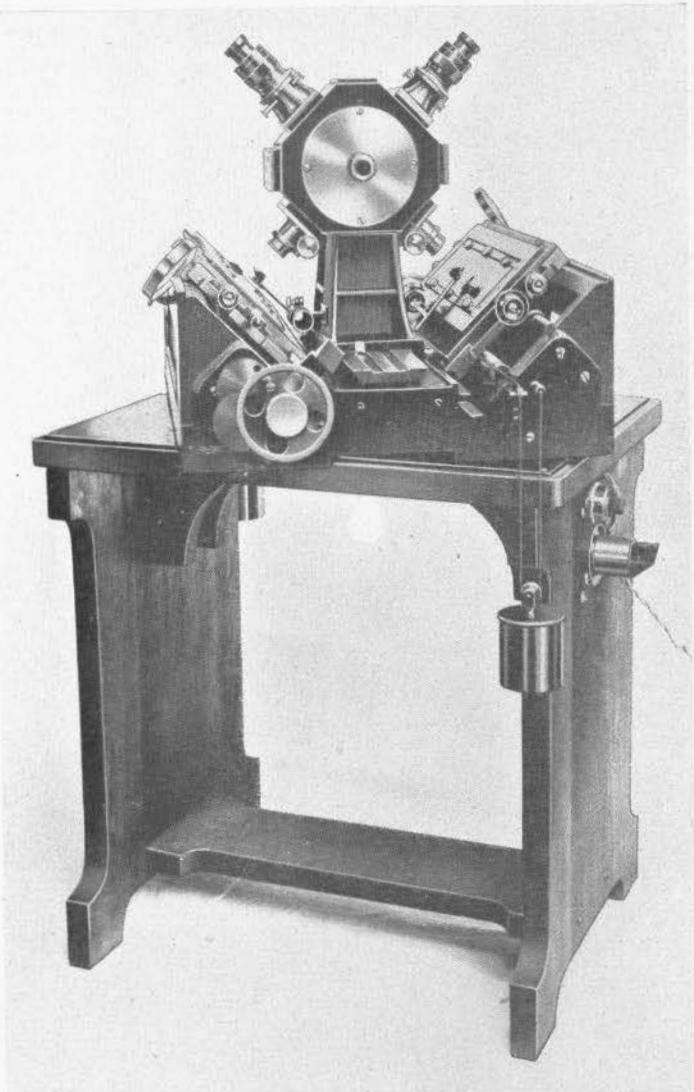


Figure 14.—Spectrocomparator Rotated on its Table to Show Arrangement of Optical Parts.

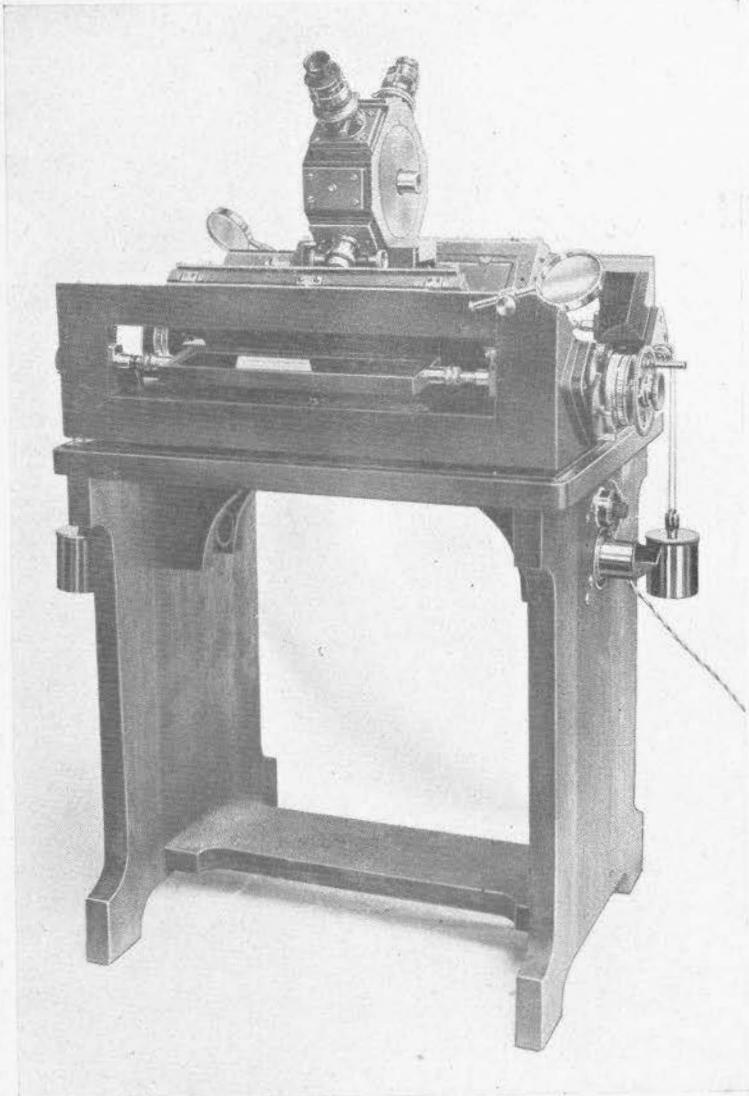


Figure 15.—Spectrocomparator in Normal Position.

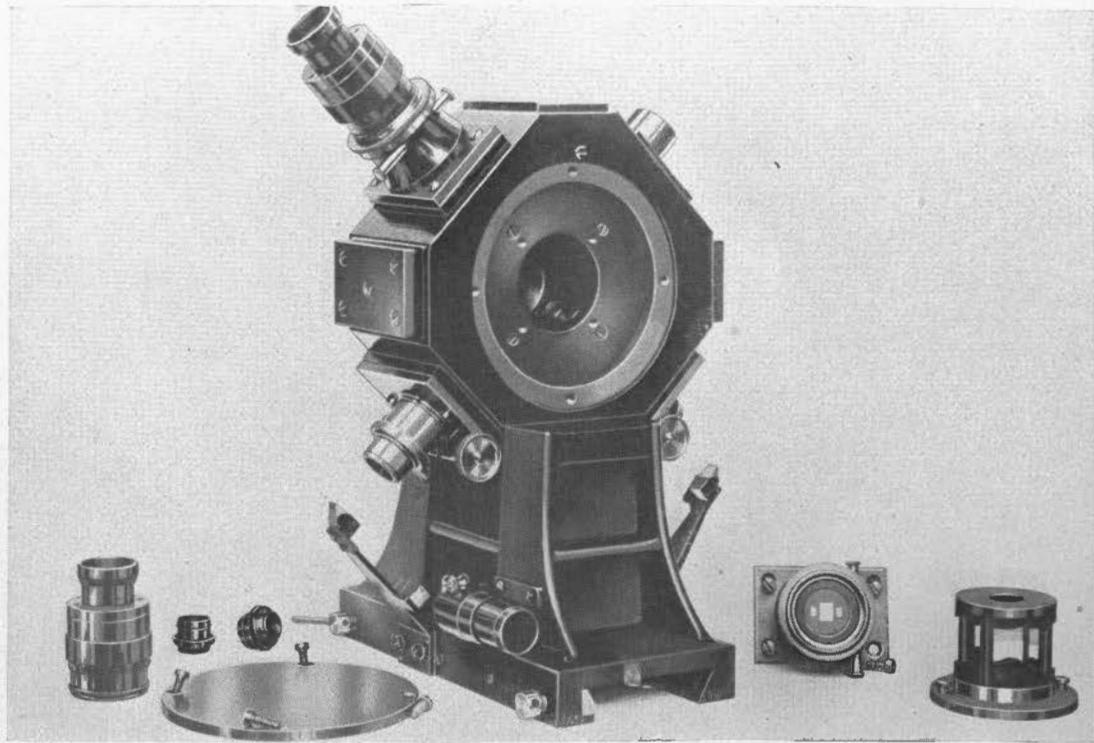


Figure 16.—Microscopes, Mountings and Attachments.

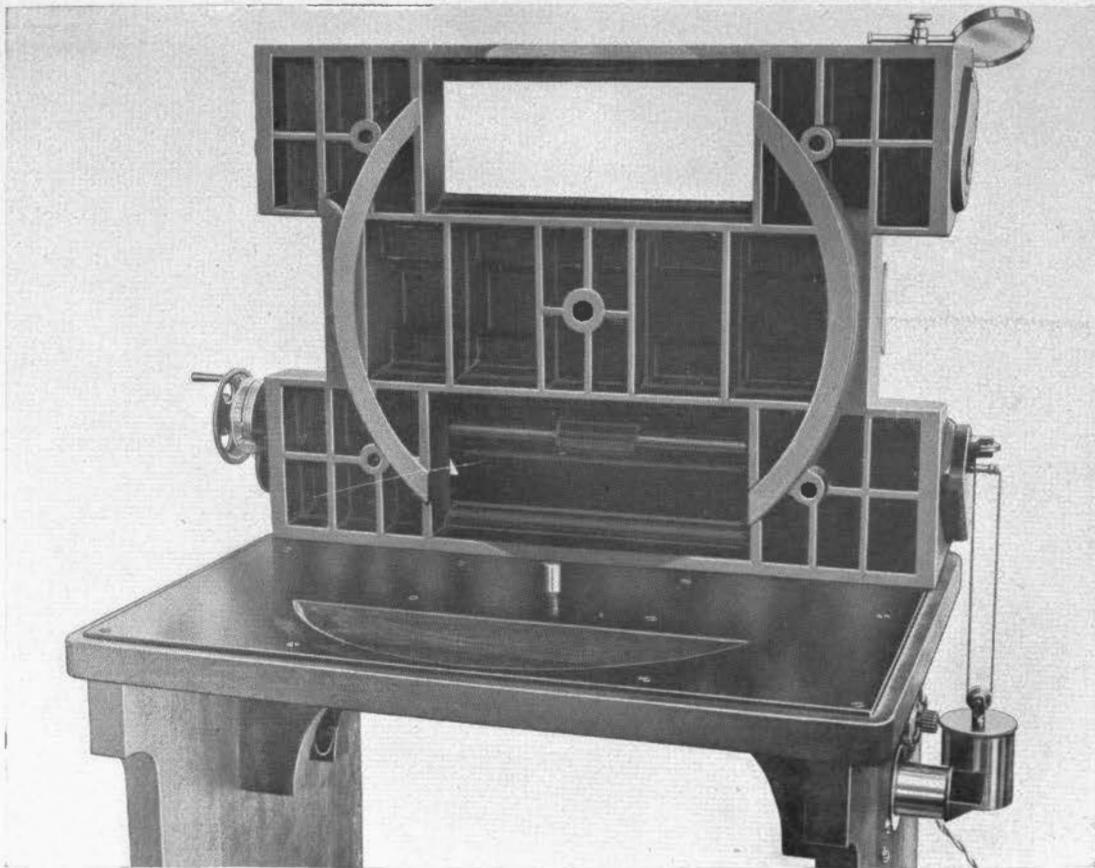


Figure 17.—Base of Spectrocomparator Tilted Up on its Side on the Table.

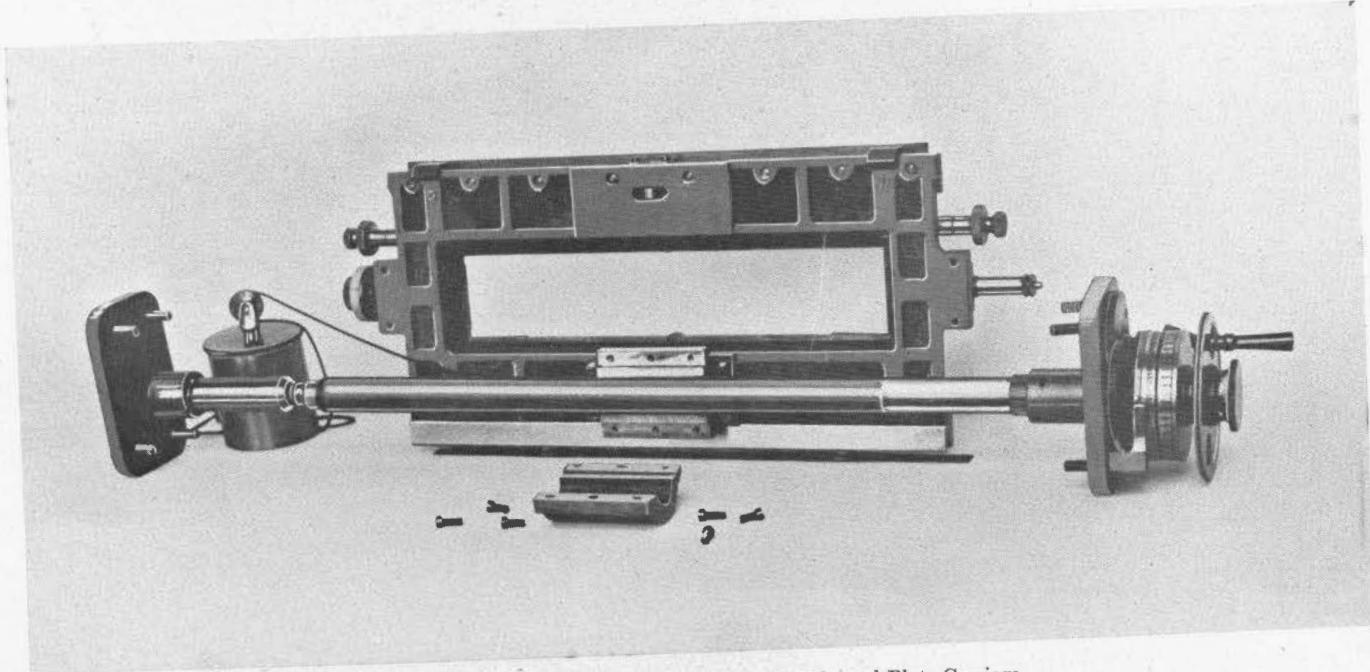
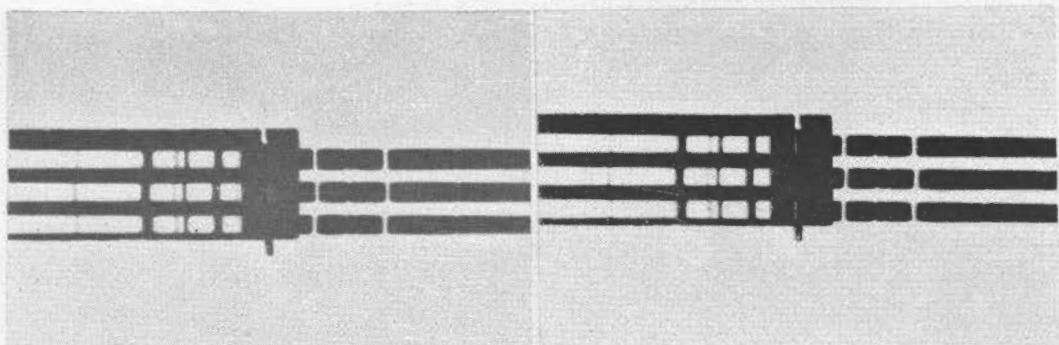
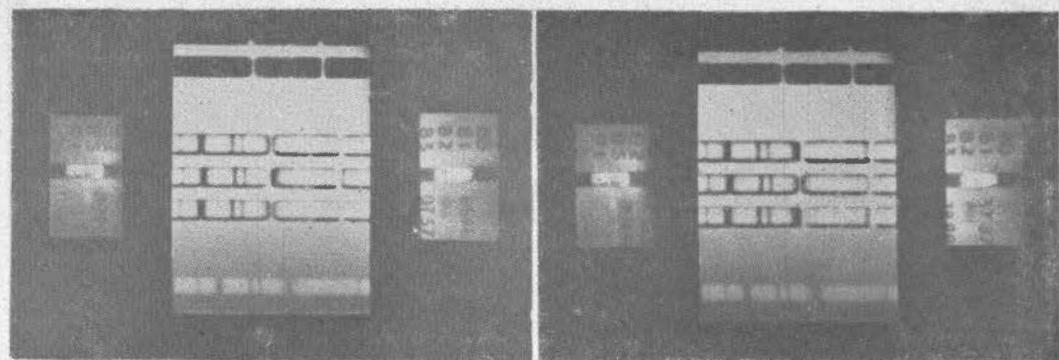


Figure 18.—Micrometer Screw, Nut, Drum, Weight and Plate-Carriage.



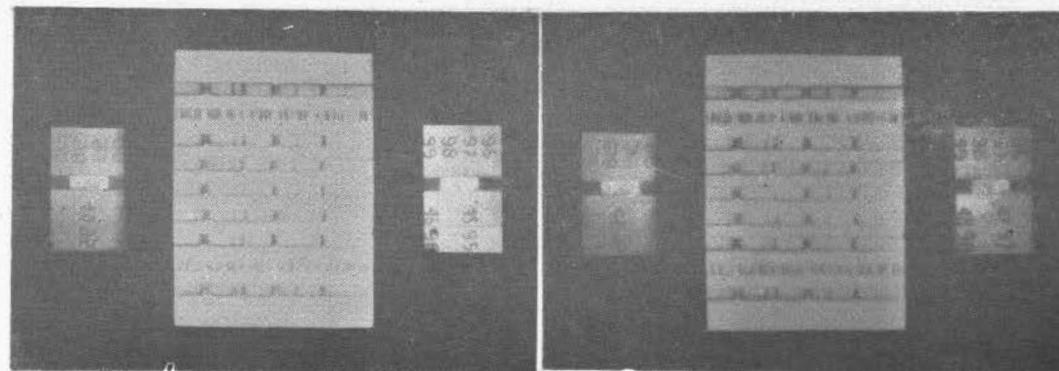
1

2



3

4



5

6

Figure 19.—Three Pairs of Settings of Spectrum Lines Photographed in Focal Plane.

The bottom of the microscope stand is machined to fit the bevelled slide of the base of the instrument providing movement of the microscopes parallel to the micrometer screws, and it may be clamped in any position by a gib apparent in the figure. On both sides of the base of the microscope casting are mounted a pair of prisms and a photo-visual lens in focussing tube, for directing images of the micrometer drums up through the microscopes to their focal planes. The images are placed in rectangular openings on either side of the central opening in each focal plane mask. The mask with three openings is seen in the eye-piece mount, the second object from the right in the figure.

Base and Table.—The base is shown in Figure 17 tilted up on its side on the table. The iron casting is 19 in. by 26 in. by 8 in. (48 cm. by 65 cm. by 20 cm.), and is honey-combed beneath to give strength without excessive weight. A ground circular strip on the bottom of the casting serves as a bearing for rotating the machine on the steel plate top of the table, a pivot in the latter entering a hole in the centre of the casting. One of the openings in the top of the table for admitting light up through the machine may be seen in the figure. The corresponding rectangular opening may be seen in the casting. These openings are closed by plates of glass to prevent the heating of the machine by the lamp. Through the lower opening in the figure the plate-carriage with nut and screw is visible, while the carriage and micrometer have been removed from the other side of the base. Figures 14 and 15 show the upper part of the base with the plate-carriages resting on its ground surfaces. The lower angular grooves on which the carriages roll on ball bearings are ground in bars of steel screwed firmly to the casting of the base. All of these surfaces were machined and ground at one setting on a large shaper², to ensure parallelism to the axes of the micrometer screws. The latter are supported by end-thrust and cylindrical bearings, in castings screwed to raised platforms on the ends of the base, ground at right-angles to the longitudinal ground surfaces of the large casting. Figure 14 also shows the bevelled plate on which the microscope stand slides. Millimeter scales on this plate indicate the position of the stand.

The construction of the table is evident. The electric switch for the light is seen on one end of the table, and reflectors mounted on the ends of tubes direct beams of light to illuminate the micrometer drums.

Micrometers.—The micrometer screws were made from rods of steel turned to one inch in diameter. They are of half-millimeter pitch and have 775 threads, so that with the bronze nuts 75 mm. long (150 threads), the screws can be used to measure the 300 mm. solar spectrum negatives over their whole length. The screws and nuts were cut on a lathe provided with a specially made screw of 4 mm. pitch. In Figure 18 a micrometer screw is shown in the base of the split nut which is screwed to a platform on the under side of the plate-carriage, the cap of the nut having been removed. In this figure are also seen the cylindrical and end-thrust bearings of the screw, with the weight which keeps

²Our thanks are due to Dr. A. H. W. Cleave for permitting the machining of the large castings in the machine-shop of the Royal Mint, Ottawa.

the polished ball-bearing in the end of the screw held tightly against the polished end-thrust plate, as shown. The drums were graduated into 500 divisions with a double set of numbers reading to hundredths of a millimeter, the divisions being half a millimeter apart, making it possible to read to thousandths of a millimeter and to estimate to ten-thousandths. Another drum on the other side of the pointer is divided into 200 divisions, equivalent to 100 mm. of travel of the plate-carriage. The micrometer drums are clamped firmly to the ends of the screws by the disc handles and clamping-caps. A gear of 46 teeth, 1·000 in. in diameter on the micrometer screw, drives a second gear of 115 teeth, external diameter 2·4375 in.; a pinion on the latter of 15 teeth, 0·3542 in. in diameter, drives a third gear of 120 teeth, 2·5417 in. external diameter, on which is another pinion of 15 teeth which meshes with an idler, also of 15 teeth, and this in turn drives a fourth gear of 150 teeth, 3·1667 in. in diameter which is screwed concentrically on the back of the millimeter drum. Thus, two revolutions forward of the micrometer produce a forward motion of the millimeter drum of two divisions, equivalent to an advance of one millimeter of the plate-carriage.

Plate Frames and Carriages.—The holders for the plates are made from quarter-inch brass with openings to receive the 2·5 in. by 12 in. solar spectrum plates. The plate is held in the holder by stiff springs, one near each corner, pressing it upwards against half-turn thumb-screw stops. The centre of the plate is raised to the same plane by a clamp-screw at each edge. These six screw stops always bring the film of the plate to the same plane, irrespective of the thickness or curvature of the glass. A rocking adjustment is provided for the holder for the purpose of setting the strips of spectra parallel to the micrometer screw. To do this the ends of the holder are bevelled to turn in a quarter-inch brass frame, bevelled to a diameter of 13 inches; a screw and spring playing on the upper edge, one against each end of the holder, control this adjustment. The brass frame is screwed to a three-sixteenth in. brass plate bevelled at its ends to run by rack and pinion on a nine-sixteenth inch cast-iron bed bevelled at right-angles to the direction of the micrometer screws so that any desired observation on the photographic plate may be placed directly under the microscope. The bed, in turn, is bevelled on its under side to run on the upper surface of the carriage and an adjustment made by opposing spring and screw with graduated drum is thus provided in a direction parallel to that of the micrometers. These parts may be seen in Figures 14 and 15.

The under surface of the carriage is shown in Figure 18. On its lower edge is seen a steel bar which provides on the upper surface of the carriage a bevelled slide to receive the corresponding bevelled edge of the bed mentioned above, and also provides on its lower edge a ground right-angled groove to receive the ball bearings (two in number and one-half in. in diameter) on which the carriage rolls. These bearings are seen, spaced by a strip of brass, directly below the grooved steel bar. When the carriage is in its normal position, inclined 45° to the horizon, the ball bearings rest in a corresponding half-inch right-angled groove ground in a steel bar screwed to the base of the instrument. A roller bearing, seen inset, supports the upper part of the carriage on a ground surface of the base.

Devices for Reading Micrometer Drums.—Between the millimeter and micrometer drums, screwed to the end of the bearing in which the micrometer screw turns, and about which the millimeter drum revolves, is a three-pronged plate with indicator marks for reading the drums at three different places,—the first is seen in a direction parallel to the face of the photographic plate and read through a reading glass held by its handle in an adjusting screw clamp; the second in a direction normal to the plane of the photographic plate is read by the aid of the three reflecting prisms and the photo-visual lens which produce an image of the pointer and drums in the focal plane of the microscope itself; while the third, pointing downward, provides for the possibility of photographing the drum readings only. The prisms and lenses which direct the images of the drums to the focal planes of the microscopes, may be seen in their mounts in Figures 14 and 16. The image of the right-hand micrometer drum, operated in making the settings, is seen through the small rectangular opening in the right side of the focal plane mask. The light from this drum passes through two lenses, is reflected four times, and is turned through three right-angles; consequently the drum appears turned through a right angle and not inverted. Light from the left-hand drum passes through a path differing from that of the right-hand drum in having only three reflections, so that this drum appears, turned through a right angle and inverted, in the left-hand opening of the focal plane mask. Actual photographs, taken in the focal plane, and enlarged 3·3 times are reproduced in Figure 19.

It is obvious that with its two focal planes the instrument provides a ready means of recording photographically, not only the readings of the micrometer drums, but also the actual settings of the spectrum lines. Such photographic records would insure not only accurate records of the drum readings, but would make possible the re-examination of questionable settings. By such a method a saving would be effected in the cost of measuring, and possibly also in the cost of publication; and it is likely that, freed from the necessity of recording his measures, an observer would make more accurate settings.

With the instalment of a photographic recorder in view, a bearing has been left on the axis of the microscope block on which may be mounted an arm carrying the photographic film so that it may be rotated readily from one focal plane to the other. This bearing may be seen projecting through the centre of a cover plate on the microscope stand in Figures 14 and 15.

Methods of Measuring.—The instrument may be used for measuring spectrograms in several ways:—

(a). *By setting a spider thread on images of spectrum lines.* With spider threads in both focal planes it is possible to measure negatives in the ordinary way with either eyepiece and with either micrometer,—in fact, with suitable masks inserted in the focal planes, two observers could measure plates at the same time.

(b) *By aligning the images of the spectrum lines of two plates.* The spaces between the strips of spectrum of the usual solar spectrogram are wide enough to permit the placing of the spectrum strips in the image of one plate between those in the image of another.

(c). *By overlapping the images of two negatives.* This method is surprisingly satisfactory when a coloured filter is used with one of the negatives to gain contrast.

(d). *By overlapping the images of a positive and a negative.* A wide range of intensity and width of spectrum lines may be measured by employing coloured filters or by adjusting the intensities of the beams of light illuminating the plates.

When a plate has been measured say in the "violet right" position it need not be reversed in its frame and again adjusted parallel to the direction of the micrometer screws for the measurement "violet left," since it may be measured through the opposite eye-piece, either by rotating the instrument on its table, or by the observer changing his position to the opposite side of the table.

When two plates are measured with one another to determine certain displacements of the spectrum lines, employing either of the methods (b), (c), (d), the percentage of error can be halved by reversing the plates end for end thus doubling the displacements to be measured, as suggested by Evershed. Settings by this method are shown in Figure 19. The upper pair show settings on the outside and central strips of spectra, with parts of the negative and of the positive alone, intensities of plates being evenly matched. The second pair show similar settings with complete overlapping of positive and negative, and the drum readings as well, intensities of plates being unmatched to show overlapping lines. The third pair of settings are of positive and negative, unmatched as to intensity, not reversed end for end,—in one setting the iodine comparison spectra are overlapped and in the other the solar spectra,—a method which is useful in determining variations in the position of the solar lines with reference to a fixed standard spectrum.

Two of the microscope lenses are of such a focal length (3.25 in.) that they are normally placed midway (optically) between the plates and their images, thus providing images of the same scales as the plates. With such an arrangement it is possible to measure a series of negatives in comparison with a standard negative or positive, without consideration of any small change in scale that may occur in the series of plates, for by altering slightly the position of one of the lenses it is possible to bring the images of the plate to the same scale as that of the standard without seriously altering the position of its focal plane from that of the standard. This is apparent from the following table of conjugate foci, their ratios and differences, for a lens of focal length 3.25 in.

F'	F''	$\frac{F''}{F'}$	$F'+F''-13$
6.8 in.	6.227 in.	0.916	0.027 in.
6.7	6.310	0.942	0.010
6.6	6.403	0.955	0.003
6.5	6.5	1.000	0.000
6.4	6.603	1.032	0.003
6.3	6.713	1.066	0.013
6.2	6.831	1.102	0.031

Direct comparison of the probable errors of settings on spectrum lines by spider thread and by overlapping of positive and negative images was made in four series of sixteen rapid settings on the same spectrum lines by each method. As seen from the following table of probable errors computed for these series, the error of setting is about the same for the two methods. Systematic differences between the two methods may result from the fact that many spectrum lines are unsymmetrical, but in general the two methods have yielded nearly similar results for the average solar lines. The very weakest lines that can be measured by spider line bisections are not measured easily by the positive and negative method; but on the other hand strong broad spectrum lines are much more readily measured by the latter than by the former method. By the use of coloured filters and by variation of the relative intensity of illumination of positive and negative, the range of spectrum lines that may be measured can be greatly extended. The two methods of using the instrument will serve to supplement and check one another.

		Weak line		Strong line		Means
		DeLury	O'Connor	DeLury	O'Connor	
Spider Thread Settings	p.e. single setting.....	.0019mm.	.0020mm.	.0012 mm.	.0011 mm.	.0016 mm.
	p.e. mean of sixteen.....	.0005	.0005	.0003	.0003	.0004
Positive and Negative	p.e. single setting.....	.0020	.0022	.0012	.0014	.0017
	p.e. mean of sixteen.....	.0005	.0005	.0003	.0004	.0004

Two other uses of this form of instrument have been suggested in cases where minute variations are looked for,—the first in comparing objects with a standard object, such as screws; the second, in comparing two photographs of the same object or group of objects, such as minute portions of astronomical photographs, or successive aeroplane photographs for determining elevations. In the latter case this form of comparator would be very valuable because of the possibility of changing the scale of one photograph to that of another without altering the focal plane appreciably.

In designing the instrument, the writer found it advantageous to construct a model in wood, and this was done in such a manner as to provide patterns for the various castings required. The scale and system of operation of the 300 mm. Toepfer machine used in the measurements of solar spectra at this observatory, was adhered to as closely as possible. With the exception of the preliminary machining of the large castings the work of constructing the instrument was performed in the machine-shop of the Observatory almost entirely by Mr. L. Christensen to whom the writer wishes to express his thanks.

DOMINION OBSERVATORY,

OTTAWA,

October 1, 1923.

DEPARTMENT OF THE INTERIOR
CANADA

HON. CHARLES STEWART, *Minister.*

W. W. CORY, C.M.G., *Deputy Minister*

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Spectroscopic Investigations of the Sun

PART I

GENERAL OUTLINE OF OBSERVATIONS, INSTRUMENTS, AND
METHODS—SECTION 6

BY

RALPH E. DELURY AND JOHN L. O'CONNOR

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GENERAL OUTLINE OF OBSERVATIONS, INSTRUMENTS AND METHODS

SECTION 6—DIFFERENTIAL EFFECTS IN BLENDED SPECTRA

BY

RALPH E. DELURY AND JOHN L. O'CONNOR.

Observations have been made of definite blendings of spectra to determine the effects on the measurement of spectrum lines¹. A knowledge of this is desirable, not only for solar but for all spectroscopic investigations on account of the impossibility of observing a spectrum free from blending; and indeed it is often desirable to resolve a blended spectrum into its components. This requirement has arisen in our investigations, and especially so in the measurements of a group of six spectrum lines in a great number of observations. Fortunately, these lines are on the plates of the observations cited, and they have been measured doubly by each of the writers.

Observations.—The observations, which were photographic, were made with the 80 ft. (24.4 m.) cœlostat and the 23 ft. (7 m.) solar spectrograph using reflecting prisms by means of which a strip of spectrum from one limb is photographed simultaneously with and between two strips from the diametrically opposite limb. Details of the observations are given in Table I. Plate L854 was taken September 20, 1911; plates L911 to L913 on June 22, 1912; and plates L914 to L917 on June 24, 1912. On the two latter dates the observing conditions were recorded as, "Bright day, steady, with general haze", and "Bright, but steady. Haze over all", respectively. In the first three columns of the table are given, respectively, the number of the plate, the position angles of the limb observations measured in degrees from the equatorial limbs, and the distances of the points of limb observations measured from the centre of the solar disc and expressed as decimals of the radius. The duration of a limb exposure is denoted by l seconds, and blended with the spectra of the limbs in turn was an exposure of c seconds on the spectrum of the centre of the solar disc, the values of l and c being given, for the different exposures on each plate, in columns headed (1) to (9). Values are also given in these columns of R , which denotes the computed ratio of density of the photographic deposit produced by the continuous spectrum of a limb to the total photographic density produced by the blended continuous spectra of limb and centre. From additional exposures of limb and centre, separately, on plates L914 to L917, it was estimated that equal photographic densities resulted from exposures of 50 seconds and 21 seconds on continuous spectra of limb, and centre, respectively, of the solar disc. The brightness of the centre is 1.8 times that of a point 0.97 of the radius from the centre of the solar disc for radiation about $\lambda 5600$, (plates L911 to L917) and 1.6 times that of a point 0.91 from the centre of the disc² (L854). Consequently from Schwarzschild's formula, which is a sufficiently close approximation,

¹Jour. R.A.S.C., Vol. X, 201-219, 1916.

²The Sun, Charles G. Abbot, p. 107..

$50^p = 1.8 \times 21^p$, and hence $p = 0.7$ for the Cramer Iso-Process plates employed. From this it appears that

$$R = \frac{c_1^{0.7}}{(c_1 + c)^{0.7}} = \frac{l^{0.7}}{(l + l_1)^{0.7}}$$

where $1.8c_1^{0.7} = l^{0.7}$, and $l_1^{0.7} = 1.8c^{0.7}$

Fourfold enlargements from narrow strips of the plates including the six spectrum lines measured, are reproduced in Figure 20. The gradual lessening of the displacements of the spectrum lines in the middle strip from those in the strip on either side, in progressing from observations (1) to (9), is noticeable particularly in those plates taken at the lower latitudes where the displacements are greater.

The means of the measurements, "violet right" and "violet left," for each observer are given in the Tables (a, b, c) and (α, β, γ), and means of these again in Tables II and X.

The measurements by each observer, of Plate L854, in Tables II (a) and II (α) and their means in Table II (a, α), show that, for the various degrees of blending of the spectrum of the centre of the solar disc with the spectra of the east and west equatorial limbs, the amount of lessening of the displacement of a line in the limb spectra due to the solar rotation, varies from line to line depending on the intensity, being greater for the weak than for the strong lines. This is more definitely expressed by the means of the weak and of the strong in Tables II (b) and II (β) and their means in II (b, β); and by these values reduced to a unity basis in II (c) and II (γ) and their means in II (c, γ). Similar differential effects of blending are apparent in the measurements of Plates L911 to L917 which have a greater range in the proportions of blending than Plate L854, and which also present results for a considerable range of displacements of the lines in the limb spectra,—namely the rotation displacements for latitudes from 0° to 80° . Means of the measurements of these plates by each observer are given in Tables X (a, b, c) and X (α, β, γ) and means of these means in Table X. These results are in turn reduced to a unity basis in Tables XI (a, b, c) and XI (α, β, γ) and XI, respectively.

It is seen from the means in Table X, that there is for the value $R = 1.00$, a difference in displacement, depending on the intensity of the spectrum line, similar to that found for the various degrees of blending (*i.e.*, for the various values of R). In other words, there appears to be, in the actual measures of the displacements due to solar rotation, a variation with intensity similar to that produced by blended spectra. Since the plates were taken on hazy days, it is possible that the blended spectrum of haze produced some or all of the differential effects in the columns headed $R = 1.00$,—effects similar to those obtained from various series of observations of the solar rotation. By reducing the values for each line to unity (Table XI, column headed $R = 1.00$) this initial effect is eliminated, and it is seen that the differential effect remains. This is more apparent from the charts in Figure 21, the values for strong and weak lines being indicated by large and small circles, respectively, and their means by the black circles.

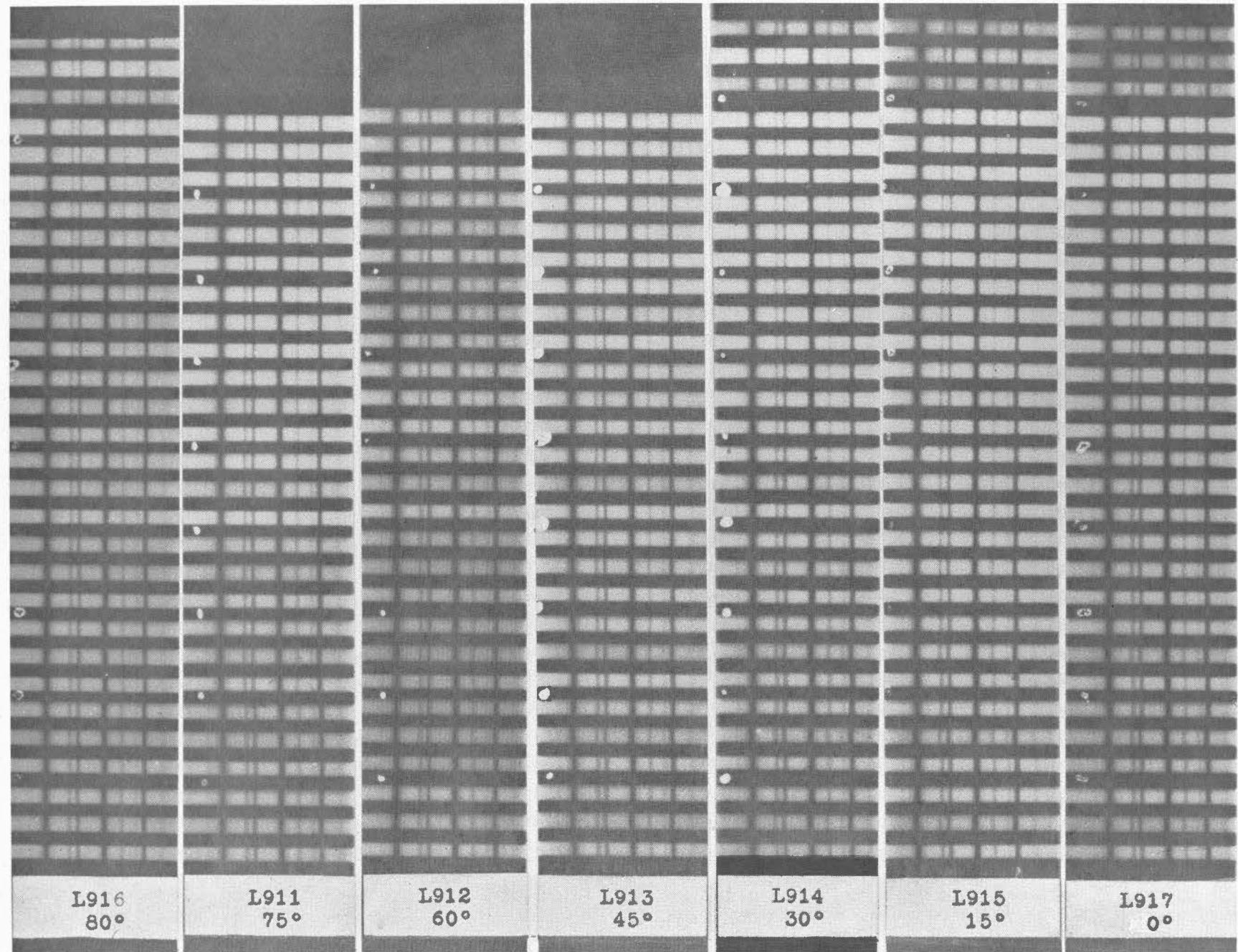


Figure 20—Fourfold Enlargements from the Plates including the six Spectrum Lines measured.

TABLE I.—OBSERVATIONAL DATA.

Plate	Position Angle	Limb Distance	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	
			l	R	l	R	l	R	l	R	l	R
L854.....	0°	0.91	40 0	39 1	38 2	36 4	32 8	28 12				
			R=1.00	0.89	0.83	0.74	0.62	0.54				
L916.....	80°	0.97	50 0	45 3.5	40 7	35 10.5	30 14	25 17.5	23 21	15 24.5	10 28	
			R=1.00	0.89	0.79	0.69	0.60	0.51	0.42	0.33	0.24	
L911.....	75°	0.97	50 0	45 3.5	40 7	35 10.5	30 15.5	25 17.5	23 23.5	15 24.5	10 28	
			R=1.00	0.89	0.79	0.69	0.58	0.51	0.43	0.33	0.24	
L912.....	60°	0.97	50 3.5	50 0	40 7	35 10.5	30 14	20 21	25 17.5	15 24.5	10 28	
			R=0.90	1.00	0.79	0.69	0.60	0.42	0.51	0.33	0.24	
L913.....	45°	0.97	50 0	45 3.5	40 7	35 10.5	30 14	25 17.5	20 21	15 24.5	10 28	
			R=1.00	0.89	0.79	0.69	0.60	0.51	0.42	0.33	0.24	
L914.....	30°	0.97	50 0	45 3.5	40 7	35 10.5	30 14	25 17.5	20 21	15 24.5	10 28	
			R=1.00	0.89	0.79	0.69	0.60	0.51	0.42	0.33	0.24	
L915.....	15°	0.97	50 0	45 3.5	40 7	35 10.5	30 14	25 17.5	20 21	15 24.5	10 28	
			R=1.00	0.89	0.79	0.69	0.60	0.51	0.42	0.33	0.24	
L917.....	0°	0.97	50 0	45 3.5	40 7	35 10.5	30 14	25 17.5	20 21	15 24.5	10 28	
			R=1.00	0.89	0.79	0.69	0.60	0.51	0.42	0.33	0.24	

Note.—The durations in seconds of the exposures to limb and centre spectra are denoted by l and c , respectively. R is the computed ratio of density of the continuous spectrum from the limb exposure to the total density of the exposures of limb and centre.

TABLE II. (a, b, c)

Observation:—L854, (1) to (6). Spectra of solar limbs at 0° , blended with spectrum of centre of solar disc.

Measurement:—By De Lury, 2 settings of spider-thread on each line, each way, plate right and plate left, and means taken.

Computation:—(a) Half-displacements expressed in km:sec. (b) Means of (a) grouped as to intensity. (c) Means of (b) divided by 1.795.

λ	El., I	R = 1.00	0.89	0.83	0.74	0.62	0.54	Means 0.72
(a)								
5,586.991.....	Fe 7	1.530	1.673	1.564	1.565	1.467	0.960	1.446
5,587.800.....	Fe 0	1.922	1.613	1.130	1.467	1.192	0.658	1.212
5,588.084.....	Ni 1	1.986	1.643	1.547	1.641	1.090	0.783	1.341
5,588.985, s.....	Ca 6	1.814	1.545	1.552	1.603	1.179	0.879	1.352
5,589.582.....	Ni 0	1.803	1.650	1.556	1.250	0.992	0.958	1.281
5,590.343, s.....	Ca 3	1.713	1.735	1.564	1.601	1.284	0.954	1.428
Means.....	2.8	1.795	1.643	1.485	1.521	1.201	0.865	1.343
(b)								
3 weak lines.....	0.3	1.904	1.635	1.411	1.453	1.091	0.800	1.278
3 strong lines.....	5.3	1.686	1.651	1.560	1.590	1.310	0.931	1.409
(c)								
3 weak lines.....	0.3	1.06	0.91	0.79	0.81	0.61	0.45	0.71
3 strong lines.....	5.3	0.94	0.92	0.87	0.89	0.73	0.52	0.78
Means.....	2.8	1.00	0.92	0.83	0.85	0.67	0.48	0.75

TABLE II, (α , β , γ)

Observation:—L854, (1) to (6). Spectra of solar limbs at 0° , blended with spectrum of centre of solar disc.

Measurement:—By O'Connor, 2 settings of spider-thread on each line, each way, plate right and plate left, and means taken.

Computation:—(a) Half-displacements expressed in km/sec. (β) Means of (a) grouped as to intensity. (γ) Means of (β) divided by 1.750.

λ	El., I	R =	1.00	.089	0.83	0.74	0.62	0.54	Means 0.72
(a)									
5,586.991.....	Fe 7	1.647	1.630	1.556	1.575	1.365	1.037	1.433	
5,587.800.....	Fe 0	1.809	1.573	1.301	1.522	1.068	0.668	1.226	
5,588.084.....	Ni 1	1.728	1.575	1.499	1.535	1.117	0.883	1.322	
5,588.985, s.....	Ca 6	1.771	1.567	1.515	1.498	1.171	0.958	1.342	
5,589.582.....	Ni 0	1.797	1.675	1.692	1.535	1.135	1.005	1.409	
5,590.343, s.....	Ca 3	1.745	1.660	1.464	1.320	1.169	0.934	1.309	
Means.....	2.8	1.750	1.613	1.504	1.498	1.171	0.914	1.340	
(β)									
3 weak lines.....	0.3	1.778	1.608	1.497	1.531	1.107	0.852	1.319	
3 strong lines.....	5.3	1.721	1.619	1.512	1.464	1.235	0.976	1.361	
(γ)									
3 weak lines.....	0.3	1.02	0.92	0.85	0.87	0.63	0.49	0.75	
3 strong lines.....	5.3	0.98	0.92	0.86	0.84	0.71	0.56	0.78	
Means.....	2.8	1.00	0.92	0.85	0.86	0.67	0.53	0.77	

TABLE III

Observation:—L854 (1) to (6).

Measurement:—De Lury and O'Connor.

Computation:—Means of Tables. II (a, b, c) and II (α , β , γ)

TABLE III. (a, b, c)

Observation:—L916, (1) to (9), Spectra of solar limbs at 80° , blended with spectrum of centre of solar disc.

Measurement:—By De Lury, 2 settings on each line, each way, plate right and plate left, and means taken.

Computation:—(a) Half-displacements expressed in km:sec. (b) Means of (a) grouped as to intensity. (c) Means of (b) divided by 0.149.

λ	El.	I	R = 1.00	0.89	0.79	0.69	0.60	0.51	0.42	0.33	0.24	Means 0.56
(a)												
5,586.991.....	Fe	7	0.038	0.206	0.081	0.008	0.049	-0.066	0.138	0.040	-0.064	0.049
5,587.800.....	Fe	0	0.198	0.077	0.209	-0.234	0.042	-0.098	-0.021	-0.147	-0.126	-0.037
5,588.084.....	Ni	1	0.153	0.017	0.064	-0.115	0.006	-0.221	0.098	-0.104	0.098	-0.020
5,588.985, s.....	Ca	6	0.174	0.143	0.253	0.053	0.021	-0.104	0.251	-0.028	0.023	0.076
5,589.582.....	Ni	0	0.057	-0.045	0.094	0.102	0.240	-0.221	0.345	-0.092	-0.083	0.042
5,590.343, s.....	Ca	3	0.275	0.091	0.241	0.006	0.191	-0.026	0.264	-0.126	0.125	0.096
Means.....		2.8	0.149	0.081	0.157	-0.030	0.091	-0.123	0.179	-0.076	-0.005	0.034
(b)												
3 weak lines.....		0.3	0.136	0.016	0.122	-0.082	0.096	-0.180	0.140	-0.114	-0.037	-0.005
3 strong lines.....		5.3	0.162	0.147	0.192	0.022	0.087	-0.065	0.218	-0.038	0.028	0.074
(c)												
3 weak lines.....		0.3	0.91	0.11	0.82	-0.55	0.64	-1.21	0.94	-0.76	-0.25	0.03
3 strong lines.....		5.3	1.09	0.99	1.29	0.15	0.58	-0.44	1.46	-0.25	0.19	0.50
Means.....		2.8	1.00	0.54	1.05	-0.20	0.61	-0.83	1.20	-0.51	-0.03	0.26

TABLE III, (α , β , γ)

Observation:—L916, (1) to (9) Spectra of solar limbs at 80° , blended with spectrum of centre of solar disc.

Measurement:—By O'Connor, 2 settings each line, each way, plate right and plate left, and means taken.

Computation:—(a) Half-displacements expressed in km: sec. (b) Means of (a) grouped as to intensity.
(c) Means of (b) divided by 0.147.

λ	El., I	R =	1.00	0.89	0.79	0.69	0.60	0.51	0.42	0.33	0.24	Means 0.56
(a)												
5,586.991.....	Fe 7	0.087	0.234	0.151	-0.166	0.092	-0.038	-0.008	-0.096	0.051	0.028	
5,587.800.....	Fe 0	0.166	0.040	0.231	-0.219	0.036	-0.055	-0.004	-0.109	0.045	-0.005	
5,588.084.....	Ni 1	0.236	0.130	0.194	-0.126	0.062	-0.185	0.204	-0.174	0.051	0.020	
5,588.985, s.....	Ca 6	0.151	0.164	0.266	-0.043	0.021	-0.066	0.115	-0.077	0.047	0.064	
5,589.582.....	Ni 0	0.049	-0.108	0.094	-0.064	0.128	-0.183	0.187	-0.142	0.060	-0.003	
5,590.343, s.....	Ca 3	0.191	0.172	0.191	-0.109	0.138	-0.143	0.136	-0.121	0.104	0.046	
Means.....		2.8	0.147	0.105	0.188	-0.107	0.080	-0.112	0.105	-0.120	0.060	0.025
(b)												
3 weak lines.....		0.3	0.150	0.021	0.173	-0.136	0.075	-0.141	0.129	-0.142	0.052	0.004
3 strong lines.....		5.3	0.143	0.190	0.203	-0.077	0.084	-0.082	0.081	-0.098	0.067	0.046
(c)												
3 weak lines.....		0.3	1.02	0.14	1.18	-0.93	0.51	-0.96	0.88	-0.97	0.35	0.03
3 strong lines.....		5.3	0.97	1.29	1.38	-0.52	0.57	-0.56	0.55	-0.67	0.46	0.31
Means.....		2.8	1.00	0.71	1.28	-0.73	0.54	-0.76	0.71	-0.82	0.41	0.17

TABLE IV, (a, b, c)

Observation:—L911, (1) to (9) Spectra of solar limbs at 75° , blended with spectrum of centre of solar disc.

Measurement:—By De Lury, 2 settings each line, each way, plate right and plate left, and means taken.

Computation:—(a) Half-displacements expressed in km: sec. (b) Means of (a) grouped as to intensity. (c) Means of (b) divided by 0.366.

λ	El., I	R =	1.00	0.89	0.79	0.69	0.58	0.51	0.43	0.33	0.24	Means 0.56
(a)												
5,586.991.....	Fe 7	0.479	0.192	0.049	0.196	0.126	0.166	-0.044	0.209	0.045	0.117	
5,587.800.....	Fe 0	0.257	0.241	0.226	0.287	0.177	0.004	0.038	0.115	-0.089	0.125	
5,588.084.....	Ni 1	0.389	0.279	0.028	0.266	-0.040	0.057	0.117	0.081	0.015	0.100	
5,588.985, s.....	Ca 6	0.547	0.375	0.240	0.251	0.158	0.000	0.121	0.074	0.111	0.166	
5,589.582.....	Ni 0	0.264	0.149	0.375	0.185	0.108	0.002	0.177	0.134	-0.294	0.104	
5,590.343, s.....	Ca 3	0.258	0.451	0.221	0.211	0.100	0.168	0.028	0.106	0.087	0.171	
Means.....		2.8	0.366	0.281	0.190	0.233	0.105	0.066	0.073	0.120	-0.021	0.130
(b)												
3 weak lines.....		0.3	0.303	0.223	0.210	0.246	0.082	0.021	0.110	0.110	-0.123	0.110
3 strong lines.....		5.3	0.428	0.339	0.170	0.219	0.128	0.111	0.035	0.130	0.081	0.151
(c)												
3 weak lines.....		0.3	0.83	0.61	0.57	0.67	0.22	0.06	0.30	0.30	-0.34	0.30
3 strong lines.....		5.3	1.17	0.93	0.46	0.60	0.35	0.30	0.10	0.35	0.22	0.41
Means.....		2.8	1.00	0.77	0.52	0.63	0.29	0.18	0.20	0.33	-0.06	0.35

TABLE IV, (α , β , γ)

Observation:—L911, (1) to (9) Spectra of solar limbs at 75° , blended with spectrum of centre of solar disc.

Measurement: By O'Connor, 2 settings each line, each way, plate right and plate left, and means taken.

Computation: (a) Half-displacements expressed in km: sec. (b) Means of (a) grouped as to intensity. (c) Means of (b) divided by 0.357.

λ	El., I	R =	1.00	0.89	0.79	0.69	0.58	0.51	0.43	0.33	0.24	Means 0.56
(a)												
5,586.991.....	Fe 7	0.553	0.304	0.238	0.328	0.140	0.153	0.145	0.138	0.130	0.197	
5,587.800.....	Fe 0	0.258	0.298	0.321	0.357	0.158	0.228	0.038	0.151	0.094	0.206	
5,588.084.....	Ni 1	0.273	0.317	0.264	0.198	0.132	0.081	0.143	0.121	0.104	0.170	
5,588.985, s.....	Ca 6	0.330	0.347	0.236	0.328	0.249	0.132	0.160	0.168	0.077	0.212	
5,589.582.....	Ni 0	0.268	0.349	0.217	0.240	0.196	0.151	0.228	0.251	0.055	0.211	
5,590.343, s.....	Ca 3	0.460	0.285	0.208	0.234	0.130	0.096	0.147	0.138	0.047	0.161	
Means.....		2.8	0.357	0.317	0.247	0.281	0.168	0.140	0.144	0.161	0.085	0.193
(b)												
3 weak lines.....		0.3	0.267	0.321	0.267	0.265	0.162	0.153	0.136	0.174	0.084	0.196
3 strong lines.....		5.3	0.448	0.312	0.227	0.297	0.173	0.127	0.151	0.148	0.085	0.190
(c)												
3 weak lines.....		0.3	0.75	0.90	0.75	0.74	0.45	0.43	0.38	0.49	0.24	0.55
3 strong lines.....		5.3	1.25	0.87	0.65	0.83	0.48	0.36	0.42	0.41	0.24	0.53
Means.....		2.8	1.00	0.89	0.69	0.79	0.47	0.39	0.40	0.45	0.24	0.54

TABLE V, (a, b, c)

Observation:—L912, (1) to (9). Spectra of solar limbs at 60° , blended with spectrum of centre of solar disc.

Measurement:—By DeLury, 2 settings each line, each way, plate right and plate left, and means taken.

Computation:—(a) Half-displacements expressed in km: sec. (b) Means of (a) grouped as to intensity. (c) Mean of (b) divided by 0.660.

λ	El., I	R =	1.00	0.89	0.79	0.69	0.60	0.51	0.42	0.33	0.24	Means 0.56
(a)												
5,586.991.....	Fe 7	0.779	0.805	0.622	0.328	0.404	0.281	0.175	0.102	-0.062	0.332	
5,587.800.....	Fe 0	0.526	0.800	0.683	0.115	0.428	0.017	0.115	0.072	-0.108	0.265	
5,588.084.....	Ni 1	0.545	0.628	0.492	0.243	0.109	-0.028	0.059	0.070	0.053	0.203	
5,588.985, s.....	Ca 6	0.794	0.519	0.492	0.407	0.398	0.253	0.219	0.008	-0.008	0.286	
5,589.582.....	Ni 0	0.681	0.643	0.704	0.583	0.351	0.275	0.453	-0.042	0.011	0.372	
5,590.343, s.....	Ca 3	0.634	0.592	0.613	0.300	0.266	0.036	0.232	-0.057	-0.085	0.237	
Means.....		2.8	0.660	0.665	0.601	0.329	0.326	0.139	0.209	0.026	-0.033	0.283
(b)												
3 weak lines.....		0.3	0.584	0.690	0.626	0.314	0.296	0.088	0.209	0.033	-0.015	0.280
3 strong lines,		5.3	0.736	0.639	0.576	0.345	0.356	0.190	0.209	0.018	-0.052	0.286
(c)												
3 weak lines.....		0.3	0.88	1.05	0.95	0.48	0.45	0.13	0.32	0.05	-0.02	0.42
3 strong lines.....		5.3	1.12	0.97	0.87	0.52	0.54	0.29	0.32	0.03	-0.08	0.43
Means.....		2.8	1.00	1.01	0.91	0.50	0.49	0.21	0.32	0.04	-0.05	0.43

TABLE V, (α , β , γ)

Observation:—L912 (1) to (9). Spectra of solar limbs at 60° , blended with spectrum of centre of solar disc.
Measurement:—By O'Connor, 2 settings each line, each way, plate right and plate left, and means taken.
Computation: (a) Half-displacements expressed in km: sec. (b) Means of (a) grouped as to intensity. (c) Means of (b) divided by 0.609.

λ	El., I	R=	1.00	0.89	0.79	0.69	0.60	0.51	0.42	0.33	0.24	Means 0.56
(a)												
5,586.991.....	Fe 7	0.651	0.632	0.651	0.473	0.336	0.274	0.257	0.175	0.038	0.354	
5,587.800.....	Fe 0	0.411	0.553	0.389	0.230	0.315	0.170	0.157	0.089	-0.013	0.236	
5,588.084.....	Ni 1	0.624	0.647	0.426	0.338	0.234	0.087	0.125	0.060	0.019	0.242	
5,588.985, s.....	Ca 6	0.660	0.547	0.568	0.264	0.357	0.209	0.192	0.102	0.047	0.286	
5,589.582.....	Ni 0	0.587	0.565	0.538	0.270	0.430	0.228	0.417	0.034	-0.147	0.292	
5,590.343, s.....	Ca 3	0.719	0.630	0.436	0.313	0.292	0.196	0.194	0.042	-0.032	0.259	
Means.....		2.8	0.609	0.596	0.501	0.315	0.327	0.194	0.224	0.084	-0.015	0.278
(b)												
3 weak lines.....		0.3	0.541	0.589	0.451	0.279	0.326	0.162	0.233	0.061	-0.047	0.257
3 strong lines.....		5.3	0.677	0.603	0.552	0.350	0.328	0.226	0.214	0.106	0.018	0.300
(c)												
3 weak lines.....		0.3	0.89	0.97	0.74	0.46	0.53	0.27	0.38	0.10	-0.08	0.42
3 strong lines.....		5.3	0.11	0.99	0.91	0.57	0.54	0.37	0.35	0.17	0.03	0.49
Means.....		2.8	1.00	0.98	0.82	0.52	0.54	0.32	0.37	0.14	-0.02	0.46

TABLE VI, (a, b, c)

Observation:—L913, (1) to (9). Spectra of solar limbs at 45° , blended with spectrum of centre of solar disc.
Measurement: By DeLury, 2 settings each line, each way, plate right and plate left, and means taken.
Computation: (a) Half-displacements expressed in km: sec. (b) Means of (a) grouped as to intensity. (c) Means of (b) divided by 1.096.

λ	El., I	R=	1.00	0.89	0.79	0.69	0.60	0.51	0.42	0.33	0.24	Means 0.56
(a)												
5,586.991.....	Fe 7	0.994	0.932	1.024	0.649	0.762	0.381	0.274	0.179	0.034	0.529	
5,587.800.....	Fe 0	1.152	0.830	0.598	0.630	0.183	0.200	0.136	-0.040	-0.066	0.309	
5,588.084.....	Ni 1	1.164	0.777	0.558	0.443	0.189	0.228	0.121	-0.068	0.075	0.290	
5,588.985, s.....	Ca 6	1.115	1.011	0.798	0.696	0.515	0.179	0.115	0.068	0.292	0.459	
5,589.582.....	Ni 0	1.005	1.018	0.709	0.456	0.528	-0.009	0.108	-0.032	-0.142	0.330	
5,590.343, s.....	Ca 3	1.149	1.075	0.826	0.400	0.338	0.275	0.168	0.043	0.091	0.402	
Means.....		2.8	1.096	0.941	0.752	0.546	0.419	0.209	0.153	0.025	0.047	0.387
(b)												
3 weak lines.....		0.3	1.107	0.875	0.622	0.510	0.300	0.140	0.122	-0.047	-0.044	0.310
3 strong lines.....		5.3	1.086	1.006	0.883	0.582	0.538	0.278	0.186	0.097	0.139	0.463
(c)												
3 weak lines.....		0.3	1.01	0.80	0.57	0.47	0.27	0.13	0.11	-0.04	-0.04	0.28
3 strong lines.....		5.3	0.99	0.92	0.81	0.53	0.49	0.25	0.17	0.09	0.13	0.42
Means.....		2.8	1.00	0.86	0.69	0.50	0.38	0.19	0.14	0.02	0.04	0.35

TABLE VI, (α , β , γ)

Observation:—L913, (1) to (9). Spectra of solar limbs at 45° , blended with spectrum from centre of solar disc.

Measurement:—By O'Connor, 2 settings each line, each way, plate right and plate left, and means taken.

Computation: (a) Half-displacements expressed in km: sec. (b) Means of (a) grouped as to intensity. (c) Means of (b) divided by 1.165.

λ	El., I	R = 1.00	0.89	0.79	0.69	0.60	0.51	0.42	0.33	0.24	Means 0.56	
(a)												
5,586.991.....	Fe 7	1.141	1.059	0.895	0.887	0.730	0.504	0.324	0.226	0.094	0.590	
5,587.800.....	Fe 0	1.177	0.860	0.630	0.616	0.432	0.404	0.192	0.040	0.074	0.409	
5,588.084.....	Ni 1	1.177	0.866	0.566	0.681	0.074	0.434	0.208	0.066	0.094	0.373	
5,588.985, s.....	Ca 6	1.118	0.948	0.606	0.986	0.515	0.402	0.266	0.140	0.138	0.500	
5,589.582.....	Ni 0	1.171	1.024	0.572	0.598	0.498	0.309	0.232	0.138	0.023	0.424	
5,590.343, s.....	Ca 3	1.197	0.918	0.780	0.784	0.622	0.345	0.226	0.109	0.087	0.484	
Means.....		2.8	1.165	0.946	0.675	0.759	0.478	0.400	0.241	0.120	0.085	0.463
(b)												
3 weak lines.....		0.3	1.175	0.917	0.589	0.632	0.335	0.382	0.211	0.081	0.064	0.402
3 strong lines.....		5.3	1.155	0.975	0.760	0.886	0.622	0.417	0.272	0.158	0.106	0.525
(c)												
3 weak lines.....		0.3	1.01	0.79	0.51	0.54	0.29	0.33	0.18	0.07	0.05	0.34
3 strong lines.....		5.3	0.99	0.84	0.65	0.76	0.53	0.36	0.23	0.14	0.09	0.45
Means.....		2.8	1.00	0.81	0.58	0.65	0.41	0.34	0.21	0.10	0.07	0.40

TABLE VII, (a, b, c)

Observation: L914, (1) to (9). Spectra of solar limbs at 30° , blended with spectrum of centre of solar disc.

Measurement:—By DeLury, 2 settings each line each way, plate right and plate left, and means taken.

Computation:—(a) Half-displacements expressed in km: sec. (b) Means of (a) grouped as to intensity. (c) Means of (b) divided by 1.404.

λ	El., I	R = 1.00	0.89	0.79	0.69	0.60	0.51	0.42	0.33	0.24	Means 0.56	
(a)												
5,586.991.....	Fe 7	1.398	1.215	1.075	0.805	0.568	0.519	0.449	0.423	0.070	0.640	
5,587.800.....	Fe 0	1.356	0.971	1.051	0.274	0.074	0.004	0.192	-0.002	0.009	0.322	
5,588.084.....	Ni 1	1.405	1.117	0.864	0.702	0.372	0.147	0.113	0.032	0.087	0.429	
5,588.985, s.....	Ca 6	1.424	1.145	1.064	0.717	0.423	0.400	0.115	0.241	0.019	0.515	
5,589.582.....	Ni 0	1.465	1.215	0.930	0.649	0.392	0.224	-0.057	0.015	-0.096	0.409	
5,590.343, s.....	Ca 3	1.379	1.132	0.971	0.592	0.336	0.279	0.064	0.285	0.064	0.465	
Means.....		2.8	1.404	1.132	0.992	0.623	0.361	0.262	0.146	0.166	0.025	0.463
(b)												
3 weak lines.....		0.3	1.409	1.101	0.948	0.542	0.279	0.125	0.082	0.015	0.000	0.387
3 strong lines.....		5.3	1.400	1.164	1.037	0.705	0.442	0.399	0.209	0.316	0.051	0.540
(c)												
3 weak lines.....		0.3	1.00	0.78	0.67	0.39	0.20	0.09	0.06	0.01	0.00	0.28
3 strong lines.....		5.3	1.00	0.83	0.74	0.50	0.31	0.28	0.15	0.22	0.04	0.38
Means.....		2.8	1.00	0.81	0.71	0.44	0.26	0.19	0.10	0.12	0.02	0.33

TABLE VII, (α , β , γ)

Observation: L914, (1) to (9). spectra of solar limbs at 30° , blended with spectrum of centre of solar disc.

Measurement: By O'Connor, 2 settings each line, each way, plate right and plate left, and means taken.

Computation:—(a) Half-displacements expressed in km: sec. (b) Means of (a) grouped as to intensity. (c) Means of (b) divided by 1.425.

λ	El., I	R =	1.00	0.89	0.79	0.69	0.60	0.51	0.42	0.33	0.24	Means 0.56
(a)												
5,586.991.....	Fe 7	1.394	1.034	0.977	0.928	0.560	0.560	0.283	0.298	0.192	0.192	0.604
5,587.800.....	Fe 0	1.471	0.943	0.811	0.504	0.047	0.151	0.175	0.085	-0.064	0.332	
5,588.084.....	Ni 1	1.313	1.083	0.779	0.600	0.311	0.133	0.119	0.126	0.072	0.400	
5,588.985, s.....	Ca 6	1.424	1.154	0.983	0.694	0.434	0.311	0.241	0.224	0.072	0.514	
5,589.582.....	Ni 0	1.454	1.205	0.909	0.528	0.247	0.226	0.108	0.140	0.066	0.429	
5,590.343, s.....	Ca 3	1.492	1.194	0.909	0.700	0.262	0.294	0.166	0.268	0.074	0.483	
Means.....		2.8	1.425	1.102	0.895	0.659	0.310	0.276	0.182	0.190	0.069	0.460
(b)												
3 weak lines.....		0.3	1.413	1.077	0.833	0.544	0.202	0.163	0.134	0.117	0.025	0.387
3 strong lines.....		5.3	1.437	1.127	0.956	0.774	0.419	0.388	0.230	0.263	0.113	0.534
(c)												
3 weak lines.....		0.3	0.99	0.76	0.58	0.38	0.14	0.11	0.09	0.08	0.02	0.027
3 strong lines.....		5.3	1.01	0.79	0.67	0.54	0.29	0.27	0.16	0.18	0.08	0.037
Means.....		2.8	1.00	0.77	0.63	0.46	0.22	0.19	0.13	0.13	0.05	0.32

TABLE VIII, (a, b, c)

Observation:—L915, (1) to (9). Spectra of solar limbs, at 15° , blended with spectrum of centre of solar disc

Measurement:—By DeLury, 2 settings each line, each way, plate right and plate left, and means taken.

Computation:—(a) Half-displacements expresed in km: sec. (b) Means of (a) grouped as to intensity. (c) Means of (b) divided by 1.744.

λ	El., I	R =	1.00	0.89	0.79	0.69	0.60	0.51	0.42	0.33	0.24	Means 0.56
(a)												
5,586.991.....	Fe 7	1.884	1.763	1.424	0.928	1.047	0.481	0.174	0.274	0.102	0.774	
5,587.800.....	Fe 0	1.379	1.375	1.203	0.702	0.641	0.255	-0.077	0.028	0.002	0.516	
5,588.084.....	Ni 1	1.905	1.399	1.303	0.575	0.347	0.025	-0.034	-0.053	-0.100	0.433	
5,588.985, s.....	Ca 6	1.675	1.596	1.283	0.866	0.754	0.406	0.234	0.059	0.008	0.650	
5,589.582.....	Ni 0	1.856	1.364	1.081	0.877	0.743	0.381	-0.051	0.292	-0.223	0.558	
5,590.343, s.....	Ca 3	1.767	1.518	1.203	0.798	0.481	0.098	0.019	0.032	-0.119	0.504	
Means.....		2.8	1.744	1.503	1.250	0.791	0.669	0.274	0.044	0.105	-0.055	0.573
(b)												
3 weak lines.....		0.3	1.713	1.379	1.196	0.718	0.577	0.220	-0.054	0.089	-0.107	0.502
3 strong lines.....		5.3	1.775	1.626	1.303	0.864	0.761	0.328	0.142	0.122	-0.003	0.643
(c)												
3 weak lines.....		0.3	0.98	0.79	0.69	0.41	0.33	0.13	-0.03	0.05	-0.06	0.29
3 strong lines.....		5.3	1.02	0.93	0.75	0.50	0.44	0.19	0.08	0.07	0.00	0.37
Means.....		2.8	1.00	0.86	0.72	0.45	0.38	0.16	0.03	0.06	-0.03	0.33

TABLE VIII, (α , β , γ)

Observation:—L915 (1) to (9). Spectra of solar limbs at 15° , blended with spectrum of centre of solar disc.

Measurement:—By O'Connor, 2 settings each line, each way, plate right and plate left, and means taken.

Computation:—(a) Half-displacements expressed in km:sec. (b) Means of (a) grouped as to intensity. (c) Means of (b) divided by 1.739.

λ	El., I	R = 1.00	0.89	0.79	0.69	0.60	0.51	0.42	0.33	0.24	Means 0.56
(a)											
5,586.991.....	Fe 7	1.805	1.558	1.379	0.943	0.802	0.307	0.324	0.185	0.075	0.697
5,587.800.....	Fe 0	1.707	1.367	1.162	0.828	0.604	0.343	0.070	-0.247	0.109	0.530
5,588.084.....	Ni 1	1.778	1.482	1.264	0.849	0.560	0.251	-0.077	-0.032	0.051	0.543
5,588.985, s.....	Ca 6	1.686	1.533	1.333	0.722	0.628	0.240	0.202	0.002	0.066	0.591
5,589.582.....	Ni 0	1.665	1.462	1.088	0.788	0.570	0.349	0.221	0.281	0.059	0.602
5,590.343, s.....	Ca 3	1.790	1.597	1.209	0.881	0.737	0.360	0.126	0.075	0.042	0.629
Means.....		2.8	1.739	1.500	1.239	0.835	0.650	0.308	0.144	0.044	0.067
(b)											
3 weak lines.....		0.3	1.717	1.437	1.171	0.822	0.578	0.314	0.071	0.001	0.073
3 strong lines.....		5.3	1.760	1.563	1.307	0.849	0.722	0.302	0.217	0.087	0.061
(c)											
3 weak lines.....		0.3	0.99	0.83	0.67	0.47	0.33	0.18	0.04	0.00	0.04
3 strong lines.....		5.3	1.01	0.90	0.75	0.49	0.42	0.17	0.12	0.05	0.04
Means.....		2.8	1.00	0.86	0.71	0.48	0.37	0.18	0.08	0.03	0.04

TABLE IX, (a, b, c)

Observation:—L917 (1) to (9). Spectra of solar limbs at 0° , blended with spectrum of centre of solar disc.

Measurement:—By DeLury, 2 settings each line, each way, plate right and plate left, and means taken.

Computation:—(a) Half-displacements expressed in km:sec. (b) Means of (a) grouped as to intensity. (c) Means of (b) divided by 1.775.

λ	El., I	R = 1.00	0.89	0.79	0.69	0.60	0.51	0.42	0.33	0.24	Means 0.56
(a)											
5,586.991.....	Fe 7	1.803	1.671	1.471	1.030	1.058	0.485	0.649	0.470	0.285	0.890
5,587.800.....	Fe 0	1.854	1.301	1.028	0.785	0.645	-0.023	0.428	0.189	0.170	0.565
5,588.084.....	Ni 1	1.601	1.581	1.060	0.962	0.547	0.043	0.345	-0.132	0.130	0.569
5,588.985, s.....	Ca 6	1.850	1.777	1.320	0.920	0.822	0.170	0.426	0.217	0.240	0.737
5,589.582.....	Ni 0	1.688	1.811	1.026	0.624	0.647	0.198	0.311	-0.198	0.208	0.578
5,590.343, s.....	Ca 3	1.856	1.279	1.086	0.594	0.628	0.241	0.370	0.055	0.147	0.551
Means.....		2.8	1.775	1.570	1.167	0.819	0.725	0.186	0.422	0.100	0.196
(b)											
weak lines.....		0.3	1.714	1.564	1.038	0.790	0.613	0.073	0.361	-0.047	0.169
3 strong lines.....		5.3	1.836	1.576	1.296	0.848	0.836	0.299	0.482	0.247	0.224
(c)											
3 weak lines.....		0.3	0.96	0.88	0.58	0.44	0.35	0.04	0.20	-0.03	0.10
3 strong lines.....		5.3	1.03	0.89	0.73	0.48	0.47	0.17	0.27	0.14	0.13
Means.....		2.8	1.00	0.88	0.65	0.46	0.41	0.10	0.24	0.06	0.11

TABLE IX, (α , β , γ)

Observation:—L917 (1) to (9). Spectra of solar limbs at 0° , blended with spectrum of centre of solar disc.

Measurement:—By O'Connor, 2 settings each line, each way, plate right and plate left, and means taken.

Computation:—(a) Half-displacements expressed in km: sec. (b) Means of (a) grouped as to intensity. (c) Means of (b) divided by 1.743.

λ	El., I	R =	1.00	0.89	0.79	0.69	0.60	0.51	0.42	0.33	0.24	Means 0.56
(a)												
5,586.991.....	Fe 7	1.811	1.567	1.350	1.071	0.751	0.409	0.585	0.311	0.160	0.776	
5,587.800.....	Fe 0	1.664	1.369	0.971	0.762	0.523	-0.075	0.285	0.149	0.147	0.516	
5,588.084.....	Ni 1	1.730	1.507	1.120	0.617	0.494	-0.057	0.347	0.009	0.021	0.508	
5,588.985, s.....	Ca 6	1.773	1.564	1.217	0.830	0.749	0.094	0.477	0.132	0.179	0.655	
5,589.582.....	Ni 0	1.814	1.552	0.994	0.836	0.453	0.140	0.330	0.153	0.358	0.564	
5,590.343, s.....	Ca 3	1.669	1.498	1.088	0.762	0.666	0.181	0.358	0.089	0.070	0.589	
Means.....		2.8	1.743	1.509	1.123	0.813	0.606	0.115	0.397	0.090	0.156	0.601
(b)												
3 weak lines.....		0.3	1.736	1.476	1.028	0.738	0.491	0.003	0.321	0.002	0.175	0.529
3 strong lines.....		5.3	1.751	1.543	1.218	0.888	0.722	0.228	0.473	0.177	0.136	0.673
(γ)												
3 weak lines.....		0.3	1.00	0.85	0.59	0.42	0.28	0.00	0.18	0.00	0.10	0.30
3 strong lines.....		5.3	1.00	0.89	0.70	0.51	0.41	0.13	0.27	0.10	0.08	0.39
Means.....		2.8	1.00	0.87	0.64	0.47	0.35	0.07	0.23	0.05	0.09	0.34

TABLE X, (a, b, c)

Observation:—L911 to L917.

Measurement: By DeLury.

Computation: (a) Means of half-displacements expressed in km:sec. (b) Means of (a) grouped as to intensity. (c) Means of (b) divided by 1.028.

λ	El., I	R =	1.00	0.89	0.79	0.69	0.60	0.51	0.42	0.33	0.24	Means 0.56
(a)												
5,586.991.	Fe 7	1.054	0.969	0.821	0.563	0.573	0.321	0.259	0.242	0.059	0.476	
5,587.800.	Fe 0	0.960	0.799	0.714	0.366	0.313	0.051	0.136	0.031	-0.030	0.295	
5,588.084.	Ni 1	1.023	0.828	0.624	0.439	0.219	0.036	0.117	-0.025	0.051	0.286	
5,588.985, s.	Ca 6	1.083	0.938	0.779	0.559	0.442	0.186	0.212	0.091	0.098	0.413	
5,589.582.	Ni 0	1.002	0.879	0.703	0.497	0.430	0.121	0.184	0.011	-0.088	0.342	
5,590.343, s.	Ca 3	1.045	0.876	0.739	0.414	0.334	0.153	0.164	0.048	0.044	0.347	
Means.....		2.8	1.028	0.882	0.730	0.473	0.385	0.145	0.175	0.067	0.022	0.360
(b)												
3 weak lines.....		0.3	0.995	0.835	0.680	0.434	0.320	0.070	0.139	0.006	-0.022	0.309
3 strong lines.....		5.3	1.060	0.928	0.780	0.512	0.450	0.219	0.211	0.127	0.067	0.412
(c)												
3 weak lines.....		0.3	0.967	0.812	0.661	0.422	0.311	0.068	0.135	0.006	-0.021	0.300
3 strong lines.....		5.3	1.030	0.902	0.758	0.498	0.437	0.213	0.205	0.123	0.065	0.400
Means.....		2.8	0.999	0.857	0.711	0.460	0.374	0.141	0.170	0.065	0.022	0.350

TABLE X, (α , β , γ)*Observation:*—L911 to L917.*Measurement:*—By O'Connor.*Computation:* (a) Means of half-displacements expressed in km: sec. (b) Means of (a) grouped as to intensity. (γ) Means of (b) divided by 1.026.

λ	El., I	R = 1.00	0.89	0.79	0.69	0.60	0.51	0.42	0.33	0.24	Means 0.56	
(a)												
5,586.991.....	Fe 7	1.063	0.913	0.806	0.638	0.487	0.311	0.271	0.177	0.106	0.464	
5,587.800.....	Fe 0	0.979	0.776	0.645	0.440	0.302	0.167	0.130	0.023	0.056	0.318	
5,588.084.....	Ni 1	1.019	0.862	0.659	0.451	0.267	0.103	0.153	0.025	0.059	0.322	
5,588.985, s.....	Ca 6	1.020	0.894	0.744	0.552	0.422	0.189	0.236	0.099	0.089	0.403	
5,589.582.....	Ni 0	1.001	0.864	0.630	0.457	0.360	0.174	0.246	0.078	0.068	0.360	
5,590.343, s.....	Ca 3	1.074	0.899	0.689	0.509	0.407	0.190	0.193	0.086	0.056	0.379	
Means.....		2.8	1.026	0.868	0.695	0.508	0.374	0.189	0.205	0.081	0.073	0.374
(b)												
3 weak lines.....		0.3	1.000	0.834	0.645	0.449	0.310	0.148	0.176	0.042	0.061	0.333
3 strong lines.....		5.3	1.053	0.902	0.746	0.567	0.427	0.230	0.233	0.120	0.084	0.415
(γ)												
3 weak lines.....		0.3	0.975	0.813	0.629	0.438	0.302	0.144	0.170	0.041	0.059	0.325
3 strong lines.....		5.3	1.027	0.879	0.727	0.552	0.428	0.224	0.227	0.117	0.082	0.405
Means.....		2.8	1.001	0.846	0.678	0.495	0.359	0.184	0.199	0.079	0.071	0.365

TABLE X

Observation:—L911 to L917.*Measurement:*—DeLury and O'Connor.*Computation:*—Means of Tables, X, (a, b, c), and X, (α , β , γ).

λ	El., I	R = 1.00	0.89	0.79	0.69	0.60	0.51	0.42	0.33	0.24	Means 0.56	
(a, a)												
5,586.991.....	Fe 7	1.059	0.941	0.805	0.601	0.530	0.316	0.266	0.210	0.083	0.470	
5,587.800.....	Fe 0	0.970	0.788	0.680	0.403	0.308	0.109	0.133	0.027	0.013	0.307	
5,588.084.....	Ni 1	1.021	0.845	0.642	0.445	0.243	0.070	0.135	0.000	0.055	0.304	
5,588.985, s.....	Ca 6	1.052	0.916	0.762	0.556	0.432	0.188	0.224	0.095	0.094	0.408	
5,589.582.....	Ni 0	1.002	0.872	0.667	0.477	0.395	0.148	0.215	0.042	-0.010	0.351	
5,590.343, s.....	Ca 3	1.060	0.888	0.714	0.462	0.371	0.172	0.179	0.067	0.050	0.363	
Means.....		2.8	1.027	0.875	0.713	0.491	0.380	0.167	0.190	0.074	0.048	0.367
(b, β)												
3 weak lines.....		0.3	0.998	0.835	0.668	0.442	0.315	0.109	0.158	0.024	0.020	0.321
3 strong lines.....		5.3	1.057	0.915	0.763	0.540	0.444	0.225	0.222	0.124	0.076	0.414
(c, γ)												
3 weak lines.....		0.3	0.971	0.812	0.645	0.430	0.306	0.106	0.154	0.023	0.019	0.312
3 strong lines.....		5.3	1.028	0.890	0.742	0.525	0.432	0.219	0.216	0.111	0.074	0.403
Means.....		2.8	1.000	0.851	0.694	0.478	0.369	0.163	0.185	0.067	0.047	0.358

TABLE XI, (a, b, c)

Observation:—L911 to L917.*Measurement:*—DeLury.*Computation:*—Values of Table X (a, b, c) expressed as decimals of first number in each line.

λ	El., I	R =	1.00	0.89	0.79	0.69	0.60	0.51	0.42	0.33	0.24	Means 0.56	
(a)													
5,586.991.....	Fe 7	1.00	0.92	0.78	0.53	0.54	0.30	0.25	0.23	0.06	0.451		
5,587.800.....	Fe 0	1.00	0.83	0.74	0.38	0.33	0.05	0.11	0.03	-0.03	0.307		
5,588.084.....	Ni 1	1.00	0.81	0.61	0.43	0.21	0.04	0.11	-0.02	0.05	0.279		
5,588.985, s.....	Ca 6	1.00	0.87	0.72	0.52	0.41	0.14	0.20	0.08	0.09	0.382		
5,589.582.....	Ni 0	1.00	0.88	0.70	0.50	0.43	0.12	0.19	0.01	-0.09	0.338		
5,590.343, s.....	Ca 3	1.00	0.84	0.71	0.40	0.32	0.15	0.16	0.05	0.04	0.332		
Means.....		2.8	1.00	0.86	0.71	0.46	0.37	0.14	0.17	0.07	0.02	0.350	
(b)													
3 weak lines.....		0.3	1.00	0.84	0.68	0.44	0.32	0.07	0.14	0.01	-0.02	0.311	
3 strong lines.....		5.3	1.00	0.88	0.74	0.48	0.42	0.21	0.20	0.12	0.06	0.389	

TABLE XI (a, β , γ)*Observation:*—L911 to L917.*Measurement:*—O'Conor.*Computation:*—Values of Table X (a, β , γ) expressed as decimals of first number in each line.

λ	El. I	R =	1.00	0.89	0.79	0.69	0.60	0.51	0.42	0.33	0.24	Means 0.56	
(a)													
5,586.991.....	Fe 7	1.00	0.86	0.76	0.60	0.46	0.29	0.25	0.17	0.10	0.436		
5,587.800.....	Fe 0	1.00	0.79	0.66	0.45	0.31	0.17	0.13	0.02	0.06	0.325		
5,588.084.....	Ni 1	1.00	0.85	0.65	0.44	0.26	0.10	0.15	0.02	0.06	0.316		
5,588.985, s.....	Ca 6	1.00	0.88	0.73	0.54	0.41	0.19	0.23	0.10	0.09	0.395		
5,589.582.....	Ni 0	1.00	0.86	0.63	0.45	0.36	0.17	0.25	0.07	0.07	0.360		
5,590.343, s.....	Ca 3	1.00	0.84	0.64	0.47	0.38	0.18	0.18	0.08	0.05	0.353		
Means.....		2.8	1.00	0.85	0.68	0.50	0.36	0.18	0.20	0.08	0.07	0.365	
(b)													
3 weak lines.....		0.3	1.00	0.83	0.65	0.45	0.31	0.15	0.18	0.04	0.06	0.333	
3 strong lines.....		5.3	1.00	0.86	0.71	0.54	0.42	0.22	0.22	0.11	0.08	0.395	

TABLE XI

Observation:—L911 to L917.*Measurement:*—DeLury and O'Connor.*Computation:*—Means of Tables XI, (a, b, c), and XI, (a, β , γ).

λ	El., I	R =	1.00	0.89	0.79	0.69	0.60	0.51	0.42	0.33	0.24	Means 0.56	
(a, a)													
5,586.991.....	Fe 7	1.000	0.890	0.769	0.565	0.500	0.295	0.250	0.200	0.080	0.444		
5,587.800.....	Fe 0	1.000	0.810	0.700	0.415	0.320	0.110	0.120	0.025	0.015	0.316		
5,588.084.....	Ni 1	1.000	0.830	0.630	0.435	0.235	0.070	0.130	0.000	0.055	0.298		
5,588.985, s.....	Ca 6	1.000	0.875	0.725	0.530	0.410	0.165	0.215	0.090	0.090	0.389		
5,589.582.....	Ni 0	1.000	0.870	0.665	0.475	0.395	0.145	0.220	0.040	-0.010	0.349		
5,590.343, s.....	Ca 3	1.000	0.840	0.675	0.435	0.350	0.165	0.170	0.065	0.045	0.343		
Means.....		2.8	1.000	0.855	0.695	0.480	0.365	0.160	0.185	0.075	0.045	0.358	
(b, β)													
3 weak lines.....		0.3	1.000	0.835	0.665	0.445	0.315	0.110	0.160	0.022	0.020	0.322	
3 strong lines.....		5.3	1.000	0.870	0.725	0.510	0.420	0.215	0.210	0.118	0.070	0.392	

Any differences in the effects of blending due to the differences in magnitude of the initial displacements are slight, as is seen from the decimal values in the (c) and (γ) parts of the tables. There may be a slightly greater lessening of the displacements due to blending, for the smaller than for the larger initial displacements.

The cause of the differential effects produced in blendings of spectra and dependent on the intensities of the spectrum lines, is traceable (as pointed out in the earlier measures of these plates, see foot-note on page 41) to the fact that the weak lines are relatively more weakened in the limb spectra than are the stronger lines.

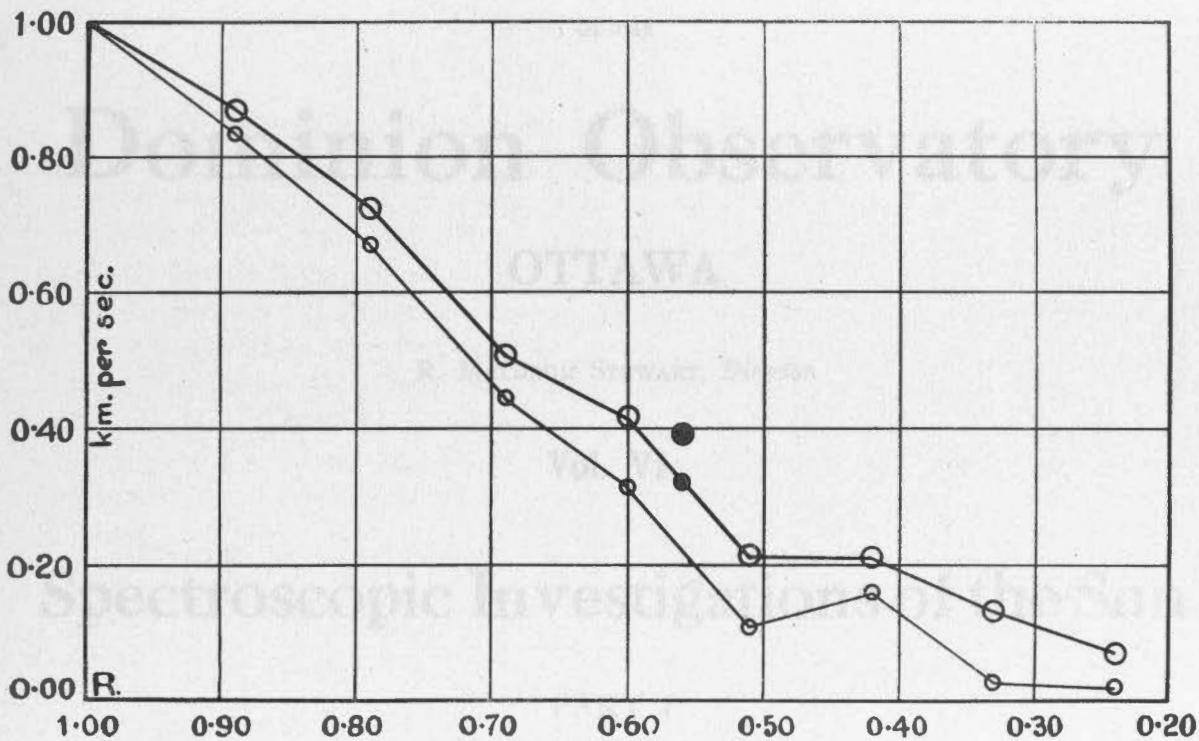


Figure 21—Differential Effects for Strong and Weak Lines in Blended Spectra.

Briefly, the conclusions from the present measurements of blended spectra are:—

- (1) There are differential effects in the blending of limb and centre solar spectra dependent on the intensities of the spectrum lines, and due to variations in the relative intensities of the lines in the two sources.
- (2) Similar differential effects in the unblended spectra are probably due to overlapping spectrum of haze.
- (3) There is possibly a slight difference in the proportion of the lessening of the displacements of the spectrum lines due to blending, dependent on the initial displacements of the lines, being greater for the smaller initial displacements than for the larger.

DOMINION OBSERVATORY,

OTTAWA,

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DEPARTMENT OF THE INTERIOR
CANADA

HON. THOMAS G. MURPHY, *Minister*

H. H. ROWATT, *Deputy Minister*

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Vol. VI

Spectroscopic Investigations of the Sun

PART I

GENERAL OUTLINE OF OBSERVATIONS, INSTRUMENTS, AND
METHODS—SECTION 7

BY

RALPH E. DE LURY

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GENERAL OUTLINE OF OBSERVATIONS, INSTRUMENTS AND METHODS

SECTION 7.—A DEVICE AND TABLES FOR COMPUTING THE COMPONENTS OF THE ORBITAL VELOCITY OF THE EARTH TO POINTS ON THE SUN

BY

RALPH E. DE LURY

In spectroscopic determinations of the rotational velocity of the sun, the correction to be applied to the observations due to the components of the earth's orbital velocity may be obtained with the aid of the table¹ given by Dunér for points on the solar limb relatively to the centre. The Ottawa observations made from 1913 on, however, include not only spectra from pairs of points within the limb, but also from the centre and intermediate positions, and from laboratory sources for determining spectrum wave-lengths and their variations for individual solar points. Consequently, the need arose for computing the component of the earth's orbital velocity to any point on the sun. For this purpose, and of course also for the determination of the difference between the components to any pair of points on the solar disc, the device described herein possesses advantages, especially for a considerable number of points on the sun observed at one time.

Using Chauvenet's notation, the angle i between the normal to the direction of the orbital motion of the earth and the radius vector is related to the eccentricity of the earth's orbit, e , and the true anomaly, u , by the equation:—

$$\tan i = \frac{e \sin u}{1 + e \cos u}$$

and since e is 0.01674, this becomes, in a form convenient for computation,

$$\cot i = 59.737 \operatorname{cosec} u + \cot u,$$

and u is, for year Y , $\odot - 281^\circ 39' - 1' . 03$ ($Y - 1925.0$). In Table XII are given the values of i corresponding to each degree in the range of values of u , from 0° to 180° when the normal to the earth's orbital motion is west of the radius vector, and from 180° to 360° when the normal is east of the radius vector.

The greatest value of i is $57' . 56$ when $\cos u$ is $-e$, or when u is $180^\circ \mp 89^\circ 2' . 45$, at which times the semi-diameter of the sun, s , is $16' . 03$; so that a point on the sun is at most about $73' . 6$ from the normal to the direction of the orbital motion of the earth. Sines of angles smaller than this are very closely proportional to the angles, and hence the computation of the components of the orbital velocity of the earth to points on the

¹ N. C. Dunér, Nova Acta Regiae Societatis Scientiarum Upsaliensis, Ser. IV, Vol. I, N. 6, p. 24, 1907.

sun may be reduced to linear graphical measurement when the value of i and the difference between the components of velocity to two points on the ecliptic near the radius vector have been determined. This difference follows readily from the zero velocity along the normal and the velocity along the radius vector determined from the change dR in the length of the radius vector in one day. However, for the smaller values of i and dR the scale of velocity-differences along the line of the ecliptic cannot be found with sufficient accuracy, so that in general the scale is derived from the difference between the components of the orbital velocity, $R \cdot \sec i \cdot d\odot : dt$, to the centre of the solar disc and to a limb point on the ecliptic, namely, $R \cdot \sec i \{ \sin(i+s) - \sin i \} \cdot d\odot : dt$, or very closely, $R \cdot \sin s \cdot d\odot : dt$, or $r \cdot d\odot : dt$, where r the radius of the sun is 695,553 km. Hence,

$$\begin{aligned} r \cdot d\odot : dt &= 0.002342 \cdot d\odot \text{ km. per sec. } (d\odot \text{ in minutes per day}) \\ &= 0.000937 \cdot d\odot \text{ km. per sec. } (d\odot \text{ in seconds per hour}). \end{aligned}$$

In this way the values of $r \cdot d\odot : dt$ of Table XIII were computed for the range in values of $d\odot$ per day and per hour.

In Table XIV are given the differences between the components of the earth's orbital velocity to the centre of the sun and to a point on the limb β° from the ecliptic, for the range of values of $d\odot$ per hour from $143''$ to $153''$, computed from the formula $r \cdot \cos \beta \cdot d\odot : dt$, to four figures, to insure an accuracy of interpolation to 0.001 km. per sec.

The angle p between the diameters of the solar disc lying in the planes of the ecliptic and the solar equator, with reference to which latter the observations are made, is readily computed from the heliographic latitude of the centre of the sun's disc, B_0 , as tabulated in the ephemerides, the relationship being derived as follows: in figure 22 the circle represents the limb of the sun, E the pole of the ecliptic and S the pole of the sun, C the point where the surface of the sun cuts the radius vector, and D the point where the equator of the sun is cut by the great circle through S and C . Then, p being equal to the angle ECS , it follows that,

$$\begin{aligned} \cos p &= \cos ES \cdot \sec DC \\ &= \cos 7^\circ 15' \cdot \sec B_0. \end{aligned}$$

Using this equation the values of p given in Table XV were computed for the range of values of the heliographic latitude of the centre of the solar disc, B_0 .

Early in June when the earth is ascending through the sun's equatorial plane, at which time \odot is N , say, the pole of the sun reaches its maximum separation of $7^\circ 25'$ westerly from the pole of the ecliptic. The solar pole appears west of the pole of the ecliptic during the interval when \odot varies from $N - 90^\circ$ to $N + 90^\circ$, and east of the pole of the ecliptic while \odot progresses from $N + 90^\circ$ to $N + 270^\circ$, N being, in accordance with Carrington's deductions, $74^\circ 42' 48'' \cdot 75 + 50'' \cdot 25$ ($Y - 1925 \cdot 0$), where Y is the year; or, in other words, p is measured west from the pole of the ecliptic while the heliographic latitude of the centre of the sun's disc, B_0 , varies from $-7^\circ 25'$ to $+7^\circ 25'$, and east from the pole of the ecliptic while B_0 varies from $+7^\circ 25'$ to $-7^\circ 25'$.

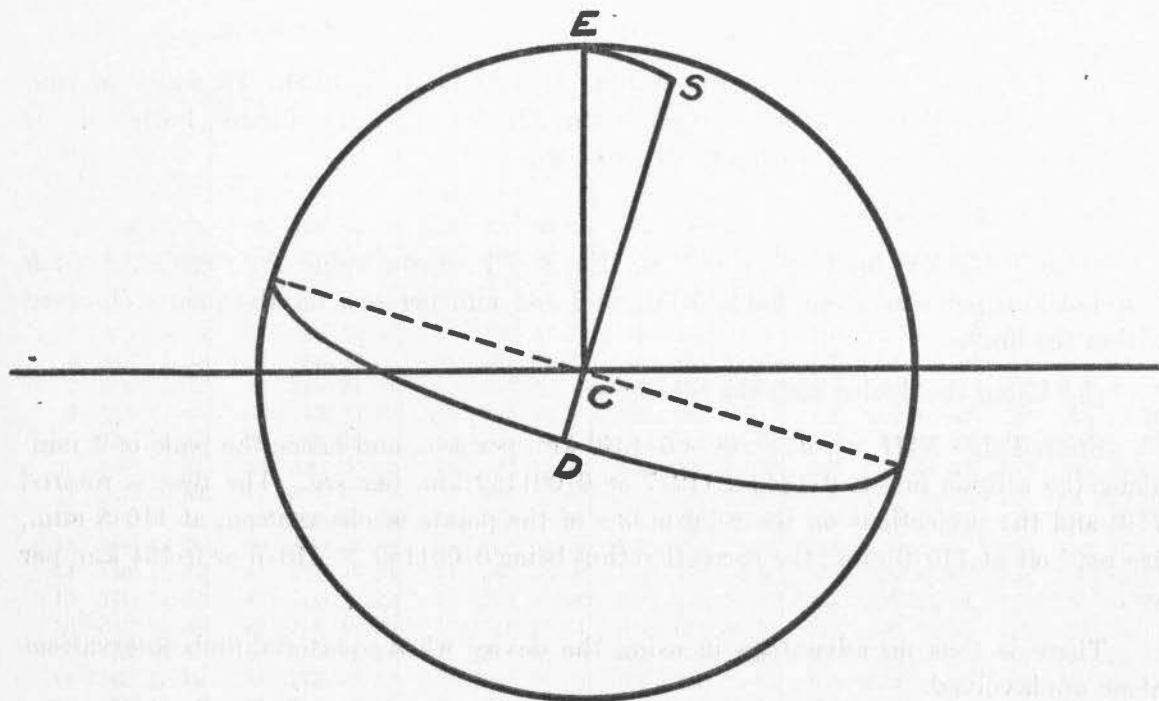


FIG. 22.

To facilitate the application of the tables to the computation of the several components of the orbital motion involved in a single observation, a device was constructed as follows:—

Three concentric circles of 110, 115, and 120 mm. radii were scratched on a strip of white celluloid—the radius of the solar image observed always lying within this range. Along the middle of the strip a straight line was scratched through the centre of the circles to represent the line of the ecliptic. This line was graduated in mm. and numbered at every cm. out to 430 mm. on each side of the centre. A sliding-scale, graduated in mm. and numbered at every 10 in both directions from 0 to 550 mm., was inset in the strip of film parallel and adjacent to the fixed scale. At intervals of 5 mm. out to 120 mm. on each side of the centre, lines were scratched perpendicular to the line representing the ecliptic and terminating at the circumference of the outer circle. Concentric with the circles is mounted, by external clamp-screws, a brass ring of 130 mm. external radius, graduated in degrees numbered at every ten from 0 to 360. The inner edge of the ring is bevelled to hold a disc of stiff transparent film, held also at the centre by a small bolt clamping it to the celluloid strip. Two diameters are scratched at right angles to one another on this transparent disc. The device is used to read the projected positions of the points of observation on the scale of the ecliptic, after first setting the brass ring p° from the ecliptic, pole from pole, and then rotating the transparent disc to the position angle of the observation measured around the brass ring. The following representative computations illustrate the methods employed, and fig. 23 shows the central part of the apparatus with the settings those of Example 3.

Example 1. Limbs at the solar equator.

Plate L 315, June 21, 11.34 a.m., or June 22, 4.34 G.M.T., 1909. Diameter of sun, 225.4 mm.; separation of points of observation, 221.5 mm.; ratio of these, 1.018. $d\odot$ is 57'.15 per day or 143''.13 per hour. B_\odot is 1°.89.

(a) Using the tables:—

From Table XV, for 1°.89, p is 7°.0. For $\beta = 7^\circ.0$, the value of $r \cdot \cos \beta \cdot d\odot : dt$ is 0.133 km. per sec., from Table XIV, or 0.131 km. per sec. for the points observed within the limb.

(b) Using the device with the tables:—

From Table XIII, $r \cdot d\odot : dt$ is 0.1340 km. per sec., and hence the scale of 1 mm. along the ecliptic line is 0.1340 : 112.7 or 0.001189 km. per sec. The disc is rotated 7°.0 and the projections on the ecliptic line of the points of observation, at 110.8 mm., are read off at 110.0 mm., the correction thus being 0.001189 × 110.0 or 0.131 km. per sec.

There is thus no advantage in using the device when equatorial limb observations alone are involved.

Example 2. Limbs at various position angles.

Plate L 889, June 8, 9.20 a.m., or June 9, 2.20 G.M.T., 1912. Positions, W 0° E, WN 15° ES, also 30°, 45°, 60°, 75°, 80°, 85°, and 90°. Diameter of Sun, 226.0 mm.; separation of the points of observation at the same focal plane, 219.6 + 1.4 or 221.0 mm.; ratio, 1.023. $d\odot$ is 143''.43 per hour, and B_\odot is 0°.35.

(a) Using the tables:—

The value of P , Table XV, is 7°.24, the north pole of the sun being west of the north pole of the ecliptic. By subtracting this angle from the position angles, the values of β are found; from Table XIV the corresponding values of $r \cdot \cos \beta \cdot d\odot : dt$ are read off, thus:—

Position	0°	15°	30°	45°	60°	75°	80°	85°	90°
β	-7°.24	7°.76	22°.76	37°.76	52°.76	67°.76	72°.76	77°.76	82°.76
km./sec.	0.133	0.133	0.124	0.106	0.081	0.051	0.040	0.028	0.017

These components to the limb points are reduced to the points of observation by dividing by 1.023.

TABLE XII.—ANGLE BETWEEN RADIUS VECTOR AND NORMAL TO THE EARTH'S ORBITAL MOTION

<i>u</i>	<i>i</i>	u	i	u	i	u	i	u	i	u	i	u	i
0 0	/	0 0	/	0 0	/	0 0	/	0 0	/	0 0	/	0 0	/
1 359	0.98	31 329	29.23	61 299	49.92	91 269	57.55	121 239	49.76	151 209	28.32		
2 358	1.99	32 328	30.07	62 298	50.42	92 268	57.55	122 238	49.24	152 208	27.43		
3 357	2.97	33 327	30.91	63 297	50.89	93 267	57.52	123 237	48.71	153 207	26.53		
4 356	3.96	34 326	31.74	64 296	51.35	94 266	57.48	124 236	48.16	154 206	25.62		
5 355	4.95	35 325	32.55	65 295	51.79	95 265	57.41	125 235	47.60	155 205	24.70		
6 354	5.93	36 324	33.38	66 294	52.22	96 264	57.32	126 234	47.02	156 204	23.78		
7 353	6.91	37 323	34.18	67 293	52.63	97 263	57.23	127 233	46.43	157 203	22.84		
8 352	7.89	38 322	34.97	68 292	53.02	98 262	57.12	128 232	45.82	158 202	21.90		
9 351	8.87	39 321	35.76	69 291	53.41	99 261	56.98	129 231	45.20	159 201	20.95		
10 350	9.85	40 320	36.52	70 290	53.77	100 260	56.84	130 230	44.57	160 200	20.00		
11 349	10.82	41 319	37.29	71 289	54.12	101 259	56.67	131 229	43.91	161 199	19.04		
12 348	11.79	42 318	38.03	72 288	54.45	102 258	56.49	132 228	43.25	162 198	18.07		
13 347	12.75	43 317	38.78	73 287	54.76	103 257	56.28	133 227	42.58	163 197	17.10		
14 346	13.71	44 316	39.50	74 286	55.06	104 256	56.06	134 226	41.88	164 196	16.13		
15 345	14.67	45 315	40.22	75 285	55.34	105 255	55.83	135 225	41.18	165 195	15.15		
16 344	15.63	46 314	40.92	76 284	55.61	106 254	55.58	136 224	40.47	166 194	14.16		
17 343	16.58	47 313	41.62	77 283	55.86	107 253	55.30	137 223	39.74	167 193	13.17		
18 342	17.52	48 312	42.30	78 282	56.09	108 252	55.01	138 222	38.99	168 192	12.18		
19 341	18.46	49 311	42.96	79 281	56.31	109 251	54.71	139 221	38.24	169 191	11.18		
20 340	19.39	50 310	43.62	80 280	56.51	110 250	54.39	140 220	37.48	170 190	10.17		
21 339	20.32	51 309	44.26	81 279	56.69	111 249	54.05	141 219	36.70	171 189	9.17		
22 338	21.24	52 308	44.89	82 278	56.86	112 248	53.70	142 218	35.91	172 188	8.16		
23 337	22.15	53 307	45.50	83 277	57.00	113 247	53.32	143 217	35.10	173 187	7.15		
24 336	23.06	54 306	46.11	84 276	57.13	114 246	52.93	144 216	34.30	174 186	6.13		
25 335	23.96	55 305	46.69	85 275	57.24	115 245	52.53	145 215	33.47	175 185	5.12		
26 334	24.86	56 304	47.27	86 274	57.34	116 244	52.14	146 214	32.64	176 184	4.10		
27 333	25.75	57 303	47.83	87 273	57.42	117 243	51.67	147 213	31.79	177 183	3.08		
28 332	26.63	58 302	48.37	88 272	57.48	118 242	51.21	148 212	30.94	178 182	2.06		
29 331	27.51	59 301	48.91	89 271	57.52	119 241	50.74	149 211	30.07	179 181	1.04		
30 330	28.37	60 300	49.43	90 270	57.54	120 240	50.26	150 210	29.20	180 180	0.00		

TABLE XIII.—DIFFERENCE BETWEEN COMPONENTS OF THE EARTH'S ORBITAL VELOCITY TO SOLAR CENTRE AND LIMB POINTS ON THE ECLIPTIC

$d\odot$ per day	$d\odot$ per hour	$r \frac{d\odot}{dt}$	$d\odot$ per day	$d\odot$ per hour	$r \frac{d\odot}{dt}$	$d\odot$ per day	$d\odot$ per hour	$r \frac{d\odot}{dt}$	$d\odot$ per day	$d\odot$ per hour	$r \frac{d\odot}{dt}$
'	"	km./sec.	'	"	km./sec.	'	"	km./sec.	'	"	km./sec.
.....	143.0	0.1339	58.2	145.5	0.1363	59.2	148.0	0.1386	60.2	150.5	0.1410
57.2	.1	.1340	.....	.6	.1364	.....	.1	.1387	.....	.6	.1411
.....	.2	.1341	58.3	.7	.1365	.....	.2	.1388	60.3	.7	.1412
57.3	.3	.1342	.....	.8	.1366	59.3	.3	.1389	.....	.8	.1413
.....	.4	.1343	.....	.9	.1367	.....	.4	.1390	.....	.9	.1413
57.4	.5	.1344	58.4	146.0	.1368	59.4	.5	.1391	.....	151.0	.1414
.....	.6	.1345	.....	.1	.1368	.....	.6	.1392	60.4	.1	.1415
.....	.7	.1346	.....	.2	.1369	59.5	.7	.1393	.....	.2	.1416
57.5	.8	.1347	58.5	.3	.1370	.....	.8	.1394	60.5	.3	.1417
.....	.9	.1348	.....	.4	.1371	.....	.9	.1395	.....	.4	.1418
57.6	144.0	.1349	58.6	.5	.1372	59.6	149.0	.1396	60.6	.5	.1419
.....	.1	.1350	.....	.6	.1373	.....	.1	.1397	.....	.6	.1420
57.7	.2	.1351	.....	.7	.1374	.....	.2	.1398	.....	.7	.1421
.....	.3	.1352	58.7	.8	.1375	59.7	.3	.1398	60.7	.8	.1422
.....	.4	.1353	.....	.9	.1376	.....	.4	.1399	.....	.9	.1423
57.8	.5	.1354	58.8	147.0	.1377	.....	.5	.1400	60.8	152.0	.1424
.....	.6	.1354	.....	.1	.1278	59.8	.6	.1401	.....	.1	.1425
.....	.7	.1355	58.9	.2	.1379	.....	.7	.1402	60.9	.2	.1426
57.9	.8	.1356	.....	.3	.1380	59.9	.8	.1403	.....	.3	.1427
.....	.9	.1357	.....	.4	.1381	.....	.9	.1404	.....	.4	.1428
58.0	145.0	.1358	59.0	.5	.1382	60.0	150.0	.1405	.....	.5	.1428
.....	.1	.1359	.....	.6	.1383	.....	.1	.1406	61.0	.6	.1429
.....	.2	.1360	59.1	.7	.1384	.....	.2	.1407	.....	.7	.1430
58.1	.3	.1361	.....	.8	.1384	60.1	.3	.1408	61.1	.8	.1431
.....	.4	.1362	.....	.9	.1385	.....	.4	.1409	.....	.9	.1432

TABLE XIV.—DIFFERENCE BETWEEN COMPONENTS OF THE EARTH'S ORBITAL VELOCITY
TO SOLAR CENTRE AND POINTS ON THE LIMB

β	$d \odot$ per hour										
	143''	144''	145''	146''	147''	148''	149''	150''	151''	152''	153''
°	km./sec.	km./sec.	km./sec.	km./sec.	km./sec.	km./sec.	km./sec.	km./sec.	km./sec.	km./sec.	km./sec.
0	0.1339	0.1349	0.1358	0.1368	0.1377	0.1386	0.1396	0.1405	0.1414	0.1424	0.1433
2	.1338	.1348	.1357	.1367	.1376	.1385	.1395	.1404	.1413	.1423	.1432
4	.1336	.1346	.1355	.1365	.1374	.1383	.1393	.1402	.1411	.1421	.1430
6	.1332	.1342	.1351	.1361	.1369	.1378	.1388	.1397	.1406	.1416	.1425
8	.1326	.1336	.1345	.1355	.1364	.1373	.1382	.1391	.1400	.1410	.1419
10	.1319	.1329	.1337	.1347	.1356	.1365	.1375	.1384	.1393	.1402	.1411
12	.1310	.1320	.1328	.1338	.1347	.1356	.1365	.1374	.1383	.1393	.1402
14	.1299	.1309	.1318	.1327	.1336	.1345	.1355	.1363	.1372	.1382	.1390
16	.1287	.1297	.1305	.1315	.1324	.1332	.1342	.1351	.1359	.1369	.1377
18	.1273	.1283	.1292	.1301	.1310	.1318	.1328	.1336	.1345	.1354	.1363
20	.1258	.1268	.1276	.1286	.1294	.1302	.1312	.1320	.1329	.1338	.1347
22	.1241	.1251	.1259	.1268	.1277	.1285	.1294	.1303	.1311	.1320	.1329
24	.1223	.1232	.1241	.1250	.1258	.1266	.1275	.1284	.1292	.1301	.1309
26	.1203	.1212	.1221	.1230	.1238	.1246	.1255	.1263	.1271	.1280	.1288
28	.1182	.1191	.1199	.1208	.1216	.1224	.1233	.1241	.1248	.1257	.1265
30	.1160	.1168	.1176	.1185	.1193	.1200	.1209	.1217	.1225	.1233	.1241
32	.1136	.1144	.1152	.1160	.1168	.1175	.1184	.1192	.1199	.1208	.1215
34	.1110	.1118	.1126	.1134	.1142	.1149	.1157	.1165	.1172	.1181	.1188
36	.1083	.1091	.1099	.1107	.1114	.1121	.1129	.1137	.1144	.1152	.1159
38	.1055	.1063	.1070	.1078	.1085	.1092	.1100	.1107	.1114	.1122	.1129
40	.1026	.1033	.1040	.1048	.1055	.1062	.1069	.1076	.1083	.1091	.1098
42	.0995	.1003	.1009	.1017	.1023	.1030	.1037	.1044	.1051	.1058	.1065
44	.0963	.0970	.0977	.0984	.0991	.0997	.1004	.1011	.1017	.1024	.1031
46	.0930	.0937	.0943	.0950	.0957	.0963	.0970	.0976	.0982	.0989	.0995
48	.0896	.0903	.0909	.0915	.0921	.0927	.0934	.0940	.0946	.0953	.0959
50	.0861	.0867	.0873	.0879	.0885	.0891	.0897	.0903	.0909	.0915	.0921
52	.0824	.0831	.0836	.0842	.0848	.0853	.0859	.0865	.0871	.0877	.0882
54	.0787	.0793	.0798	.0804	.0809	.0815	.0821	.0826	.0831	.0837	.0842
56	.0749	.0754	.0759	.0765	.0770	.0775	.0781	.0786	.0791	.0796	.0801
58	.0710	.0715	.0720	.0725	.0730	.0734	.0740	.0745	.0749	.0755	.0759
60	.0670	.0675	.0679	.0684	.0689	.0693	.0698	.0703	.0707	.0712	.0717
62	.0629	.0633	.0638	.0642	.0646	.0651	.0655	.0660	.0664	.0669	.0673
64	.0587	.0591	.0595	.0600	.0604	.0608	.0612	.0616	.0620	.0624	.0628
66	.0545	.0549	.0552	.0556	.0560	.0564	.0568	.0571	.0575	.0579	.0583
68	.0502	.0505	.0509	.0512	.0516	.0519	.0523	.0526	.0530	.0533	.0537
70	.0458	.0461	.0464	.0468	.0471	.0474	.0477	.0481	.0484	.0487	.0490
72	.0414	.0417	.0420	.0423	.0426	.0428	.0431	.0434	.0437	.0440	.0443
74	.0369	.0372	.0374	.0377	.0380	.0382	.0385	.0387	.0390	.0393	.0395
76	.0324	.0326	.0329	.0331	.0333	.0335	.0338	.0340	.0342	.0344	.0347
78	.0278	.0280	.0282	.0284	.0286	.0288	.0290	.0292	.0294	.0296	.0298
80	.0233	.0234	.0236	.0238	.0241	.0241	.0242	.0244	.0246	.0247	.0249
82	.0186	.0188	.0189	.0190	.0192	.0193	.0194	.0196	.0197	.0198	.0199
84	.0140	.0141	.0142	.0143	.0144	.0145	.0146	.0147	.0148	.0149	.0150
86	.0093	.0094	.0095	.0095	.0096	.0097	.0097	.0098	.0099	.0099	.0100
88	.0047	.0047	.0047	.0048	.0048	.0048	.0049	.0049	.0049	.0050	.0050

TABLE XV.—ANGLE BETWEEN ECLIPTIC AND EQUATORIAL DIAMETERS OF THE SOLAR DISC

B_o	p	$B_o$	$p$	$B_o$	$p$	$B_o$	$p$	$B_o$	$p$	$B_o$	$p$
°	°	°	°	°	°	°	°	°	°	°	°
7.25	0.00	7.05	1.70	6.70	2.78	6.00	4.03	4.90	5.35	2.90	6.65
7.24	0.38	7.04	1.74	6.68	2.82	5.95	4.15	4.80	5.44	2.80	6.69
7.23	0.54	7.03	1.78	6.66	2.87	5.90	4.22	4.70	5.53	2.70	6.73
7.22	0.67	7.02	1.82	6.64	2.92	5.85	4.29	4.60	5.61	2.60	6.78
7.21	0.76	7.01	1.86	6.62	2.96	5.80	4.36	4.50	5.69	2.50	6.81
7.20	0.85	7.00	1.89	6.60	3.01	5.75	4.42	4.40	5.77	2.40	6.84
7.19	0.93	6.98	1.97	6.58	3.05	5.70	4.49	4.30	5.84	2.30	6.88
7.18	1.01	6.96	2.04	6.56	3.09	5.65	4.55	4.20	5.92	2.20	6.91
7.17	1.08	6.94	2.10	6.54	3.14	5.60	4.61	4.10	5.98	2.10	6.94
7.16	1.14	6.92	2.17	6.52	3.18	5.55	4.67	4.00	6.05	2.00	6.97
7.15	1.20	6.90	2.23	6.50	3.22	5.50	4.73	3.90	6.12	1.80	7.02
7.14	1.26	6.88	2.29	6.45	3.32	5.45	4.78	3.80	6.18	1.60	7.07
7.13	1.32	6.86	2.35	6.40	3.42	5.40	4.84	3.70	6.24	1.40	7.11
7.12	1.37	6.84	2.41	6.35	3.51	5.35	4.90	3.60	6.30	1.20	7.15
7.11	1.42	6.82	2.47	6.30	5.60	5.30	4.95	3.50	6.35	1.00	7.18
7.10	1.47	6.80	2.52	6.25	3.68	5.25	5.01	3.40	6.41	0.80	7.21
7.09	1.52	6.78	2.57	6.20	3.77	5.20	5.06	3.30	6.46	0.60	7.23
7.08	1.57	6.76	2.63	6.15	3.85	5.15	5.11	3.20	6.51	0.40	7.24
7.07	1.61	6.74	2.68	6.10	3.93	5.10	5.16	3.10	6.56	0.20	7.25
7.06	1.65	6.72	2.73	6.05	4.00	5.00	5.26	3.00	6.60	0.00	7.25

TABLE XVI.—COMPONENTS OF THE EARTH'S ROTATIONAL VELOCITY TO THE CENTRE OF THE SUN FOR OTTAWA

 $0.3263 \cos \delta \sin t \text{ km./sec.}$

$t \backslash \delta$	0°	5°	10°	15°	20°	25°	$t \backslash \delta$	0°	5°	10°	15°	20°	25°
h m							h m						
0 5	0.0071	0.0071	0.0070	0.0068	0.0067	0.0064	3 5	0.2357	0.2348	0.2321	0.2277	0.2215	0.2136
10	.0143	.0142	.0140	.0138	.0134	.0129	10	.2406	.2396	.2369	.2323	.2261	.2180
15	.0213	.0213	.0210	.0206	.0200	.0193	15	.2453	.2444	.2417	.2369	.2305	.2224
20	.0284	.0283	.0280	.0274	.0267	.0256	20	.2500	.2490	.2462	.2415	.2348	.2266
25	.0355	.0354	.0350	.0343	.0334	.0322	25	.2536	.2527	.2506	.2458	.2391	.2306
30	.0426	.0424	.0419	.0411	.0400	.0386	30	.2581	.2572	.2541	.2500	.2433	.2351
35	.0497	.0495	.0489	.0479	.0466	.0450	35	.2632	.2622	.2592	.2541	.2473	.2385
40	.0567	.0565	.0558	.0547	.0533	.0514	40	.2673	.2663	.2633	.2581	.2511	.2423
45	.0636	.0634	.0627	.0615	.0598	.0577	45	.2713	.2703	.2672	.2621	.2549	.2459
50	.0707	.0704	.0696	.0680	.0663	.0640	50	.2752	.2742	.2710	.2658	.2585	.2494
55	.0776	.0773	.0764	.0749	.0729	.0704	55	.2790	.2779	.2747	.2694	.2621	.2528
1 0	.0844	.0841	.0831	.0815	.0793	.0765	4 0	.2826	.2816	.2784	.2729	.2655	.2561
5	.0913	.0910	.0900	.0882	.0857	.0827	5	.2861	.2850	.2818	.2763	.2688	.2593
10	.0981	.0977	.0966	.0948	.0924	.0890	10	.2894	.2884	.2851	.2796	.2719	.2624
15	.1048	.1045	.1033	.1015	.0985	.0951	15	.2926	.2915	.2882	.2827	.2749	.2653
20	.1116	.1112	.1105	.1078	.1048	.1011	20	.2957	.2946	.2913	.2856	.2778	.2680
25	.1182	.1178	.1165	.1142	.1111	.1072	25	.2987	.2976	.2941	.2884	.2807	.2707
30	.1249	.1244	.1229	.1206	.1173	.1132	30	.3015	.3004	.2969	.2911	.2833	.2732
35	.1314	.1309	.1295	.1270	.1234	.1191	35	.3041	.3030	.2996	.2937	.2858	.2756
40	.1379	.1374	.1358	.1332	.1296	.1250	40	.3066	.3055	.3020	.2961	.2881	.2779
45	.1444	.1437	.1421	.1394	.1356	.1308	45	.3090	.3078	.3043	.2985	.2903	.2801
50	.1507	.1501	.1484	.1456	.1415	.1365	50	.3112	.3100	.3065	.3006	.2914	.2821
55	.1569	.1564	.1546	.1516	.1475	.1422	55	.3132	.3121	.3085	.3026	.2943	.2839
2 0	.1632	.1625	.1607	.1576	.1533	.1479	5 0	.3151	.3140	.3104	.3044	.2961	.2857
5	.1693	.1687	.1668	.1635	.1590	.1534	5	.3170	.3157	.3121	.3061	.2979	.2873
10	.1753	.1747	.1727	.1693	.1648	.1589	10	.3186	.3174	.3137	.3077	.2994	.2887
15	.1812	.1806	.1785	.1751	.1703	.1643	15	.3201	.3189	.3151	.3091	.3007	.2900
20	.1872	.1865	.1844	.1807	.1758	.1696	20	.3214	.3202	.3163	.3104	.3020	.2912
25	.1929	.1922	.1900	.1864	.1812	.1749	25	.3225	.3213	.3176	.3115	.3030	.2923
30	.1986	.1979	.1956	.1918	.1867	.1800	30	.3235	.3223	.3186	.3124	.3040	.2932
35	.2043	.2035	.2011	.1972	.1919	.1851	35	.3244	.3232	.3194	.3132	.3048	.2940
40	.2097	.2090	.2066	.2026	.1971	.1901	40	.3251	.3239	.3201	.3139	.3054	.2946
45	.2151	.2144	.2119	.2078	.2022	.1950	45	.3256	.3244	.3207	.3144	.3059	.2951
50	.2204	.2196	.2171	.2129	.2072	.1998	50	.3260	.3248	.3211	.3148	.3063	.2954
55	.2257	.2248	.2223	.2179	.2120	.2045	55	.3262	.3250	.3213	.3150	.3065	.2956
3 0	.2307	.2299	.2273	.2229	.2168	.2091	6 0	.3263	.3251	.3214	.3151	.3066	.2957

(NOTE.—When using this table at another observatory, multiply the value derived from a given δ and t by the necessary factor).

(b) Using the device:—

The *N* pole of the graduated ring is rotated $7^{\circ}24' W$ of the *N* pole of the ecliptic. The observed point, 110.5 mm. from the centre, is marked on a diameter of the transparent disc measured on the mm. scale of the ecliptic. The disc is rotated so that its *N* pole coincides with the *N* pole of the ring, and the projection of the observed point on the ecliptic is read, corresponding to position 0° . The disc is rotated back 15° , 30° , and so on to 90° , and the projections of the marked point read on the ecliptic line. Since $d\odot$ is $143''43$, the scale per mm. along the ecliptic is $0.1343 : 113.0$ or 0.001189 km. per sec., and the projections are converted into km. per sec. values, thus:—

Position	0°	15°	30°	45°	60°	75°	80°	85°	90°
mm.	109.5	109.5	102.0	87.5	66.7	41.7	32.5	23.0	14.0
km./sec.	0.130	0.130	0.121	0.104	0.079	0.050	0.039	0.027	0.017

It is advantageous to use the device in such cases where there are many observed points at various position angles for the one setting of the graduated ring.

Example 3. Centre, intermediate, and limb points.

Plate L 2320, August 12, 3:13 - 18 (8:15 G.M.T.), 1917. Centre; a pair of points 57.0 mm. from centre, and a pair 111.0 mm. from centre at 15° (*WN - ES*); a pair at 111.0 mm. from centre at 75° (*NE - SW*). Diameter of sun, 226.0 mm.; $d\odot = 144''07$ per hour, so from Table XIII, $r : d\odot : dt$ is 0.1355 km. per sec.; and scale is $0.1355 : 113.0$ or 0.001199 km. per sec. for 1 mm. along the ecliptic line. B_0 is $+6^{\circ}55'$, and from Table XV, therefore, p is $3^{\circ}12'$; also $dR : dt$ is -0.299 km. per sec.

The device is advantageously used for such observations, thus: The *N* pole of the graduated ring is rotated $3^{\circ}12' W$ of the *N* pole of the ecliptic, and the *N* pole of the disc is placed $15^{\circ} E$ of the pole of the ring. All the observed points at 57.0 mm. and 111.0 mm. from the centre are marked permanently on the film as they are used in many observations. The projections of the points on the fixed mm. scale of the ecliptic are read and by multiplying these by 0.001199 the components relative to the centre are obtained, and from these the orbital components are found by adding -0.299 km. per sec., as follows:—

	<i>ES</i>	<i>ME</i>	<i>NE</i>	<i>C</i>	<i>SW</i>	<i>MW</i>	<i>WN</i>
mm.....	108.7	55.4	22.9	0	23.0	55.3	108.8
km./sec.....	0.130	0.066	0.027	0.000	-0.027	-0.066	-0.130
km./sec. -0.299.....	-0.169	-0.233	-0.272	-0.299	-0.326	-0.365	-0.429

Corresponding to the value of u for this plate, namely, $\odot - 281^{\circ}39' - 1'03$ (1917.6 - 1925.0) or $217^{\circ}99'$, the value of i from Table XII is $35'90$. The radius of the sun is $15'82$, which corresponds to 0.1355 km. per sec. along the ecliptic line, and consequently $35'90$ corresponds to -0.307 km. per sec. The disagreement of this value, involving $d\odot : dt$, with the value of $dR : dt$, -0.299 km. per sec., is attributable to the moon, Jupiter, and other planets. The value, -0.299 km. per sec., measured along the ecliptic

is 250·0 mm., and by setting the sliding-scale with its zero 250·0 mm. *E* of the centre, the components to the various points are read off directly:

mm.	141·4	194·6	227·3	250·0	273·0	305·2	358·8
km./sec.	-0·169	-0·233	-0·272	-0·299	-0·326	-0·365	-0·429

It may be noted here that while the effect of Jupiter is included in $dR : dt$, a rotational term, approximately $0\cdot012 \cdot \cos \beta$, remains.

In Table XVI are given the components to the sun of the earth's rotational velocity at Ottawa, $0\cdot3263 \cdot \cos \delta \cdot \sin t$ km. per sec. for every 5° declination of the sun, δ , and every 5 minutes of hour angle of the sun, t , to 6 hours. This value is derived from the distance, 4486·8 km., of the coelostat from the axis of rotation of the earth, computed from the expression $a^2 (a^2 + b^2 \tan^2 \phi)^{-0\cdot5} + 0\cdot084 \cos \phi$, using the values of Hayford's spheroid of 1909, the position of the coelostat being, latitude, ϕ , $45^\circ 23' 39''\cdot0$, longitude, 5h. 2 m. 51·9s., and elevation 275·4 feet or 0·084 km.

In employing Table XVI at other observatories it will be necessary only to multiply the interpolated readings by a factor.

DOMINION OBSERVATORY,

OTTAWA, CANADA,

June, 1928.

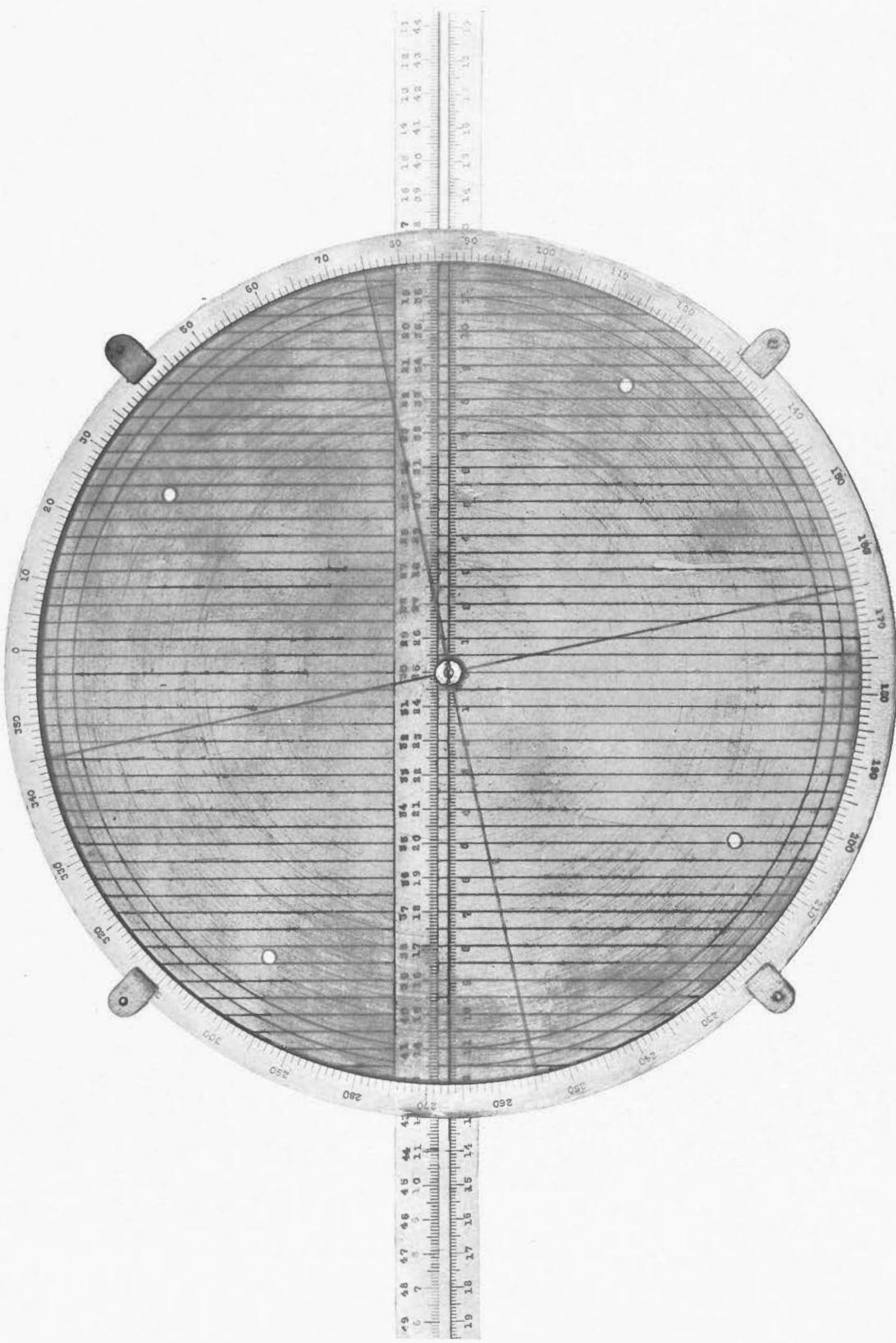


FIG. 23.—Device for Computing the Components of the Orbital Velocity of the Earth to Points on the Sun.

DEPARTMENT OF THE INTERIOR
CANADA

HON. THOMAS G. MURPHY, *Minister*

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Vol. VI

Spectroscopic Investigations of the Sun

PART I

GENERAL OUTLINE OF OBSERVATIONS, INSTRUMENTS, AND
METHODS—SECTIONS 8 and 9

BY

RALPH E. DELURY

OTTAWA
J. O. PATENAUME
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
1835

GENERAL OUTLINE OF OBSERVATIONS, INSTRUMENTS AND METHODS

SECTION 8—TABLES FOR COMPUTING THE HELIOGRAPHIC CO-ORDINATES, AND THE COMPONENT TO EARTH OF THE ROTATIONAL VELOCITY, OF AN OBSERVED POINT ON THE SUN

BY

RALPH E. DE LURY

The following tables facilitate the computation of heliographic co-ordinates and components of the velocity of the sun's rotation directed to the observer. The Ottawa series of spectroscopic observations of the solar rotation is so extensive that it is imperative to employ some such method of lessening considerably the time involved in the computations. A graduated sphere and co-ordinate frame, described in the next Section, was devised for similar purposes to those for which the tables are applicable.

The computation of heliographic positions of observed points on the solar disc is based on the adopted determinations¹ due to Carrington,

" $I = 7^\circ 15'$, and $N = 73^\circ 40'$ for 1850.0", where I is the inclination of the solar equator to the ecliptic, and N is the longitude of the ascending node on the solar equator. Subsequent determinations do not differ seriously from these values.

From I , N and \odot (longitude of the sun), B_\circ , the heliographic latitude of the centre of the solar disc, is determined from the following equation:

$$\sin B_\circ = \sin I \sin (\odot - N) \quad (1)$$

However, daily values of B_\circ are now published in the ephemerides².

In observing it is necessary to know P , the angle between the solar and terrestrial axes projected on the solar disc. This is determined by computing the following two angles (though now as in the case of B_\circ it may be read from an ephemeris):

p , the angle on the solar disc between the projected solar axis and the normal to the ecliptic, and

p' , the angle on the solar disc between the projected terrestrial axis and the normal to the ecliptic.

$$\text{Then } \tan p = \tan I \cos (\odot - N) \quad (2)$$

$$\tan p' = \tan \epsilon \cos \odot \quad (3)$$

or

$$\cos p = \cos I \sec B_\circ \quad (2a)$$

$$\cos p' = \cos \epsilon \sec \delta \quad (3a)$$

where ϵ is the obliquity of the ecliptic, and δ is the declination of the sun.

¹ R. C. Carrington, "Observations of Solar Spots", 1854-1861.

² "Ephemeris for Physical Observations of the Sun" in *The Nautical Almanac*, and in *The American Ephemeris and Nautical Almanac*.

(The angle p is also required in the computation of the components of the earth's orbital velocity to observed points on the sun, for which purpose it is convenient to tabulate it with reference to B_0 , as done by means of equation (2a) in the preceding Section 7.)

In practice, the direction of the "East-West line" is determined from the drifting of the solar image due to the earth's rotation or the rotating on its polar axis of the coelostat or telescope. The direction of the "equatorial diameter" of the solar disc is measured P° from the East-West line.

The position on the solar disc of an observed point is recorded by measuring:
 a , the position-angle between the equatorial diameter and the radius of the disc on which the observed point lies, and

r , the distance from the centre of the disc along that radius, expressed as a decimal of the length of the radius.

The two measurements, a and r , together with B_0 for the recorded time of the observation, and s , the angular semi-diameter of the sun, serve as follows in determining the heliographic co-ordinates and the angle between the line to the observer and the direction of the solar rotation of the observed point:

ρ , the heliocentric angle between the observer and the observed point on the solar disc, may be computed from the equation

$$\rho = \sin^{-1} r - rs \quad (4)$$

However, this computation is rendered unnecessary by the useful table, issued in 1878 by Warren de la Rue, of values of $\log \cos \rho$ and $\log \sin \rho$ for values of r progressing by thousandths of the radius from centre to limb of the disc, using the average value of s (which suffices for our purposes). The values of $\sin \rho$ and $\cos \rho$, used in computing the tables below, were derived from this table.

ϕ , the heliographic latitude, is computed by the equation

$$\sin \phi = \sin B_0 \cos \rho + \cos B_0 \sin \rho \sin a \quad (5)$$

This computation is greatly expedited by the use of Table XVII of $\sin B_0 \cos \rho$, and Table XVIII of $\cos B_0 \sin \rho$, arranged with arguments of B_0 and r .

In most series of observations of the solar rotation, the values of the position-angle a are selected from multiples of 5° , so that a table of the selected values of $\sin a$ should be convenient for performing (by machine) the multiplication in the last term. Since B_0 is at most $7^\circ 25$, the integral values of B_0 used in computing the tables suffice for interpolation; and likewise the values of r , in hundredths of the radius, permit of easy and accurate interpolation, particularly in Table XVIII, where 0.001 in the values of r corresponds to 0.0010 in the product throughout the table.

In rotation observations two points equidistant from the centre are usually observed on a diameter of the solar disc, so that it is convenient in the use of equation (5) to regard $\sin \phi$ as positive, the quadrant being indicated, and the two values of $\sin \phi$ apply as follows:

$$-\sin B_0 \cos \rho + \cos B_0 \sin \rho \sin a$$

for points in the half of the disc bounded by the equatorial diameter and containing the equator, and

$$+ \sin B_0 \cos \rho + \cos B_0 \sin \rho \sin \alpha$$

for points in the other half of the disc.

λ , the heliographic longitude, measured from the plane containing the axis of the sun and the radius vector, is computed from the equation

$$\sin \lambda = \sin \rho \cos \alpha \sec \phi \quad (6)$$

For this computation, $\sin \rho$ is taken from Table XVIII and multiplied by the product $\cos \alpha \sec \phi$ from Table XIX.

In Table XIX the values of ϕ progress by increments varying from 1° to $0^\circ.1$ to insure sufficiently accurate interpolation. The values of α progress by increments of 5° . When other than these standard values of α occur, the values of $\sec \phi$ included in Table XIX will be convenient for the multiplication. The values of ϕ are sufficiently extended to cover the interpolation for the greatest values of ϕ possible for each value of α . These maximum values occur at the values of ρ in the following equation:

$$\tan \rho = \cot 7^\circ 25 \sin \alpha \quad (7)$$

γ_0 , the angle between the radius vector and the pole of the plane containing the solar axis and the observed point³, may be determined from the equation

$$\cos \gamma_0 = \cos B_0 \sin \lambda \quad (8)$$

$$= \cos B_0 \sin \rho \cos \alpha \sec \phi \quad (9)$$

It is readily computed by multiplying the selected value of $\cos B_0 \sin \rho$ from Table XVIII by $\cos \alpha \sec \phi$ from Table XIX.

The angle γ_0 is approximately the inclination between the direction of the solar rotation at the observed point and the line from the point to the observer, since s , the angular semi-diameter of the sun, is very small.

γ , the angle between the pole of the plane normal to the line from the observer to the observed point, and the pole of the plane containing the solar axis and the observed point, may be computed from the equation

$$\cos \gamma = \cos (B_0 \pm rs \sin \alpha) \sin (\lambda + rs \cos \alpha) \quad (10)$$

where $B_0 + rs \sin \alpha$ applies to points in the half of the solar disc bounded by the equatorial diameter which contains the equator, and $B_0 - rs \sin \alpha$, to points in the other half.

The component toward the observer of the velocity of the sun's rotation, V , at the observed point, is

$$V \cos \gamma \quad (11)$$

³ N. C. Dunér, in his pioneer spectroscopic investigations of the solar rotation, computed a table of values of this angle for the special case of observed points on the solar limb.

The difference between $\cos \gamma$ and $\cos \gamma_0$ is small and for points very near the limb or the axis it may be neglected; but for points on other parts of the disc the difference is appreciable. $\cos \gamma$ may be derived rapidly from $\cos \gamma_0$ by the addition of a small number tabulated in Table XX. This addendum is derived as follows:

Since B_0 is at most $7^{\circ} \cdot 25$ and $rs \sin a$ has a maximum value of about $16'$, the error in using $\cos B_0$ for $\cos(B_0 \pm rs \sin a)$ cannot exceed 1 part in about 1650, and this largest error occurs only for points near the poles of the sun. (If desired, however, the modified B_0 may be used instead of B_0 in selecting the product from Table XVIII.) Hence, approximately,

$$\begin{aligned}\cos \gamma &= \cos B_0 \sin(\lambda + rs \cos a) \\ &= \cos B_0 (\sin \lambda + \cos \lambda r \cos a \sin s) \\ &= \cos B_0 (\sin \lambda + \cos \lambda \sin \rho \cos a \sin s) \\ &= \cos B_0 (\sin \lambda + \sin \lambda \cos \lambda \cos \phi \sin s), \text{ from equation (6).}\end{aligned}$$

Hence, since $\cos B_0$ is never less than 0.9920, it follows to a sufficiently close approximation that

$$\begin{aligned}\cos \gamma &= \cos B_0 \sin \lambda + \sin \lambda \cos \lambda \cos \phi \sin s, \text{ or} \\ \cos \gamma &= \cos \gamma_0 + \sin \lambda \cos \lambda \cos \phi \sin s,\end{aligned}\tag{12}$$

in which the (average) value of $\sin s$ is 0.0047. The addendum never exceeds 0.0023, having its maximum values when $\lambda = 45^\circ$.

The tables were computed by machine multiplication of the natural trigonometric functions. The values of the factors used and the computations were checked by Mr. John L. O'Connor. It is believed that the use of the tables will yield the various desired angles to the nearest tenth of a degree, which is as accurate as the usual observations justify.

DOMINION OBSERVATORY,
OTTAWA, CANADA,
December, 1933.

TABLE XVII—VALUES OF $\sin B_0 \cos \rho$, FOR VALUES OF B_0 AND r

r	$\cos \rho$	B_0							r	$\cos \rho$	B_0						
		1°	2°	3°	4°	5°	6°	7°			1°	2°	3°	4°	5°	6°	7°
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
10	99995	0174	0349	0523	0698	0872	1045	1219	510	86139	0150	0301	0451	0601	0751	0900	1050
20	99979	0174	0349	0523	0697	0871	1045	1218	20	85542	0149	0299	0448	0597	0746	0894	1043
30	99956	0174	0349	0523	0697	0871	1045	1218	30	84930	0148	0296	0445	0592	0740	0888	1035
40	99922	0174	0349	0523	0697	0871	1044	1218	40	84302	0147	0294	0441	0588	0735	0881	1027
50	99876	0174	0349	0523	0697	0871	1044	1217	50	83657	0146	0292	0438	0584	0729	0874	1020
60	99821	0174	0348	0522	0696	0870	1043	1217	60	82995	0145	0290	0434	0579	0723	0868	1011
70	99756	0174	0348	0522	0696	0869	1043	1216	70	82315	0144	0287	0431	0574	0717	0860	1003
80	99683	0174	0348	0522	0695	0869	1042	1215	80	81619	0142	0285	0427	0569	0711	0853	0995
90	99598	0174	0348	0521	0695	0868	1041	1214	90	80902	0141	0282	0423	0564	0705	0846	0986
100	99504	0174	0347	0521	0694	0867	1040	1213	600	80168	0140	0280	0420	0559	0699	0838	0977
10	99399	0173	0347	0520	0693	0866	1039	1211	10	79413	0139	0277	0416	0554	0692	0830	0968
20	99284	0173	0347	0520	0693	0865	1038	1210	20	78639	0137	0274	0412	0549	0685	0822	0958
30	99159	0173	0346	0519	0692	0864	1037	1208	30	77845	0136	0272	0407	0543	0678	0814	0949
40	99024	0173	0346	0518	0691	0863	1035	1207	40	77028	0134	0269	0403	0537	0671	0805	0939
50	98878	0173	0345	0518	0690	0862	1034	1205	50	76190	0133	0266	0399	0532	0664	0796	0929
60	98723	0172	0345	0517	0689	0860	1032	1203	60	75329	0131	0263	0394	0525	0657	0787	0918
70	98558	0172	0344	0516	0688	0859	1030	1201	70	74444	0130	0260	0390	0519	0649	0778	0907
80	98381	0172	0343	0515	0686	0857	1028	1199	80	73536	0128	0257	0385	0513	0641	0769	0896
90	98195	0171	0343	0514	0685	0856	1026	1197	90	72602	0127	0253	0380	0506	0633	0759	0885
200	97999	0171	0342	0513	0684	0854	1024	1194	700	71642	0125	0250	0375	0500	0624	0749	0873
10	97791	0171	0341	0512	0682	0852	1022	1192	10	70655	0123	0247	0370	0493	0616	0739	0861
20	97573	0170	0341	0511	0681	0850	1020	1189	20	69639	0122	0243	0364	0486	0607	0728	0849
30	97344	0170	0340	0509	0679	0848	1018	1186	30	68593	0120	0239	0359	0479	0598	0717	0836
40	97105	0169	0339	0508	0677	0846	1015	1183	40	67515	0118	0236	0353	0471	0588	0706	0823
50	96855	0169	0338	0507	0676	0844	1012	1180	50	66406	0116	0232	0348	0463	0579	0694	0809
60	96592	0169	0337	0506	0674	0842	1010	1177	60	65262	0114	0228	0342	0455	0569	0682	0795
70	96321	0168	0336	0504	0672	0840	1007	1174	70	64081	0112	0224	0335	0447	0559	0670	0781
80	96037	0168	0335	0503	0670	0837	1004	1170	80	62861	0110	0219	0329	0439	0548	0657	0766
90	95741	0167	0334	0501	0668	0834	1001	1167	90	61601	0107	0215	0322	0430	0537	0644	0751
300	95436	0167	0333	0500	0666	0832	0998	1163	800	60298	0105	0210	0316	0421	0526	0630	0735
10	95117	0166	0332	0498	0664	0829	0994	1159	10	58948	0103	0206	0309	0411	0514	0616	0718
20	94789	0165	0331	0496	0661	0826	0991	1155	20	57549	0100	0201	0301	0401	0502	0602	0701
30	94450	0165	0330	0494	0659	0823	0987	1151	30	56097	0098	0196	0294	0391	0489	0586	0684
40	94096	0164	0328	0492	0656	0820	0984	1147	40	54587	0095	0191	0286	0381	0476	0571	0665
50	93732	0164	0327	0491	0654	0817	0980	1142	50	53015	0093	0185	0277	0370	0462	0554	0646
60	93356	0163	0326	0489	0651	0814	0976	1138	60	51374	0090	0179	0269	0358	0448	0537	0626
70	92967	0162	0324	0487	0649	0810	0972	1133	70	49658	0087	0173	0260	0346	0433	0519	0605
80	92566	0162	0323	0484	0646	0807	0968	1128	80	47858	0084	0167	0250	0334	0417	0500	0583
90	92151	0161	0322	0482	0643	0803	0963	1123	90	45965	0080	0160	0241	0321	0401	0480	0560
400	91725	0160	0320	0480	0640	0799	0959	1118	900	43966	0077	0153	0230	0307	0383	0460	0536
10	91287	0159	0319	0478	0637	0796	0954	1113	10	41850	0073	0146	0219	0292	0365	0437	0510
20	90834	0159	0317	0475	0634	0792	0949	1107	20	39582	0069	0138	0207	0276	0345	0414	0482
30	90369	0158	0315	0473	0630	0788	0945	1101	30	37162	0065	0130	0195	0259	0324	0388	0453
40	89890	0157	0314	0470	0627	0783	0940	1095	40	34530	0060	0121	0181	0241	0301	0361	0421
50	89396	0156	0312	0468	0624	0779	0934	1089	50	31645	0055	0110	0166	0221	0276	0331	0386
60	88891	0155	0310	0465	0620	0775	0929	1083	60	28432	0050	0099	0149	0198	0248	0297	0347
70	88369	0154	0308	0463	0616	0770	0924	1077	70	24751	0043	0087	0130	0173	0216	0259	0302
80	87833	0153	0307	0460	0613	0766	0918	1070	80	20347	0036	0071	0106	0142	0177	0213	0248
90	87283	0152	0305	0457	0609	0761	0912	1064	90	14565	0025	0051	0076	0102	0127	0152	0178
500	86718	0151	0303	0454	0605	0756	0906	1057	000	00467	0001	0002	0003	0004	0005	0006	

TABLE XVIII—VALUES OF $\cos B_0 \sin \rho$, FOR VALUES OF B_0 AND r

r	$\sin \rho$	B_0							r	$\sin \rho$	B_0						
		1°	2°	3°	4°	5°	6°	7°			1°	2°	3°	4°	5°	6°	7°
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
10	0.0995	0.099	0.099	0.099	0.099	0.099	0.099	0.099	510	50795	5079	5076	5073	5067	5060	5052	5042
20	0.1991	0.199	0.199	0.199	0.199	0.198	0.198	0.198	20	51793	5179	5176	5172	5167	5160	5151	5141
30	0.2986	0.299	0.298	0.298	0.298	0.297	0.297	0.296	30	52790	5278	5276	5272	5266	5259	5250	5240
40	0.3981	0.398	0.398	0.398	0.397	0.397	0.396	0.395	40	53787	5378	5375	5371	5366	5358	5349	5339
50	0.4977	0.498	0.497	0.497	0.496	0.496	0.494	0.	50	54786	5478	5475	5471	5465	5458	5449	5438
60	0.5972	0.597	0.597	0.596	0.596	0.595	0.594	0.593	60	55784	5578	5575	5571	5565	5557	5548	5537
70	0.6966	0.696	0.696	0.696	0.695	0.694	0.693	0.691	70	56782	5677	5675	5670	5664	5657	5647	5636
80	0.7963	0.796	0.796	0.795	0.794	0.793	0.792	0.790	80	57779	5777	5774	5770	5764	5756	5746	5735
90	0.8958	0.896	0.895	0.895	0.894	0.892	0.891	0.889	90	58777	5877	5874	5870	5863	5855	5845	5834
100	0.9954	0.995	0.995	0.994	0.993	0.992	0.990	0.988	600	59776	5977	5974	5969	5963	5955	5945	5933
10	1.0950	1.095	1.094	1.093	1.092	1.091	1.089	1.087	10	60774	6076	6074	6069	6063	6054	6044	6032
20	1.1945	1.194	1.194	1.193	1.192	1.190	1.188	1.186	20	61773	6176	6174	6169	6162	6154	6143	6131
30	1.2939	1.294	1.293	1.292	1.291	1.289	1.287	1.284	30	62771	6276	6273	6269	6262	6253	6243	6230
40	1.3935	1.393	1.393	1.392	1.390	1.388	1.386	1.383	40	63771	6376	6373	6368	6362	6353	6342	6330
50	1.4931	1.493	1.492	1.491	1.489	1.487	1.485	1.482	50	64769	6476	6473	6468	6461	6452	6441	6429
60	1.5926	1.592	1.592	1.590	1.589	1.587	1.584	1.581	60	65769	6576	6573	6568	6561	6552	6541	6528
70	1.6920	1.692	1.691	1.690	1.688	1.686	1.683	1.679	70	66768	6676	6673	6668	6661	6651	6640	6627
80	1.7917	1.791	1.791	1.789	1.787	1.785	1.782	1.778	80	67767	6776	6773	6767	6760	6751	6740	6726
90	1.8913	1.891	1.890	1.889	1.887	1.884	1.881	1.877	90	68767	6876	6873	6867	6860	6850	6839	6825
200	1.9909	1.991	1.990	1.988	1.986	1.983	1.980	1.976	700	69767	6976	6972	6967	6960	6950	6938	6925
10	2.0904	2.090	2.089	2.088	2.085	2.082	2.079	2.075	10	70767	7076	7072	7067	7059	7050	7038	7024
20	2.1900	2.190	2.189	2.187	2.185	2.182	2.178	2.174	20	71766	7176	7172	7167	7159	7149	7137	7123
30	2.2895	2.289	2.288	2.286	2.284	2.281	2.277	2.272	30	72766	7276	7272	7267	7259	7249	7237	7222
40	2.3891	2.389	2.388	2.386	2.383	2.380	2.376	2.371	40	73768	7376	7372	7367	7359	7349	7336	7322
50	2.4887	2.488	2.487	2.485	2.483	2.479	2.475	2.470	50	74769	7476	7472	7467	7459	7448	7436	7421
60	2.5883	2.588	2.587	2.585	2.582	2.578	2.574	2.569	60	75769	7576	7572	7567	7558	7548	7535	7520
70	2.6879	2.687	2.686	2.684	2.681	2.678	2.673	2.668	70	76770	7676	7672	7666	7658	7648	7635	7620
80	2.7875	2.787	2.786	2.784	2.781	2.777	2.772	2.767	80	77771	7776	7772	7766	7758	7747	7734	7719
90	2.8871	2.887	2.885	2.883	2.880	2.876	2.871	2.866	90	78773	7876	7872	7867	7858	7847	7834	7819
300	2.9866	2.986	2.985	2.983	2.979	2.975	2.970	2.964	800	79776	7976	7973	7967	7958	7947	7934	7918
10	3.0862	3.086	3.084	3.082	3.079	3.074	3.069	3.063	10	80777	8076	8073	8067	8058	8047	8033	8018
20	3.1859	3.185	3.184	3.182	3.178	3.174	3.168	3.162	20	81781	8177	8173	8167	8158	8147	8133	8117
30	3.2855	3.285	3.283	3.281	3.277	3.273	3.267	3.261	30	82783	8277	8273	8267	8258	8247	8233	8217
40	3.3851	3.385	3.383	3.380	3.377	3.372	3.367	3.360	40	83788	8378	8374	8367	8358	8347	8333	8316
50	3.4847	3.484	3.483	3.480	3.476	3.471	3.466	3.459	50	84791	8478	8474	8467	8458	8447	8433	8416
60	3.5843	3.584	3.582	3.579	3.576	3.571	3.565	3.558	60	85795	8578	8574	8568	8559	8547	8532	8516
70	3.6840	3.683	3.682	3.679	3.675	3.670	3.664	3.657	70	86800	8679	8675	8668	8659	8647	8632	8615
80	3.7836	3.783	3.781	3.778	3.774	3.769	3.763	3.755	80	87805	8779	8775	8768	8759	8747	8732	8715
90	3.8833	3.883	3.881	3.878	3.874	3.869	3.862	3.854	90	88810	8880	8876	8869	8859	8847	8832	8815
400	3.9829	3.982	3.980	3.977	3.973	3.968	3.961	3.953	900	89817	8980	8976	8969	8960	8947	8932	8915
10	4.0825	4.082	4.080	4.077	4.073	4.067	4.060	4.052	10	90824	9081	9077	9070	9060	9048	9033	9015
20	4.1823	4.182	4.180	4.177	4.172	4.166	4.159	4.151	20	91831	9182	9177	9171	9161	9148	9133	9115
30	4.2818	4.281	4.279	4.276	4.271	4.265	4.258	4.250	30	92839	9283	9278	9271	9261	9249	9233	9215
40	4.3816	4.381	4.379	4.376	4.371	4.365	4.358	4.349	40	93849	9383	9379	9372	9362	9349	9333	9315
50	4.4813	4.481	4.479	4.475	4.470	4.464	4.457	4.448	50	94862	9485	9480	9473	9463	9450	9434	9416
60	4.5809	4.580	4.578	4.575	4.570	4.563	4.556	4.547	60	95874	9586	9582	9574	9564	9551	9535	9516
70	4.6807	4.680	4.678	4.674	4.669	4.663	4.655	4.646	70	96888	9687	9683	9676	9665	9652	9636	9617
80	4.7804	4.780	4.777	4.774	4.769	4.762	4.754	4.745	80	97908	9789	9785	9777	9767	9753	9737	9718
90	4.8801	4.879	4.877	4.873	4.868	4.862	4.853	4.844	90	98933	9892	9887	9880	9869	9856	9839	9820
500	4.9798	4.979	4.977	4.973	4.968	4.961	4.953	4.943	000	99999	9998	9994	9986	9976	9962	9945	9925

a	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85
$\sin a$	0.872	1.736	2.588	3.420	4.226	5.000	5.736	6.428	7.071	7.660	8.192	8.660	9.063	9.397	9.659	9.848	9.962

TABLE XIX—VALUES OF $\cos \alpha \sec \phi$ FOR STANDARD VALUES OF α , AND THE POSSIBLE
VALUES OF ϕ

ϕ	sec ϕ	α																	
		5°	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	60°	65°	70°	75°	80°	85°	
0°	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	
0	0000	9962	9848	9659	9397	9063	8660	8192	7660	7071	6428	5736	5000	4226	3420	2588	1736	0872	
1	0002	9963	9850	9661	9398	9064	8662	8193	7662	7072	6429	5737	5001	4227	3421	2589	1737	0872	
2	0006	9968	9854	9665	9403	9069	8666	8196	7665	7075	6432	5739	5003	4229	3422	2590	1738	0872	
3	0014	9976	9862	9673	9410	9076	8672	8203	7671	7081	6437	5744	5007	4232	3425	2592	1739	0873	
4	0024	9986	9872	9683	9420	9085	8681	8211	7679	7088	6444	5750	5012	4237	3429	2595	1741	0874	
5	0038	1.	9886	9696	9433	9098	8693	8223	7690	7098	6452	5758	5019	4242	3433	2598	1743	0875	
6	0055	0017	9902	9713	9449	9113	8708	8237	7703	7110	6463	5767	5028	4249	3439	2602	1746	0876	
7	0075	0037	9922	9732	9467	9131	8725	8253	7718	7124	6476	5779	5038	4258	3446	2608	1750	0878	
8	0098	0060	9945	9754	9489	9152	8745	8272	7736	7141	6491	5792	5049	4268	3454	2614	1754	0880	
9	0125	0086	9971	9780	9514	9176	8768	8294	7756	7159	6508	5807	5062	4279	3463	2620	1758	0882	
10	0154	.	1.	9808	9542	9203	8794	8318	7779	7180	6527	5824	5077	4291	3473	2628	1763	0885	
11	0187	.	0032	9840	9573	9233	8822	8345	7804	7203	6548	5843	5094	4305	3484	2637	1769	0888	
12	0223	.	0068	9875	9607	9266	8854	8374	7832	7229	6571	5864	5112	4321	3497	2646	1775	0891	
13	0263	.	0107	9913	9644	9301	8888	8407	7862	7257	6597	5887	5132	4337	3510	2656	1782	0895	
14	0306	.	0955	9685	9341	8925	8442	7895	7288	6625	5911	5153	4356	3525	2667	1790	0898		
15	0353	.	1.	9728	9383	8966	8480	7931	7321	6655	5938	5176	4375	3541	2680	1798	0902		
16	0403	.	0049	9776	9428	9009	8522	7969	7356	6687	5967	5202	4397	3558	2693	1806	0907		
17	0457	.	0101	9826	9477	9056	8566	8010	7394	6722	5998	5228	4419	3576	2706	1816	0911		
18	0515	.	0980	9529	9106	8613	8055	7435	6759	6031	5257	4444	3596	2721	1826	0916			
19	0576	.	09938	9585	9159	8663	8102	7479	6798	6066	5288	4470	3617	2737	1837	0922			
20	0642	.	1.	9645	9216	8717	8152	7525	6840	6104	5321	4497	3640	2754	1848	0928			
21	0712	.	0065	9708	9276	8774	8205	7574	6885	6144	5356	4527	3664	2772	1860	0934			
22	0785	.	0135	9775	9340	8835	8262	7626	6933	6186	5393	4558	3689	2891	1873	0940			
23	0864	.	09846	9408	8899	8322	7682	6983	6231	5432	4591	3716	2812	1886	0947				
24	0946	.	09921	9480	8967	8385	7740	7036	6279	5473	4526	3744	2833	1901	0954				
25	1034	.	1.	9556	9038	8452	7802	7092	6329	5517	4663	3774	2856	1916	0962				
26	1126	.	0084	9635	9114	8523	7867	7152	6382	5563	4702	3805	2880	1932	0970				
27	1223	.	09720	9194	8597	7936	7214	6437	5612	4743	3839	2905	1949	0978					
28	1326	.	09808	9277	8676	8009	7280	6496	5663	4786	3874	2931	1967	0987					
29	1434	.	09902	9366	8759	8085	7349	6558	5717	4832	3910	2959	1985	0997					
30	1547	.	1.	9459	8845	8165	7422	6623	5774	4880	3949	2989	2005	1006					
31	1666	.	0103	9556	8937	8249	7499	6692	5833	4930	3990	3019	2026	1017					
32	1792	.	09659	9033	8338	7580	6764	5896	4983	4033	3052	2048	1028						
33	1924	.	09767	9134	8431	7664	6839	5962	5039	4078	3086	2071	1039						
34	2062	.	09881	9240	8529	7753	6919	6031	5098	4126	3122	2095	1051						
35	2208	.	1.	9352	8632	7847	7002	6104	5159	4175	3160	2120	1064						
36	2361	.	0125	9469	8740	7945	7090	6180	5224	4228	3199	2146	1077						
37	2521	.	09592	8854	8049	7182	6261	5292	4283	3241	2174	1091							
38	2690	.	09721	8973	8157	7279	6345	5363	4340	3284	2204	1106							
39	2868	.	09857	9099	8271	7381	6434	5438	4401	3330	2234	1122							
40	3054	.	1.	9231	8391	7488	6527	5517	4465	3379	2267	1138							
41	3250	.	0150	9369	8517	7600	6625	5600	4532	3429	2301	1155							
42	3456	.	09515	8650	7718	6728	5687	4602	3483	2337	1173								
43	3673	.	09669	8789	7843	6837	5779	4677	3539	2374	1192								
44	3902	.	09830	8936	7974	6951	5875	4755	3598	2414	1212								
45	4142	.	1.	9090	8112	7071	5977	4837	3660	2456	1233								

TABLE XIX—Continued

ϕ	sec ϕ	α								ϕ	sec ϕ	α							
		50°	55°	60°	65°	70°	75°	80°	85°			55°	60°	65°	70°	75°	80°	85°	
°	1.	0.	0.	0.	0.	0.	0.	0.	0.	°	1.	0.	0.	0.	0.	0.	0.	0.	0.
45.0	4142	9090	8112	7071	5977	4837	3660	2456	1233	53.0	6616	9531	8308	7022	5683	4301	2885	1448	
.5	4267	9171	8183	7134	6030	4880	3693	2477	1244	.5	6812	9643	8406	7105	5750	4351	2919	1465	
46.0	4396	9253	8257	7198	6084	4924	3726	2500	1255	54.0	7013	9758	8507	7190	5819	4403	2954	1483	
.5	4527	9338	8334	7264	6140	4969	3760	2523	1266	.5	7221	9877	8610	7278	5890	4457	2990	1501	
47.0	4663	9425	8410	7331	6197	5015	3795	2546	1278	55.0	7435	1.	8717	7368	5963	4512	3028	1520	
.5	4802	9515	8490	7401	6256	5063	3831	2570	1290	.5	7655	0127	8828	7461	6038	4570	3066	1539	
48.0	4945	9606	8572	7472	6316	5111	3868	2595	1303	56.0	7883	.....	8941	7558	6116	4628	3105	1559
.5	5092	9701	8656	7546	6378	5162	3906	2621	1315	.5	8118	.....	9059	7657	6197	4689	3146	1579
49.0	5243	9798	8743	7621	6442	5213	3945	2647	1329	57.0	8361	.....	9180	7760	6280	4752	3188	1600
.5	5398	9897	8832	7699	6507	5266	3985	2674	1342	.5	8612	.....	9306	7866	6366	4817	3232	1622
50.0	5557	1.	8923	7779	6575	5321	4027	2702	1356	58.0	8871	.....	9435	7975	6454	4884	3277	1645
.5	5721	0105	9017	7861	6644	5377	4069	2730	1370	7.5	9139	.....	9569	8088	6546	4954	3323	1668
51.0	5890	.....	9114	7945	6716	5435	4113	2759	1385	59.0	9416	.....	9708	8206	6641	5025	3372	1692
.5	6064	.....	9214	8032	6789	5494	4158	2789	1400	.5	9703	.....	9851	8327	6739	5100	3421	1717
.2	2.	.....	.....	.....	.....	.....	.....	.....	2.	.....	.....	.....	.....	.....	.....	.....	.....	.....
52.0	6243	.....	9316	8121	6864	5555	4204	2821	1416	60.0	0000	.....	1.	8452	6840	5176	3473	1743
.5	6427	.....	9422	8213	6942	5618	4252	2853	1432	.5	0308	.....	0154	8582	6946	5256	3526	1770
ϕ	sec ϕ	α								ϕ	sec ϕ	α							
ϕ	sec ϕ	60°	65°	70°	75°	80°	85°	ϕ	sec ϕ	70°	75°	80°	85°	ϕ	sec ϕ	75°	80°	85°	
°	2.	1.	0.	0.	0.	0.	0.	°	2.	0.	0.	0.	0.	°	2.	0.	0.	0.	
60.2	0122	0061	8504	6882	5208	3494	1754	65.2	3841	8154	6170	4140	2078	70.2	9521	7641	5126	2573	
.4	0245	0123	8556	6924	5240	3516	1765	.4	4022	8216	6217	4171	2094	.4	9811	7716	5177	2598	
.6	0371	.....	8609	6967	5272	3537	1776	.6	4207	8279	6265	4204	2110	.6	0106	7792	5228	2624
.8	0498	.....	8663	7011	5305	3559	1787	.8	4395	8344	6314	4236	2126	.8	0408	7870	5280	2650
61.0	0627	.....	8717	7055	5339	3582	1798	66.0	4586	8409	6363	4269	2143	71.0	0716	7950	5334	2677
.2	0758	.....	8773	7099	5372	3605	1809	.2	4780	8475	6414	4303	2160	.2	1030	8031	5388	2705
.4	0890	.....	8829	7145	5407	3628	1821	.4	4978	8543	6465	4337	2177	.4	1352	8115	5444	2733
.6	1025	.....	8886	7191	5442	3651	1833	.6	5180	8612	6517	4372	2195	.6	1681	8200	5501	2761
.8	1162	.....	8943	7238	5477	3675	1844	.8	5385	8682	6570	4408	2213	.8	2017	8287	5560	2791
62.0	1301	.....	9002	7285	5513	3599	1857	67.0	5593	8753	6624	4444	2231	72.0	2361	8376	5619	2821
.2	1441	.....	9062	7333	5549	3723	1869	.2	5805	8826	6679	4481	2249	.2	2712	8467	5680	2851
.4	1585	.....	9122	7382	5587	3748	1881	.4	6022	8900	6735	4519	2268	.4	3072	8560	5743	2883
.6	1730	.....	9183	7432	5624	3773	1894	.6	6242	8975	6792	4557	2287	.6	3440	8655	5807	2915
.8	1877	.....	9246	7482	5662	3799	1907	.8	6466	9052	6850	4596	2307	.8	3817	8753	5872	2947
63.0	2027	.....	9309	7534	5701	3825	1920	68.0	6695	9130	6909	4636	2327	73.0	4203	8852	5939	2981
.2	2179	.....	9373	7586	5740	3851	1933	.2	6928	9210	6969	4676	2347	.2	4598	8955	6008	3016
.4	2333	.....	9439	7638	5780	3878	1947	.4	7165	9291	7031	4717	2368	.4	5003	9060	6078	3051
.6	2490	.....	9505	7692	5821	3905	1960	.6	7407	9374	7093	4759	2389	.6	5418	9167	6150	3087
.8	2650	.....	9572	7747	5862	3933	1974	.8	7653	9458	7157	4802	2410	.8	5843	9277	6224	3124
64.0	2812	.....	9641	7802	5904	3961	1988	69.0	7904	9544	7222	4846	2432	74.0	6280	9390	6300	3162
.2	2976	.....	9710	7858	5947	3990	2003	.2	8161	9631	7289	4890	2454	.2	6727	9506	6378	3201
.4	3144	.....	9781	7916	5990	4019	2017	.4	9422	9721	7356	4935	2477	.4	7186	9624	6457	3241
.6	3314	.....	9853	7974	6034	4048	2032	.6	8689	9812	7425	4982	2500	.6	7657	9746	6539	3282
.8	3486	.....	9926	8033	6079	4078	2047	.8	8961	9905	7496	5029	2524	.8	8140	9871	6623	3324
65.0	3662	.....	1.	8093	6124	4109	2062	70.0	9238	1.	7567	5077	2548	75.0	8637	1.	6709	3368

TABLE XIX—Concluded

ϕ	sec ϕ	α		ϕ	sec ϕ	α		$\phi$	sec $\phi$	$\alpha$		$\phi$	sec $\phi$	$\alpha$		$\phi$	sec $\phi$	$\alpha$	
		80°	85°			80°	85°			80°	85°			80°	85°	80°	85°		
°	3.	0.	0.	°	4.	0.	0.	°	5.	0.	0.	°	6.	0.	0.	°	8.	0.	0.
75.1	8890	6753	3390	77.1	4793	7778	3904	79.1	2883	9183	4609	81.1	4637	5634	83.1	3238	7255		
.2	9147	6798	3412	.2	5137	7838	3934	.2	3367	9267	4651	.2	5366	5697	.2	4457	7361		
.3	9408	6843	3435	.3	5486	7899	3965	.3	3860	9353	4694	.3	6111	5762	.3	5711	7471		
.4	9672	6889	3478	.4	5841	7960	3996	.4	4362	9440	4738	.4	6874	5829	.4	7004	7583		
.5	9939	6935	3481	.5	6202	8023	4027	.5	4874	9529	4783	.5	7655	5897	.5	8337	7699		
4.																			
.6	0211	6983	3505	.6	6569	8087	4059	.6	5396	9619	4828	.6	8454	5966	.6	9711	7819	9.	
.7	0486	7030	3529	.7	6942	8151	4091	.7	5928	9712	4875	.7	9273	6038	.7	1129	7943	7.	
.8	0765	7079	3553	.8	7321	8217	4124	.8	6470	9806	4922	.8	0112	6111	.8	2593	8070		
.9	1048	7128	3578	.9	7706	8284	4158	.9	7023	9902	4970	.9	0972	6186	.9	4105	8202		
76.0	1336	7178	3603	78.0	8097	8352	4192	80.0	7588	1.	5019	82.0	1853	6263	84.0	5668	8338		
.1	1627	7229	3628	.1	8496	8421	4227	.1	8164	0100	5070	.1	2757	6341	.1	7283	8479		
.2	1923	7280	3654	.2	8901	8492	4262	.2	8751	.....	5121	.2	3684	6422	.2	8955	8625	10.	
.3	2223	7332	3680	.3	9313	8563	4298	.3	9351	.....	5173	.3	4635	6505	.3	0685	8776		
.4	2528	7385	3707	.4	9732	8636	4335	.4	9963	.....	5226	.4	5611	6590	.4	2477	8932	5.	
.5	2837	7439	3734	.5	0159	8710	4372	.5	0589	.....	5281	.5	6613	6678	.5	4334	9094		
.6	3150	7493	3761	.6	0593	8785	4410	.6	1227	.....	5337	.6	7642	6767	.6	6261	9262		
.7	3469	7548	3789	.7	1034	8862	4448	.7	1880	.....	5393	.7	8700	6860	.7	8260	9436	11.	
.8	3792	7605	3817	.8	1484	8940	4487	.8	2546	.....	5452	.8	9787	6954	.8	0336	9617	8.	
.9	4121	7662	3846	.9	1942	9020	4527	.9	3228	.....	5511	.9	0905	7052	.9	2493	9805		
77.0	4454	7719	3875	79.0	2408	9101	4568	81.0	3925	.....	5572	83.0	2055	7152	85.0	4737	1.		

Summary of the symbols used and the method of employing the Tables:

 a , is the position-angle of observed point measured from equatorial diameter of solar disc. r , is the distance of observed point from centre of solar disc, the radius being unity. ρ , is the heliocentric angle between observer and observed point. s , is the angular semi-diameter of sun. ϕ , is the heliographic latitude, and λ is the heliographic longitude of observed point. γ_0 , is the angle between the plane of the solar limb and the plane containing observed point and solar axis. γ , is the angle between plane normal to line-of-sight and plane containing observed point and solar axis.

$$\sin \phi = (\sin B_0 \cos \rho) + (\cos B_0 \sin \rho) \sin \alpha$$

Table XVII Table XVIII

$$\sin \lambda = \sin \rho (\cos \alpha \sec \phi)$$

Table XVIII Table XIX

$$\cos \gamma_0 = (\cos B_0 \sin \rho) (\cos \alpha \sec \phi)$$

$$\cos \gamma = \cos \gamma_0 + \text{Addendum of Table XX}$$

 $V \cos \gamma$ = Component to observer of the solar rotational velocity, V , at the observed point.TABLE XX—VALUES OF THE ADDENDUM, $\sin \lambda \cos \lambda \cos \phi \sin s$, FOR VALUES OF λ AND ϕ .

λ	ϕ																	
	5°	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	60°	65°	70°	75°	80°	85°	
5, 85	0004	0004	0004	0004	0004	0004	0003	0003	0003	0003	0002	0002	0002	0001	0001	0001	0000	
10, 80	8	8	8	7	7	7	6	6	5	5	4	3	3	2	1	1		
15, 75	12	11	11	11	11	10	9	8	8	7	6	5	4	3	2	1		
20, 70	15	15	14	14	14	13	12	11	10	9	7	6	5	4	3	2	1	
25, 65	18	18	17	17	16	15	15	14	13	11	10	9	8	6	5	3	2	
30, 60	20	20	19	19	18	17	17	15	14	13	12	10	9	7	5	4	2	
35, 55	22	22	21	21	20	19	18	17	16	14	13	11	9	7	6	4	2	
40, 50	23	23	22	22	21	20	19	18	16	15	13	11	10	8	6	4	2	
45, 45	0023	0023	0023	0022	0021	0020	0019	0018	0017	0015	0013	0012	0010	0008	0006	0004	0002	

GENERAL OUTLINE OF OBSERVATIONS, INSTRUMENTS AND METHODS

SECTION 9.—A GRADUATED SPHERE AND CO-ORDINATE FRAME FOR READING THE HELIOGRAPHIC LATITUDE AND LONGITUDE, AND THE INCLINATION OF THE DIRECTION OF THE SOLAR ROTATION CORRESPONDING TO AN OBSERVED POINT ON THE SOLAR DISC

BY

RALPH E. DE LURY

A graduated sphere which may be rotated on an axis through its equator, together with a co-ordinate frame capable of rotation in a plane through the centre of the sphere corresponding to the plane of which the radius vector of the earth's orbit is the pole, has been constructed in the machine-shop of the observatory, primarily for the purpose of reading directly, for an observed point on the solar disc, the heliographic latitude and longitude and the inclination of the direction of the sun's rotation to the line of observation. It was designed to eliminate much of the tedious computation involved in the large Ottawa series of observations of the solar rotation, many of which are perhaps unique in including the simultaneous observation of seven points on the solar disc together with comparison spectra¹.

The instrument is illustrated in the accompanying fig. 24. The sphere is a brass shell turned to an outside diameter of 228 mm., about the average diameter of the observed solar disc. The latitude lines are 1 degree apart, and the longitude lines 2 degrees apart. The ends of the axis through the equator of the sphere rest in a sturdy ring supported by four legs on a base plate. Inset in the ring is another ring graduated in degrees, which may be read to tenths with the aid of a vernier engraved on the former ring. The graduated position-angle ring has four blocks mounted at 0°, 90°, 180°, and 270°. On these blocks are mounted two co-ordinate plates intersecting above the centre of the sphere. The inner diameter of these plates is 228·6 mm. (9 inches), thus providing a clearance of 0·3 mm. between the sphere and the plates. The co-ordinate plates are graduated in degrees around the inner edge, numbered from the centre outward. The plates are 2 mm. thick, one of them, the "equatorial plate", with its middle vertically above the centre of the sphere, and the other, the "polar plate", with an edge vertically above the sphere's centre. The edges of the plates thus correspond to the positions of the four limb observations, two of which are on a diameter of the solar disc, while the other two are offset 1 mm. The intermediate points observed are offset again by 1 mm. from the equatorial plate, and two movable pointers, 1 mm. in thickness, correspond to the positions of these points. The finish is of dull nickel.

In operation, the sphere is turned (by means of handles on a shaft having a friction disc which bears against the bottom of the sphere) so that its polar axis is inclined at an angle B_0 , the heliographic latitude of the centre of the solar disc at the time of observa-

¹ See fig. 9, preceding Section 3, p. 15.

tion, to the plane of the position-angle ring, which plane corresponds to the plane through the centre of the sun having as its pole the radius vector. The position-angle ring with its pair of co-ordinate plates is rotated to the position-angle α of the observation. The frame is thus set for reading the heliographic co-ordinates.

The distance r from the centre of the solar disc, expressed as a decimal of the radius of the disc, being known for each point of an observation, the heliocentric angle ρ , between the observer and the observed point, may be read for each point from the accompanying Table XXI. The value of ρ in each case is used as a "pointer" on the degree scale on the inner edge of the proper co-ordinate plate, for reading the latitude ϕ , and the longitude λ on the sphere, corresponding to each observed point. A duplicate set of readings may be made at position-angle α in the other quadrant, and a similar pair of readings by tilting the opposite pole of the solar axis to the angle B .

TABLE XXI—HELIOCENTRIC ANGLE, ρ , CORRESPONDING TO DISTANCE, r , FROM THE CENTER OF THE SOLAR DISC

r	ρ	r	ρ	r	ρ	r	ρ	r	ρ	r	ρ	r	ρ	r	ρ	r	ρ	r	ρ
0.	°	0.	°	0.	°	0.	°	0.	°	0.	°	0.	°	0.	°	0.	°	0.	°
.020	1.14	310	17.98	510	30.53	710	45.06	901	64.05	921	66.83	941	69.97	961	73.69	981	78.55		
40	2.28	20	18.58	20	31.19	20	45.86	2	.18	22	.97	42	70.14	62	.90	82	.85		
60	3.42	30	19.18	30	31.86	30	46.69	3	.31	23	67.12	43	.31	63	74.11	83	79.16		
80	4.57	40	19.78	40	32.54	40	47.53	4	.45	24	.27	44	.48	64	.32	84	.47		
100	5.71	50	20.39	50	33.22	50	48.39	5	.58	25	.42	45	.65	65	.54	85	.80		
20	6.86	60	21.00	60	33.91	60	49.26	6	.72	26	.57	46	.83	66	.76	86	80.14		
40	8.01	70	21.62	70	34.60	70	50.15	7	.85	27	.73	47	71.01	67	.98	87	.49		
60	9.17	80	22.23	80	35.30	80	51.05	8	.99	28	.88	48	.19	68	75.21	88	.85		
80	10.32	90	22.85	90	36.00	90	51.97	9	65.13	29	68.03	49	.37	69	.44	89	81.23		
200	11.48	400	23.67	600	36.71	800	52.92	910	.26	930	68.19	950	71.55	970	75.67	990	.62		
10	12.07	10	24.09	10	37.43	10	53.88	11	.40	31	.34	51	.74	.71	.91	91	82.04		
20	12.65	20	24.72	20	38.15	20	54.87	12	.54	32	.50	52	.92	72	76.15	92	.48		
30	13.24	30	25.35	30	38.88	30	55.88	13	.68	33	.66	53	72.11	73	.40	93	.96		
40	13.82	40	25.99	40	39.62	40	56.92	14	.82	34	.82	54	.30	74	.65	94	83.45		
50	14.41	50	26.62	50	40.37	50	57.98	15	.96	35	.98	55	.49	75	.90	95	84.01		
60	15.01	60	27.26	60	41.12	60	59.09	16	66.10	36	69.14	56	.69	76	77.16	96	.60		
70	15.59	70	27.91	70	41.89	70	60.23	17	.25	37	.30	57	.88	77	.43	97	85.29		
80	16.18	80	28.56	80	42.66	80	61.41	18	.39	38	.47	58	73.08	78	.70	98	86.11		
90	16.77	90	29.21	90	43.45	90	62.64	19	.53	39	.63	59	.28	79	.98	99	87.17		
300	17.38	500	29.87	700	44.26	900	63.92	920	66.68	940	69.80	960	73.48	980	78.26	000	89.73		

Careful reading with the aid of a hand magnifying lens gives sufficiently accurate latitude values, but the longitude readings for points at the higher latitudes need to be supplemented by computation, using the equation

$$\sin \lambda = \sin \rho \cos \alpha \sec \phi,$$

employing the values of ϕ read from the sphere, and multiplying the values of $\sin \rho$, corresponding to the values of r , from Table XVIII, by the values of $\cos \alpha \sec \phi$ from Table XIX of the preceding Section 8.

Having obtained the longitude, λ , of an observed point, the angle, γ_0 , between the radius vector and the pole of the plane containing the solar axis and the observed point, may be read directly by two methods:

(1) from the degree scale on the edge of the polar plate which has been rotated to cut the equator at longitude $90^\circ - \lambda$, the inclination of the axis of the sphere being left undisturbed at angle B_0 , as is evident from equation (8) of the preceding Section, namely

$$\cos \gamma_0 = \cos B_0 \sin \lambda ;$$

(2) since γ_0 is also the angle between the plane of the position-angle ring and the longitude plane containing the observed point, it may be read from the degree scale of the polar plate at the point where the longitude line, λ , is at the maximum angle on the plate from the plane of the position-angle ring, easily determined by rotating the coordinate frame back and forth about the maximum point. The value of $\cos \gamma_0$ is now increased by the selected value of the addendum of Table XX, preceding Section, to yield the required $\cos \gamma$, that is, the cosine of the angle between the direction of the solar rotation at the observed point and the line from the point to the observer, the required component of the rotational velocity, V , being $V \cos \gamma$.

Less simply, the angle γ may also be read directly by the two methods of reading γ_0 :

(1) with settings $B_0 \pm rs \sin a$ and $90^\circ - \lambda - rs \cos a$ (s being the angular semi-diameter of the sun, B_0 , which never exceeds $7^\circ 25'$, may be used instead of $B_0 \pm rs \sin a$ without appreciable error, as explained in the preceding Section);

(2) by measuring on the polar plate the maximum angle between the longitude line $\lambda + rs \cos a$, and the plane of the position-angle ring, the sphere being set with its axis tilted $B_0 \pm rs \sin a$, or with sufficient accuracy it may be left at the setting B_0 .

The following example illustrates the application of the sphere to the determinations of one of the simpler earlier observations, in comparison with the computations by logarithms and by the use of the tables of the preceding Section:

Plate L 833 (1)-(7), August 10, 1911, 11^h 20^m 35^s, E.S.T.

$$r = 0.930, \text{ and } B_0 = 6^\circ 4.$$

(Two observed points within the solar limb, at equal distances r from the centre of the solar disc, on diameters of the disc at position-angle a , at intervals of 15° from 0° to 90° .)

I. BY LOGARITHMS:

α	(1) 0°	(2) 15°		(3) 30°		(4) 45°		(5) 60°		(6) 75°	
Log sin α	9.41300	.....	9.69897	.....	9.84949	.....	9.93753	.....	9.98494	.....	.....
Log cos B_0	9.99729	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Log sin ρ	9.96773	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	9.96502	9.37802	.....	9.66399	.....	9.81451	.....	9.90255	.....	9.94996	.....
	.9226	.2388	.....	.4613	.....	.6524	.....	.7990	.....	.8912	.....
Log sin B_0	9.04715	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Log cos ρ	9.5701	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	8.61725	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
sin ϕ.....	.0414	.2802	.1974	.5027	.4199	.6938	.6110	.8404	.7576	.9326	.8498
ϕ	2° 22'	16° 16'	11° 23'	30° 11'	24° 50'	43° 56'	37° 40'	57° 11'	49° 15'	68° 51'	58° 11'
Log sec ϕ	10.00037	10.01774	.00862	10.06327	.04214	10.14258	.10151	10.26604	.18525	10.44272	.27802
Log cos α	10.00000	9.98494	.98494	9.93753	.93753	9.84949	.84949	9.69897	.69897	9.41300	.41300
Log sin ρ	9.96773	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Log sin λ	9.96810	9.97041	.96129	9.96853	.94740	9.95980	.91873	9.93274	.85195	9.82345	.65875
λ	68° 18'	69° 7'	68° 10'	68° 27'	62° 22'	65° 44'	56° 2'	58° 56'	45° 20'	41° 45'	27° 7'
Log cos γ	9.96539	9.96770	.95858	9.96582	.94469	9.95709	.91602	9.93003	.84924	9.82074	.6560
cos γ.....	.9234	.9283	.9090	.9243	.8804	.9059	.8242	.8512	.7067	.6618	.4529
Addendum.....	.0016	.0016	.0016	.0016	.0017	.0013	.0017	.0012	.0015	.0008	.0010
cos γ.....	.9250	.9299	.9106	.9259	.8821	.9072	.8259	.8524	.7082	.6626	.4539

II. USING TABLES:

sin α	0.0000	0.2588	.....	-5000	.....	.7071	.....	.8660	.....	.9659	.....
cos B_0 sin ρ sin α	0.0000	.2388	.....	.4613	.....	.6524	.....	.7990	.....	.8911	.....
sin B_0 cos ρ	0.0414	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	0.0414	.2802	.1974	.5027	.4199	.6938	.6110	.8404	.7576	.9325	.8497
ϕ	2° 22'	16° 16'	11° 23'	30° 11'	24° 50'	43° 56'	37° 40'	57° 11'	49° 15'	68° 50'	58° 11'
cos α sec ϕ	1.0009	1.0063	.9854	1.0019	.9541	.9818	.8934	.9225	.7660	.7167	.4909
sin λ.....	.9292	.9352	.9148	.9302	.8858	.9115	.8294	.8564	.7111	.6654	.4557
λ	68° 19'	69° 6'	68° 11'	68° 28'	62° 21'	65° 43'	56° 2'	58° 55'	45° 19'	41° 43'	27° 7'
cos γ.....	.9234	.9284	.9091	.9244	.8804	.9058	.8943	.8511	.7067	.6612	.4529
Addendum.....	.0016	.0016	.0016	.0016	.0017	.0013	.0017	.0012	.0015	.0008	.0010
cos γ.....	.9250	.9300	.9107	.9260	.8821	.9071	.8260	.8523	.7082	.6620	.4539

III. USING SPHERE:

ϕ	2.4	16.3	11.4	30.2	24.8	44.0	37.6	57.3	49.3	68.9	58.2
	2.35	16.3	11.4	30.2	24.85	43.9	37.7	57.2	49.3	68.85	58.2
λ	68.2	69.1	66.3	68.4	62.3	65.8	56.0	58.9	45.3	41.7	27.3
	68.3	69.1	66.2	68.5	62.4	65.7	56.0	58.9	45.3	41.7	27.1
r s cos α	15'	14'	14'	13'	13'	12'	12'	7'	7'	4'	4'
$\lambda + r s \cos \alpha$	68° 36'	60° 20'	66° 29'	68° 40'	62° 34'	65° 57'	56° 12'	59° 1'	45° 25'	41° 46'	27° 16'
γ	22° 15'	21° 40'	24° 18'	22° 11'	28° 8'	24° 48'	34° 21'	31° 35'	44° 56'	48° 32'	62° 50'
cos γ.....	.9255	.9293	.9116	.9260	.8819	.9078	.8256	.8519	.7079	.6622	.4550

The means of duplicate readings on the sphere are in close agreement with the computed values of ϕ , λ , and γ , as indicated by the above comparative results. In the solar rotation work it is not necessary to determine the longitudes, except for one or two plates in a series, so that the values of the addenda may be read from Table XX. A satisfactory and speedy method in this work is to read the values of ϕ from the sphere, and from these values, selecting the products $\cos \alpha \sec \phi$ and multiplying by $\cos B \cdot \sin \rho$ from Tables XIX and XVIII of the preceding Section, to determine $\cos \gamma_0$, which with the addendum of Table XX yields $\cos \gamma$. The use of either the tables or the sphere effects a great saving of time in comparison with the use of logarithms.

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FIG. 24.—Graduated Sphere and Co-ordinate Frame for Heliographic Readings.

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Spectroscopic Investigations of the Sun

PART II

SOLAR ROTATION—SECTIONS 1-3

BY

RALPH E. DE LURY AND JOHN L. O'CONNOR

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SOLAR ROTATION

SECTION I—INTRODUCTION AND OBSERVATIONS OF THE EQUATORIAL VELOCITY IN 1909

BY
RALPH E. DE LURY

Introduction.—The investigation of the velocity of the solar rotation by measurement of the displacements it produces in the lines of spectra from points on the advancing and receding sides of the sun was commenced at Ottawa in 1909, at a time when extensive and continuous observations were greatly desired for the further elucidation of several important questions which had been raised by the previous attacks on the problem.

Not many years earlier, in 1871, Vogel and Zöllner succeeded in detecting the Fizeau displacement of the spectrum lines due to the rotational velocity of the solar limb, thus adding to the results of the work of Huggins, in 1868, on the displacements of stellar spectrum lines convincing evidence of the validity of the principle enunciated by Doppler in 1842. However, it was obvious that the spectroscopic determination of the solar rotation could be successfully accomplished only by use of spectra of very large scale. In 1876 Young demonstrated the power and convenience of the diffraction grating in measuring the solar rotational displacements of the spectrum lines.

Employing plane grating spectrosopes, series of visual observations of the displacements of two solar lines near $\lambda 6300$, with reference to undisplaced lines originating in the terrestrial atmosphere, in spectra from opposite points on the solar limb, were made by Dunér at Lund (1887–9), and again by Dunér and Bergstrand at Upsala (1898–1901) and by Halm at Edinburgh (1901–6), while photographic observations of the $\lambda 4250$ region of the spectrum and of H_{α} were obtained by Adams at Mount Wilson (1906–8).

Dunér's pioneer investigations confirmed, for the general surface of the sun, Carrington's discovery from observations of sunspots (1853–61) of the gradual lessening of the angular rate of rotation with departure in latitude from the equator, and also extended the knowledge of the rate to the higher latitudes beyond the range in which sunspots occur. Halm called attention to the variation in the measurements of the velocity of rotation and suggested that this might be related to the cyclical fluctuation in sunspots. Adams found differences in the measurements of the rotation displacements of spectrum lines of different elements which he ascribed to differences in level in the solar atmosphere of the materials producing the spectrum lines. All of the determinations, though exhibiting considerable individuality in numerical details, pointed to the Faye formula, $A - B \sin^2 \phi$ as a close approximation to the angular velocity of rotation in terms of the latitude, ϕ .

In these measurements progressive improvement resulted from increasing the focal length and stability of the spectrosopes and the diameter of the solar image. Consequently, the focal length of the Ottawa auto-collimating plane grating spectrograph¹ was chosen as large as the laboratory space permitted, namely 7 m. (23 ft.), to be used with a solar image of average diameter of about 228 mm. (9 in.) supplied by a 51 cm. (20 in.) coelostat² and a similar second flat mirror to feed the sun's light to a 46 cm. (18 in.) con-

^{1, 2} Rept. Chief Astronomer, 1909, 251–4, and 207–9.

cave mirror of 24·4 m. (80 ft.) focal length. A detailed description of this equipment, with later improvements and additions, is given in the previous Part I of this Volume, pp. 11-17, and an outline of observations made with it, pp. 5-7.

The coelostat and spectrograph were mounted in 1908, and tests and observations revealed the worthless character of the plane grating, which was not only decidedly lacking in brightness in all orders of spectra but was incapable of yielding sharp spectrum lines. After some construction work within the building the spectrograph was remounted in 1909, and focal tests in the various orders of the grating indicated a curvature of its rulings of about half their spacing³. Nevertheless, using about 8 cm. of the length of the rulings a few photographic observations were made, recording spectra of opposite points near the limb at the solar equator and a few other latitudes. Finally, in 1910, with a new plane grating, satisfactory observations at $\lambda 4500$ were made during the summer, recording solar rotation spectra at various latitudes. Later in the year the International Union for Co-operation in Solar Research initiated a program⁴ for investigating the solar rotation, in which seven regions of the spectrum were assigned to six co-operating observatories. By this arrangement the Dominion Observatory was to observe the spectrum from $\lambda 5500$ to $\lambda 5700$ as well as a common region about $\lambda 4250$. In consequence, rotation plates at $\lambda 5600$ were secured in November and December of that year, and with another more satisfactory grating observations at that region have been made yearly since then, along with series at $\lambda 4250$ and at certain other wave-lengths in some years.

Before presenting the measurements of the various series of solar rotation plates, a brief outline will be given of several supplementary investigations and suggestions made by the writer in the earlier years, as these are used in the discussion and interpretation of the measurements of the solar rotations.

Errors of Micrometer Measurement.—Systematic errors were found in the earliest measurements of the solar rotation plates. These were investigated by measuring plates on which the spectrum lines were mechanically shifted⁵ either by moving the plate-holder between exposures on adjacent strips of spectrum or by using a slit with an offset section by means of which displacements imitating the actual rotation displacements, the same for all lines, were recorded. The measurements of these artificial displacements revealed:—

- (1) Measurements made with the plate "violet left" and "violet right" differed systematically;
- (2) Systematic differences were found depending on the character of the spectrum lines;
- (3) Various observers obtained systematically different values;
- (4) The errors were large enough to make uncertain the conclusions concerning the interesting fine points in the investigation of the solar rotation.

As a result of this work and the variety of results obtained by different observers of the solar rotation, the International Union for Co-operation in Solar Research at its last meeting in 1913 suggested⁶ that in further co-operative work special attention should

³ Rept. Chief Astronomer, 1911, 256-259.

⁴ Trans. Int. Union Solar Res., Vol. III, p. 83.

⁵ Jour. Roy. Astron. Soc. Can., V, 384-407, 1911; also, Rept. Chief Astronomer, 1911, 264-281.

⁶ Trans. Int. Union Solar Res., IV, 123.

be paid to the investigation of such errors, especially in measurements of the equatorial velocity of the solar rotation.

Finally, the cause of these errors was traced to capillary action of the oil between the nut and micrometer screw⁷, which moved the nut, and with it the plate-frame holding the plate, in one direction for about three minutes, during which the measurements of the rotation displacements were usually made. It was possible to remove or control the error in later measurements and to determine its extent in the earlier measurements by repeating some of them.

Blended Spectra.—The measured values of the solar rotation displacements are reduced by the overlapping undisplaced spectrum lines from the light of the sky and its haze, and conceivably a similar blending effect might be caused by the optical parts of the observational equipment or by meteoric matter falling into the sun across the line of sight at or near the solar limb. Halm called attention to the lessening effect of a hazy sky and took precautions to avoid this as much as possible in his observations. It may be remarked that his ingenious device of using a heliometer to juxtapose two solar images on the slit of the spectroscope introduced a double effect of sky spectrum. The question was investigated by measuring artificial blends of varying amounts of centre and limb spectra⁸. A striking though expected result of these measurements was the finding of a differential effect depending on the character of the spectrum lines. In general for weak lines a greater lessening of the measured displacements was observed than for strong lines attributed to the relative differences in intensity, and possibly also in wave-length, of the lines in the two sources. The greater the decrease in the mean value of the displacement, the greater was found to be the difference between the values for weak and for strong lines. A similar effect is found in the actual observations of the solar rotation^{9, 10}; and a large series of observations would thus contain the means for determining the value of the rotation for a zero difference between the values of weak and strong lines. Observations of limb spectra when the sun is nearly totally eclipsed would be free of the effect of sky spectrum¹¹. The selective reflection of cirrus ice crystals and water droplets might result in a greater effect on spectrum lines in the green and yellow.

Reference Spectra.—In order to determine independently the velocity of rotation at each observed point, or to interpret abnormal results, it was proposed to photograph, simultaneously with the limb spectra, the spectrum of the centre of the solar disc, gaseous absorption spectra and spectra of the metallic elements¹². Such reference and comparison spectra have been employed since 1913, and they serve as well in the determinations of wave-length and of the solar distance.

Pore Theory.—To account for the redward shift and widening of most of the limb spectrum lines and for differences occurring between the measurements of observations of the solar rotation made in rapid succession which appear too great to be explained as due to error of observation or of measurement, a theory was advanced¹³ that the darker

⁷ Pub. Dom. Obs. VI, Pt. I, 18–23.

⁸ J. Roy. Astron. Soc. Can., X, 201–219, 1916; also, Pub. Dom. Obs. VI, Pt. I, 41–45.

⁹ Astrophys. J. 44, 177–189, 1916.

¹⁰ J. Roy. Astr. Soc. Can. 10, 345–357, 1916.

¹¹ Astrophys. J. 47, 199, 1918.

¹² Rept. Chief Astronomer, 1910, 168; 1911, 290 and 293.

¹³ Pub. Am. Astron. Soc. IV, 149.

"pores", lying among the brighter "granules" and constituting with them the general surface of the sun, have a similar convective system to that in the penumbra of a sunspot. This theory is supported by measurements of the penumbral displacements in sunspots situated at varying distances within the solar limb¹⁴.

Computation.—In computing the velocity of the solar rotation from the measured displacement of a line in the spectrum of a limb point, Dunér employed an approximate method of correcting for the orbital velocity of the earth, adding the correction to the product of the velocity-equivalent of the displacement and the secant of the angle, η , between the direction of rotation at the limb point and the direction of the radius vector to the earth. Obviously, the correction should be added to the velocity-equivalent of the displacement before multiplying by the factor $\sec \eta$. The values of the rotational velocity determined by Dunér's method are too small by the quantity, $v_1 (\sec \eta - 1)$, where v_1 , in Dunér's notation, is the difference between the components of the earth's orbital velocity to the centre and to the limb point of the solar disc. At times this error is large enough to affect seriously the determinations of the rotational velocities at the higher latitudes. To apply properly the correction due to the orbital velocity of the earth and at the same time to provide a method applicable not only to limb observations but to any pairs of points on the sun, usually selected for obvious reasons equidistant from the centre of the solar disc, the writer suggested the following system which was used in our first determinations of the law of the solar rotation¹⁵:

d mm. is the measured difference of position or displacement of a spectrum line in the spectra from the two points which are at latitudes ϕ_1 and ϕ_2 ;

F km. per sec. is the velocity-equivalent of a displacement of 1 mm. of the spectrum line;

γ_1 and γ_2 are the angles between the directions of rotation and the lines to the observer at the two points;

V_1 and V_2 the rotational velocities at the two observed points;

ϵ km. per sec. is the difference between the components of the earth's orbital velocity to the two points; hence,

$$d.F + \epsilon = V_1 \cos \gamma_1 + V_2 \cos \gamma_2.$$

Without further information, this equation can be solved only when,

- (1) the points are on the equatorial diameter of the solar disc, or on a line parallel to it, and $d.F + \epsilon = 2V \cos \gamma$;
- (2) one point is on the polar diameter of the solar disc, in which case $d.F + \epsilon = V \cos \gamma$;
- (3) the points are on a diameter of the solar disc, and the observer is on the plane of the solar equator, in which case $d.F + \epsilon = (V_1 + V_2) \cos \gamma$, and the average velocity in the north and south hemispheres is determined for the latitude observed.

The additional data provided by the use of a reference spectrum, such as mentioned above, permit the independent determination of V_1 and V_2 ; or an approximate solution

¹⁴ Pub. Am. Astron. Soc. IV, 214, 215 and 258.

¹⁵ Trans. Roy. Soc. Can., Vol. VI, Sec. III, 1-48, 1912.

is provided by a determination of the law of rotation, from which the ratio $V_1 : V_2$ may be derived for the latitudes ϕ_1 and ϕ_2 . This latter method was used, perforce, in the 1911 observations¹⁵.

Observations of the Equatorial Velocity of Rotation in 1909.—The few observations of the solar rotation made in 1909, while of poor quality because of the grating employed, have a special value in view of the scarcity of observations in that year and also because the measurements of the equatorial velocity made previously were about 5 per cent greater on the average than those made in subsequent years. Consequently, it was considered advisable to remeasure the 1909 plates, since the earlier measurements of them were probably affected by the systematic error later traced to the action of the micrometer oil.

In making the observations, the grating, which had a surface 10·8 by 12 cm. with 500 rulings to 1 mm., was masked to an area 8 by 8 cm. on account of the curvature of the rulings and the poorer quality of one end. Two slots slightly wider than 1·6 mm. (one-sixteenth of an inch) admitted light from within the equatorial limbs of the sun to reflecting prisms which directed one beam from the east limb to the slit of the spectrograph between two beams from the west limb, the prisms being adjusted so that all beams illuminated fully the part of the grating which was not masked. Focusing of the brighter third order spectrum was as accurate as the poor quality of the spectrum lines permitted. Long exposures of from 10 to 15 minutes were necessary, 6·3 cm. by 30·5 cm. (2·5 in. by 12 in.) process plates being used. During the exposures the solar disc was held centrally on a guide-plate by turning the drums which, by means of stretched strings, operated the adjusting handles on the mounting of the concave mirror of the coelostat telescope¹⁶. The silver-plated slotted plates were mounted on the guide-plate so that the middle of the slots could be placed the desired distance within the limb by referring to an engraved millimetre scale on the guide-plate.

In Table I the record of observations is given: plate number; date and hour of observation; position of observed points, including the position angle, α , measured from the equatorial diameter of the solar disc, the diameter of the disc and the distance, r , of the observed points from the centre of the disc expressed as a decimal of its radius; the width of the slit of the spectrograph; the exposure time; and the observing conditions and remarks, D and B representing the definition and brightness of the solar image.

In Table II are given, for each spectrum line selected for measurement: λ , the wave-length in Ångstrom units (the Rowland values and the last three figures of the International system); the element; the intensity; and F , in km. per sec., the velocity-equivalent of a displacement of 1 mm. of the spectrum line, defined by the equation, $F\lambda = (\text{scale}) (\text{velocity of light}) = 0\cdot8927$ (velocity of light), since 1 mm. = 0·8927 Å (for the $\lambda 4250$ plates). Further details of the two groups of lines at $\lambda 4250$ and $\lambda 4500$ will be given in the discussion of later series of observations.

In Table III are given the measurements and derived velocities for the individual spectrum lines in each observation. Each form provides for the results of four measurements, the measuring instrument used for each being indicated in turn, after the initial

¹⁵ J. Roy. Astron. Soc. Can., V, 33–35, 1911; Rept. Chief Astronomer, Vol. I, 1910, 169–170.

of the measurer, by T for the Toepfer 300 mm. measuring machine, and by -C for the Ottawa double spectrocomparator¹⁷, when employed as in this series in measuring negatives singly. For each observation, the following essential observed, measured, and computed quantities are given:

- α , the position angle of an observed point measured from the equatorial diameter of the solar disc;
- r , the distance of the observed points from the centre of the solar disc, the radius of the disc being taken as unity;
- B_o , the latitude of the centre of the solar disc;
- β , the position angle of an observed point measured from the ecliptic diameter of the solar disc;
- ϵ , in km. per sec., the difference between the components of the earth's orbital velocity to the two observed points;
- ϕ , the latitude of each of the observed points;
- γ , the angle between the direction of rotation at an observed point and the line from the point to the observer;
- d , in mm., the mean displacement of a spectrum line in the east with reference to the west spectra, plate measured both ways, "violet left" and "violet right";
- V , the velocity of rotation at each point;
- v , the sum, without regard to direction of rotation, of the components of V along the lines of sight at the two points.

Thus, $v = F \cdot d + \epsilon = 2V \cos \gamma$; or, $0.5v \sec \gamma = V$.

Determinations of β , ϵ , ϕ , and γ are readily made with the use of the tables and mechanical devices described in Sections 7, 8, and 9 of Part I of this volume.

Summary of Results.—The inferior spectroscopic and photographic quality of the plates precludes the possibility of fine measurement. Results obtained in 1909 include: L413, 79 lines, 5 settings on each line in each strip of spectrum, mean value 1.97 km. per sec., with a probable residual of 0.01 km. per sec., and a probable residual of the value from a single line of 0.10 km. per sec. Similar measurements of L393 and L399, 20 lines and 40 lines respectively, yielded mean values of 1.97 km. per sec. and 1.91 km. per sec. Later measurements were: L393, 27 lines, plate "violet left" and "violet right", yielding a mean value of 1.82 km. per sec., 4 settings on each line in the central strip and 2 settings on each line in each of the two outside strips being made; and 7 plates, L412-L419, 15 lines, violet left and violet right, giving a mean value of 2.039 km. per sec. The measurements of this group of 7 plates are given in Table III, accompanied by duplicate measurements, made in a manner to eliminate the micrometer oil error and yielding a mean value of 2.004 km. per sec. The difference between these two sets of measures appears to be systematic and ascribable to the oil error in the earlier series. The measurements of the 4 earlier plates (L315, L317, L393, and L399) given in the table are also practically free of the oil error.

In all, there are 22 measurements of the 11 plates which yield a mean value of 1.967 km. per sec. If the earlier measurements which were liable to have a systematic error due to the oil are discarded, the mean of the 11 measures of the 11 plates is 1.94 km. per sec. for the equatorial velocity of the solar rotation. From later experiences it seems very likely that the abnormally low values of plates L315, L317, L393 and L399 are due to the hazy observing conditions on the days they were made; and if these measurements be discarded the resulting mean of the measurements of the 7 plates, L412-L419, observed under fair conditions, is 2.00 km. per sec.

Thus it would seem that the observations of 1909 yield values of the solar rotation falling within the range of values obtained in subsequent years rather than being in agreement with the large values obtained in the years preceding 1909.

TABLE I—RECORD OF OBSERVATIONS OF THE SOLAR ROTATION, 1909

Plate	1909		Position			Slit Width	Ex- posure	Observing Conditions and Remarks		
	Date	E.S.T.	α	Disc	r			D	B	
L		h. m.	$^{\circ}$	mm.		mm.	sec.			
315	June 21	11 34	0	225.4	0.984	0.025	600			Unsteady. Hazy day.
317	" 23	11 04	0	226.5	0.979	0.025	720			"
393	Sept. 8	9 32	0	228.0	0.991	0.025	600			"
399	" 8	2 30	0	228.0	0.991	0.025	900			"
412	Oct. 5	11 42	0	232.0	0.983	0.028	600	Fair	Fair	
413	" 5	12 15	0	232.0	0.974	0.038	600	"	"	
414	" 5	2 35	0	232.0	0.974	0.038	600	"	"	
417	" 6	10 00	0	233.0	0.970	0.038	600	Poor	"	
418 (1)	" 8	12 15	0	234.0	0.966	0.038	600	"	"	
418 (2)	" 8	12 26	0	234.0	0.966	0.038	600	"	"	
419 (1)	" 8	3 02	0	234.0	0.966	0.038	660	"	"	

TABLE II—THE SPECTRUM LINES MEASURED AND THEIR VELOCITY FACTORS, F, FOR 1 MM. DISPLACEMENT

λ		Element	Intensity	F	λ		Element	Intensity	F
Rowland	I.A.				Disc	Rowland			
Å				km./sec.	Å				km./sec.
4196.699	.547	Fe-La ⁺	1	63.82	4376.942	.784	Fe-Cr	1	61.08
4197.257s	.102	CN	2	.80	4379.927	.771	Zr ⁺ Cr	0	.02
4216.136s	5.978	Fe-CN	1	.52	4383.720s	.559	Fe	15	60.96
4220.509	.349	Fe	3	.46	4404.927s	.763	Fe	10	.56
4225.619	.463	Fe	3	.38	4415.293s	.137	Fe	8	.36
4232.887	.736	Fe	2	.28	4416.636	.477	V	0	.34
4241.285	.122	Fe	2	.16					
4246.996	.838	Sc ⁺	5	.06					
4257.815	.663	Mn	2	62.90					
4258.477	.326	Fe	2	.90	4554.211s	.038	Ba ⁺	8	58.06
4266.081	5.927	Mn	2	.78	4554.626	.462	Fe	1	.06
4268.915	.758	Fe	2	.74	4561.591	.419		1	57.94
4276.836	.683	Fe	2	.62	4563.939s	.768	Ti ⁺	4	.84
4290.377	.228	Ti ⁺	2	.42	4572.156s	1.982	Ti ⁺	6	.74
4291.630	.475	Fe	2	.40	4574.396	.227	Fe	1	.70

TABLE III—RESULTS FROM INDIVIDUAL OBSERVATIONS OF THE SOLAR ROTATION, 1909

Plate:	L315, June 21, 11:34, E.S.T.			L317, June 23, 11:04			L412, Oct. 5, 11:42					
De L. on T												
" T, -C	$\alpha = 0^\circ \beta = 7^\circ 0 \gamma = 10^\circ 5$			$\alpha = 0^\circ \beta = 6^\circ 9 \gamma = 12^\circ 0$			$\alpha = 0^\circ \beta = 3^\circ 4 \gamma = 12^\circ 3$					
" T	$r = 0.984 \epsilon = 0.262 \phi = 0^\circ 3$			$r = 0.979 \epsilon = 0.260 \phi = 0^\circ 4$			$r = 0.983 \epsilon = 0.271 \phi = 1^\circ 2$					
" -C	$B_o = 1^\circ 9 \quad 0.5085v = V$			$B_o = 2^\circ 1 \quad 0.5111v = V$			$B_o = 6^\circ 4 \quad 0.5118v = V$					
λ	d	$\frac{1}{2}v$	V	d	$\frac{1}{2}v$	V	d	$\frac{1}{2}v$	V	d	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4196-699	0.0551	1.889	1.921	0.0506	1.745	1.784	0.0570	1.955	2.001	0.0543	1.868	1.912
4197-257	0.0546	1.873	1.905	0.0464	1.610	1.646	0.0645	2.194	2.246	0.0605	2.066	2.115
4216-136	0.0538	1.840	1.871	0.0597	2.026	2.071	0.0604	2.054	2.102	0.0629	2.134	2.184
4220-509	0.0575	1.955	1.988	0.0491	1.688	1.725	0.0493	1.700	1.740	0.0499	1.719	1.760
4225-619	0.0510	1.747	1.777	0.0555	1.889	1.931	0.0600	2.037	2.085	0.0581	1.977	2.024
4232-887	0.0472	1.624	1.651	0.0588	1.990	2.034	0.0594	2.015	2.063	0.0588	1.838	1.881
4241-285	0.0533	1.814	1.845	0.0482	1.652	1.689	0.0564	1.917	1.962	0.0597	2.021	2.069
4246-996	0.0465	1.597	1.624	0.0566	1.915	1.958	0.0554	1.883	1.927	0.0512	1.750	1.791
4257-815	0.0542	1.836	1.867	0.0566	1.910	1.952	0.0618	2.080	2.129	0.0587	1.982	2.029
4258-477	0.0488	1.666	1.694	0.0537	1.819	1.859	0.0546	1.853	1.897	0.0567	1.919	1.964
4266-081	0.0434	1.493	1.518	0.0552	1.863	1.904	0.0554	1.875	1.919	0.0526	1.787	1.829
4268-915	0.0571	1.922	1.954	0.0518	1.755	1.794	0.0612	2.056	2.105	0.0604	2.031	2.079
4276-836	0.0484	1.646	1.674	0.0530	1.789	1.829	0.0554	1.871	1.915	0.0579	1.949	1.995
4290-377	0.0503	1.701	1.730	0.0580	1.940	1.983	0.0604	2.208	2.260	0.0609	2.037	2.085
4291-630	0.0512	1.728	1.757	0.0527	1.774	1.813	0.0607	2.030	2.078	0.0602	2.014	2.062
Means:			1.785			1.865			2.029			1.985
Plate:	L413, Oct. 5, 12:15, E.S.T.						L414, Oct. 5, 2:35 E.S.T.					
De L. on T												
" -C	$\alpha = 0^\circ \beta = 3^\circ 4 \gamma = 14^\circ 5$						$\alpha = 0^\circ \beta = 3^\circ 4 \gamma = 14^\circ 5$					
" T	$r = 0.974 \epsilon = 0.269 \phi = 1^\circ 4$						$r = 0.974 \epsilon = 0.269 \phi = 1^\circ 4$					
" -C	$B_o = 6^\circ 4 \quad 0.5164v = V$						$B_o = 6^\circ 4 \quad 0.5164v = V$					
λ	d	$\frac{1}{2}v$	V	d	$\frac{1}{2}v$	V	d	$\frac{1}{2}v$	V	d	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4196-699	0.0537	1.846	1.906	0.0560	1.920	1.983	.....	.....	.....	.....	.....	.....
4197-257	0.0534	1.838	1.898	0.0558	1.915	1.978	.....	.....	.....	.....	.....	.....
4216-136	0.0595	2.024	2.090	0.0508	1.746	1.803	0.0546	1.867	1.928	0.0555	1.897	1.959
4220-509	0.0609	2.083	2.151	0.0542	1.854	1.915	0.0542	1.855	1.916	0.0588	2.001	2.066
4225-619	0.0547	1.869	1.930	0.0585	1.987	2.052	0.0588	1.998	2.063	0.0504	1.730	1.787
4232-887	0.0540	1.841	1.901	0.0539	1.838	1.898	0.0611	2.065	2.133	0.0505	1.953	2.017
4241-285	0.0508	1.737	1.794	0.0547	1.862	1.923	0.0651	2.192	2.264	0.0617	2.084	2.152
4246-996	0.0586	1.983	2.048	0.0586	1.982	2.047	0.0586	1.980	2.045	0.0538	1.839	1.899
4257-815	0.0554	1.875	1.936	0.0564	1.908	1.970	0.0665	2.227	2.300	0.0636	2.136	2.206
4258-477	0.0602	2.027	2.093	0.0572	1.931	1.994	0.0603	2.020	2.095	0.0606	2.038	2.105
4266-081	0.0509	1.730	1.787	0.0585	1.972	2.036	0.0601	2.020	2.086	0.0574	1.934	1.997
4268-915	0.0562	1.895	1.957	0.0539	1.825	1.885	0.0613	2.057	2.124	0.0633	2.120	2.189
4276-836	0.0567	1.909	1.971	0.0490	1.668	1.723	0.0588	1.974	2.039	0.0578	1.944	2.008
4290-377	0.0547	1.842	1.902	0.0551	1.852	1.913	0.0637	2.123	2.192	0.0691	2.292	2.367
4291-630	0.0557	1.870	1.931	0.0581	1.949	2.013	0.0616	2.055	2.122	0.0594	1.988	2.053
Means:			1.953			1.942			2.101			2.062

TABLE III—RESULTS FROM INDIVIDUAL OBSERVATIONS OF THE SOLAR ROTATION, 1909—
Continued

Plate:	L417, Oct. 6, 10:00, E.S.T.							L418 (1), Oct. 8, 12:15						
De L. on T														
" —C	$\alpha = 0^\circ \quad \beta = 3^\circ 6 \quad \gamma = 15^\circ 3$ $r = 0.970 \quad e = 0.268 \quad \phi = 1^\circ 6$ $B_o = 6^\circ 3 \quad 0.5184v = V$							$\alpha = 0^\circ \quad \beta = 3^\circ 7 \quad \gamma = 16^\circ 1$ $r = 0.966 \quad e = 0.267 \quad \phi = 1^\circ 7$ $B_o = 6^\circ 3 \quad 0.5205v = V$						
λ	d	$\frac{1}{2}v$	V	d	$\frac{1}{2}v$	V	d	$\frac{1}{2}v$	V	d	$\frac{1}{2}v$	V	d	$\frac{1}{2}v$
	mm.	km./sec.	km./sec.	mm.	k.m./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.
4196-699	0.0574	1.966	2.038	0.0547	1.879	1.948	0.0616	2.100	2.186	0.0544	1.870	1.946	0.0574	1.969
4197-257	0.0585	2.000	2.074	0.0542	1.863	1.932	0.0644	2.188	2.277	0.0690	2.335	2.431	0.0585	2.011
4216-136	0.0541	1.852	1.920	0.0525	1.801	1.867	0.0489	1.687	1.756	0.0408	1.430	1.488	0.0541	1.843
4220-509	0.0573	1.952	2.024	0.0557	1.901	1.971	0.0516	1.771	1.843	0.0516	1.771	1.843	0.0573	1.952
4225-619	0.0546	1.864	1.933	0.0560	1.909	1.979	0.0508	1.744	1.815	0.0530	1.814	1.888	0.0546	1.888
4232-887	0.0553	1.884	1.953	0.0575	1.953	2.025	0.0641	2.162	2.250	0.0598	2.026	2.109	0.0553	2.026
4241-285	0.0542	1.846	1.914	0.0576	1.953	2.025	0.0550	1.871	1.948	0.0545	1.855	1.931	0.0542	1.931
4246-996	0.0589	1.991	2.064	0.0553	1.878	1.947	0.0678	2.272	2.365	0.0543	1.846	1.922	0.0589	1.922
4257-815	0.0529	1.798	1.864	0.0556	1.883	1.952	0.0506	1.725	1.796	0.0553	1.873	1.950	0.0529	1.950
4258-477	0.0609	2.049	2.124	0.0528	1.795	1.861	0.0555	1.879	1.956	0.0574	1.939	2.018	0.0609	2.018
4266-081	0.0546	1.848	1.916	0.0505	1.719	1.782	0.0602	2.024	2.107	0.0581	1.958	2.038	0.0546	2.038
4268-915	0.0607	2.038	2.113	0.0568	1.916	1.987	0.0548	1.853	1.929	0.0551	1.862	1.938	0.0607	1.938
4276-836	0.0561	1.890	1.960	0.0513	1.740	1.804	0.0563	1.897	1.975	0.0606	2.031	2.114	0.0561	2.114
4290-377	0.0596	1.994	2.067	0.0563	1.891	1.961	0.0617	2.060	2.144	0.0562	1.888	1.965	0.0596	1.965
4291-630	0.0518	1.750	1.814	0.0525	1.772	1.837	0.0519	1.753	1.825	0.0557	1.872	1.949	0.0518	1.949
Means:			1.985			1.925			2.011			1.969		
Plate:	L418 (2), Oct. 8, 12:26, E.S.T.							L419 (1), Oct. 8, 3:02, E.S.T.						
De L. on T														
" —C	$\alpha = 0^\circ \quad \beta = 3^\circ 7 \quad \gamma = 16^\circ 1$ $r = 0.966 \quad e = 0.267 \quad \phi = 1^\circ 7$ $B_o = 6^\circ 3 \quad 0.5205v = V$							$\alpha = 0^\circ \quad \beta = 3^\circ 7 \quad \gamma = 16^\circ 1$ $r = 0.966 \quad e = 0.267 \quad \phi = 1^\circ 7$ $B_o = 6^\circ 2 \quad 0.5205v = V$						
λ	d	$\frac{1}{2}v$	V	d	$\frac{1}{2}v$	V	d	$\frac{1}{2}v$	V	d	$\frac{1}{2}v$	V	d	$\frac{1}{2}v$
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.
4196-699	0.0562	1.927	2.006	0.0560	1.921	2.000	0.0583	1.994	2.076	0.0535	1.841	1.916	0.0562	1.916
4197-257	0.0635	2.150	2.238	0.0644	2.188	2.277	0.0625	2.128	2.215	0.0479	1.662	1.730	0.0635	1.730
4216-136	0.0625	2.119	2.206	0.0668	2.256	2.348	0.0511	1.757	1.829	0.0593	2.017	2.099	0.0625	2.099
4220-509	0.0598	2.031	2.114	0.0586	1.993	2.075	0.0613	2.079	2.164	0.0707	2.377	2.474	0.0598	2.474
4225-619	0.0601	2.039	2.122	0.0612	2.073	2.158	0.0550	1.877	1.954	0.0620	2.099	2.185	0.0601	2.185
4232-887	0.0603	2.042	2.126	0.0555	1.890	1.967	0.0672	2.260	2.352	0.0608	2.058	2.142	0.0603	2.142
4241-285	0.0535	1.824	1.899	0.0578	1.959	2.039	0.0616	2.079	2.164	0.0652	2.193	2.283	0.0535	2.283
4246-996	0.0626	2.108	2.194	0.0539	1.833	1.908	0.0587	1.985	2.066	0.0625	2.105	2.191	0.0626	2.191
4257-815	0.0588	1.983	2.064	0.0554	1.876	1.953	0.0642	2.153	2.241	0.0586	1.977	2.058	0.0588	2.058
4258-477	0.0543	1.842	1.917	0.0565	1.911	1.989	0.0570	1.927	2.006	0.0549	1.861	1.937	0.0543	1.937
4266-081	0.0621	2.083	2.168	0.0552	1.867	1.943	0.0628	2.105	2.191	0.0622	2.086	2.171	0.0621	2.171
4268-915	0.0574	1.935	2.014	0.0642	2.148	2.236	0.0600	2.016	2.098	0.0535	1.812	1.886	0.0574	1.886
4276-836	0.0597	2.003	2.085	0.0634	2.119	2.206	0.0598	2.006	2.088	0.0548	1.850	1.926	0.0597	1.926
4290-377	0.0623	2.078	2.163	0.0594	1.988	2.069	0.0615	2.053	2.137	0.0563	1.891	1.968	0.0623	1.968
4291-630	0.0546	1.838	1.913	0.0570	1.912	1.990	0.0606	2.025	2.108	0.0591	1.978	2.059	0.0546	2.059
Means:			2.082			2.077			2.113			2.068		

TABLE III—RESULTS [FROM INDIVIDUAL OBSERVATIONS OF THE SOLAR ROTATION, 1909—*Concluded.*

Plate:	L393, Sept. 8, 9.37, E.S.T.			L399, Sept. 8, 2.38, E.S.T.		
De L. on — C	$\alpha=0^\circ$	$\beta=0^\circ 0$	$\gamma=10^\circ 6$	$\alpha=0^\circ$	$\beta=0^\circ 0$	$\gamma=10^\circ 6$
" "	$r=0.991$	$\epsilon=0.272$	$\phi=1^\circ 1$	$r=0.991$	$\epsilon=0.272$	$\phi=1^\circ 1$
	$B_0=7.25$	$0.5090v = V$		$B_0=7.25$	$0.5090v = V$	
λ	d	$\frac{1}{2}v$	V	d	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376.942	0.0490	1.631	1.660	0.0474	1.582	1.610
4379.927	0.0511	1.697	1.728	0.0610	1.998	2.034
4383.720	0.0530	1.750	1.782	0.0619	2.021	2.057
4404.927	0.0560	1.832	1.865	0.0627	2.036	2.073
4415.293	0.0486	1.602	1.631	0.0554	1.807	1.840
4416.636	.....	.....	.....	.....	.....	.....
4554.211	0.0643	2.002	2.038	0.0528	1.669	1.699
4554.626	0.0621	1.939	1.974	0.0586	1.836	1.869
4561.591	0.0593	1.856	1.889	0.0598	1.868	1.902
4563.939	0.0539	1.696	1.727	0.0524	1.651	1.681
4572.156	0.0537	1.685	1.715	0.0528	1.662	1.692
4574.396	0.0630	1.953	1.988	0.0525	1.651	1.681
Means:			1.817			1.831

SOLAR ROTATION

SECTION 2—DETERMINATIONS OF THE EQUATORIAL VELOCITY FROM OBSERVATIONS AT $\lambda 4500$ IN 1910

BY

RALPH E. DE LURY AND JOHN L. O'CONNOR

The observational equipment employed in 1910 was the same as in 1909 with the exception of the grating. A second Michelson plane grating, No. 55, was received in April and immediately mounted in the spectrograph. Its surface was 11 by 13 cm., ruled 700 lines to 1 mm. Astigmatism was removed from the spectrum by masking 5 cm. off one end of the rulings, and the sharpness of the spectrum lines was improved by occulting 5 cm. from one end of the ruled surface. The remaining area, 6 by 8 cm., was placed with its centre on the optical axis of the spectrograph. Unlike the earlier grating, the rulings of the new grating were apparently not curved, as indicated by the constancy of the focal setting for a given wave-length in the spectra of the various orders on either side of the normal. The second and third orders on one side were particularly brilliant, and the time required to photograph the spectrum was only 2 or 3 per cent of the exposure necessary with the earlier grating.

Many test spectrograms were made to determine the best instrumental conditions. With rather crude temporary mechanism difficulty was experienced in the adjustment of the prisms which reflected the light from opposite limbs through the slit of the spectrograph. The full width of the grating was usually easily filled with the light from both limbs, but irregularities in the adjustment along the lines of the grating frequently made it necessary to give slightly different times of exposure to the two limbs. However, the spectra were carefully focused to insure against displacements of the spectrum lines, which otherwise might result owing to a difference in the illumination of the grating from the two limbs.

Observations.—About 300 observations at $\lambda 4500$, recording a strip of spectrum from within the east limb between two strips from within the west limb, were made by Plaskett and De Lury observing together and singly. Nearly 200 of these were in the second order spectrum and the remainder in the third. They were taken at the equator and at intervals of 15° up to and including the poles. About 100 observations of the equatorial velocity displacements were made, and of these the 78 listed in Table IV were selected as suitable for measurement.

Measurements.—In 1910 the two observers measured some of the equatorial plates. These measurements¹ exhibited a large range of values of the rotational velocity and indicated the presence of certain systematic errors of measuring. The systematic difference between the measurements of the two observers persisted in the measurements of plates recording mechanical displacements of the spectrum lines² as well as in later

¹ Rept. Chief Astronomer, 1911, 129 and 262.

² *Ibid.* 268–281.

measurements of rotation plates³, and since the cause of the systematic errors was unknown in those earlier years the determinations of the equatorial velocity were uncertain by as much as 2 per cent.

Among the early measurements that of plate L569 (4) revealed something of the nature of the errors. On this plate the displacements of 70 spectrum lines were measured by making 4 settings on each line in each of the 3 strips of spectra, the image of the spectrum line being brought alternately from left and right to the setting on the fixed spider thread in the focal plane of the microscope. The means of all first, second, third, and fourth settings are as follows:—

70 spectrum lines, L569 (4),	Means of micrometer settings (mm.)			
	1st	2nd	3rd	4th
First strip, west limb.....	.5177	.5166	.5171	.5164
Excess over .5164.....	.0013	.0002	.0007	.0000
Second strip, east limb.....	.5739	.5723	.5727	.5722
Excess over .5722.....	.0017	.0001	.0005	.0000
Third strip, west limb.....	.5179	.5190	.5169	.5185
Excess over .5169.....	.0010	.0021	.0000	.0016
Three strips, means.....	.5365	.5360	.5356	.5357
Excess over .5356.....	.0009	.0004	.0000	.0001
East-west, mean displacements.....	.0561	.0545	.0557	.0547
		.0553		.0552

Thus, associated with the alternate left and right approach in the micrometer settings there was a systematic difference between the odd and even settings; and along with this peculiarity there was a gradual lessening of the readings, indicating a relative motion (progressing throughout the whole measurement of a spectrum line but more prominent in the measurement of the first two strips) between the spider thread and the image of the spectrum line. At the time, the possibility that this relative motion was caused by the face and breath of the measurer in warming the left side of the eye-piece support was considered, but check measurements made with the left eye revealed no change. Later, of course, the systematic errors were found to be due to capillary action of the oil between nut and micrometer thread, causing the plate to settle in one direction during about 3 minutes⁴.

In 1915-16, De Lury measured 32 of the second order plates of the equatorial rotation, since the $\lambda 4500$ region afforded a good selection of spectrum lines for testing the possible effect of level in the solar atmosphere on the rotational velocity displacements⁵. The spectrum lines measured were chosen (Table V and Fig. 1) after inspecting and measuring penumbral displacements in sunspot spectra observed in 1914. The strongest or most intense of these lines may be readily measured on plates of good density in the second order.

³ Astrophysical Journal, XXXVII, 87, 1913.

⁴ Pub. Dom. Obs. VI, Pt. I, 18-23.

⁵ Astrophys. J. XLIV, 186, 1916.

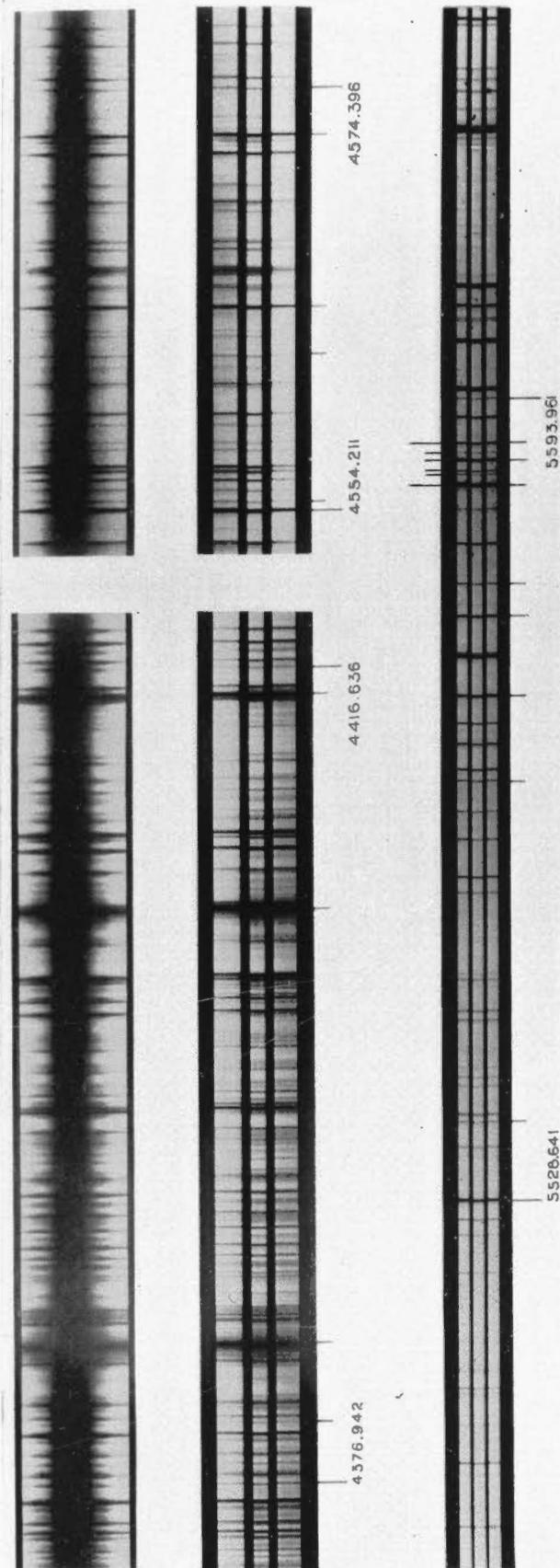


Figure 1—Above, sunspot spectra recording penumbral displacements, aligned with a spectrum of the east limb between spectra of the west limb recording rotational displacements, the spectrum lines measured in the $\lambda 4500$ region being indicated.

Below, a spectrum of the east limb between spectra of the west limb, the groups of spectrum lines used in measuring the rotational displacements in the $\lambda 5600$ region being indicated.

Half of the group of plates, namely L527 (1) to L554 (2), were measured in the usual way by making 4 settings on the central strip of the three, followed by 2 settings on each of the two outside strips. The remaining 16 spectrograms, L558 (1) to L578 (4), were measured with a similar number of settings, though on alternate lines the outside strips were measured first, beginning with the central strip first on alternate observations, so that each spectrum line was measured as many times with the central strip first as with the outside strips first in both the violet left and violet right positions of the plates. Individually, the measurements of the latter 16 revealed high and low values on alternate lines, but these differences were eliminated in the means; and it was evident that whatever was the cause of the systematic errors of measurement this procedure eliminated the errors. The measurements no longer showed the systematic difference between the violet left and violet right positions, the differences appearing to be accidental. These measurements virtually led to the discovery that the plate was actually in motion during measurement; and the micrometer oil was disclosed as the cause. By tightening the split nut the extent of the motion was lessened and the order in which the settings were made reduced any error due to this cause which remained or might develop in time. With these precautions, O'Connor repeated the measurements of the same group of 12 lines for each of the 32 observations. This repetition was particularly desirable in view of the fact that De Lury's measurements indicated no appreciable difference in rotational velocity for different levels in the solar atmosphere.

Table VI contains the measurements and derived velocities by both observers for the 32 observations; while Table VII contains similar results of 46 additional observations measured either violet left or violet right by O'Connor, using the second group of 6 spectrum lines on third order plates and on those additional second order plates of sufficient density to make this group of lines measurable.

The list of observations is given in Table IV in the form described in the preceding presentation of the observations of 1909. Table V, in addition to the Rowland wavelengths of the 12 spectrum lines selected for measurement, gives the international wavelengths, λ I.A., the element identifications, and the intensities in the spectra of the solar disc and of spots taken from the *Revision of Rowland's Preliminary Table of Solar Spectrum Wave-Lengths*⁶, and in columns headed "Flash" and "Height" the intensity and elevation in the chromosphere taken from *The Spectrum of the Chromosphere*⁷. Under "Penumbral Displacement", are given, in Å. and in km. per sec., the means of violet left and violet right measurements by De Lury of the displacements of 5 observations of sunspot spectra for each group of 6 lines, Plates L1517 and L1518. The bracketed value of "Height" for λ 4554·626 is inferred from these displacements. In the column headed "Scale" are given the values of Å. per mm. at each spectrum line determined from a scale curve derived from the measurements of plate L527. These values are about average for the group of second order plates, the greatest departure for any plate being about one part in 600; and to cover the range of scales for the various plates a supplementary table of velocity factors, F , was used, F being derived from the equation, $F \cdot \lambda = (\text{scale}) \times (\text{velocity of light})$. For the group of 6 lines measured on the third order plates the scale was

⁶ Charles E. St. John, et al.: Pub. No. 396, Carnegie Inst. of Washington; Papers of the Mt. Wilson Obs., Vol. III.

⁷ S. A. Mitchell, *Astrophys. J.* LXXI, pp. 1-62; Pub. Leander McCormick Obs., Vol. V, Part II.

practically constant at 0.6002 Å. per mm. In Tables VI and VII, containing the observed, measured, and computed data of the individual plates, the symbols used are the same as those defined in the preceding discussion of the 1909 observations, with the additions of d' denoting the measured displacements with the plate placed violet left, and d'' with plate violet right. Results for each observation are given in Table VI. Means of the observations on each plate are given in Table VII.

TABLE IV—RECORD OF OBSERVATIONS OF THE SOLAR ROTATION, $\lambda 4500$

Plate	1910		Position			Slit width	Exposure	Observing conditions and remarks		
	Date	E.S.T.	α	Disc	r			D	B	
L		h. m.	°	mm.	mm.					
493 (1), (2)	June 21	11 00	0	225.0	0.978	0.025	16	.....	.....	II order spectrum
497 (1), (2)	" 21	12 05	0	225.0	0.978	0.025	16	.....	.....	L497-L526, III order spectrum
502 (1), (2)	" 23	10 14	0	225.5	0.976	0.025	15	.....	.....
505 (1)	" 23	11 10	0	225.5	0.976	0.025	15	.....	.....
508 (3)	" 23	12 00	0	226.0	0.973	0.025	15	.....	.....
509 (1)	" 23	2 55	0	226.0	0.973	0.025	15	.....	.....	Unsteady
510 (1)	" 23	3 14	0	226.0	0.973	0.025	15	.....	.....	"
511 (1)-(4)	" 24	10 01	0	226.0	0.973	0.025	25	.....	.....	Various parts of grating used
512 (1)-(4)	" 24	11 00	0	226.0	0.973	0.025	25	.....	.....	" "
519 (1)-(4)	" 28	3 55	0	225.0	0.978	0.025	25	Good	.....
520 (1), (2)	" 28	4 24	0	225.0	0.978	0.025	25	.....	.....
522 (1), (2)	" 29	10 00	0	225.5	0.976	0.025	25	Fair	.....
525 (1), (2)	" 29	11 30	0	225.5	0.976	0.025	25	"	.....
526 (1), (2)	" 30	9 30	0	225.5	0.976	0.025	25	"	.....
527 (1), (2)	" 30	10 30	0	225.5	0.976	0.025	25	"	.....	L527-L578, II order spectrum
528 (1), (2)	July 5	10 38	0	226.0	0.973	0.025	25	"	.....	Brighter than previous smoky days
531 (1), (2)	" 5	2 46	0	226.0	0.973	0.025	25	"	.....
538 (1), (2)	" 11	10 20	0	225.5	0.931	0.025	20	"	.....
541 (1), (2)	" 11	11 35	0	225.5	0.931	0.025	17	Poorer	.....	Light clouds near sun
544 (1), (2)	" 12	10 54	0	225.0	0.933	0.025	20	Fair	.....
550 (1), (2)	" 13	10 27	0	225.0	0.933	0.025	23	Good	Clear	Fresh west wind
554 (1), (2)	" 13	11 43	0	225.0	0.933	0.025	23	Fair	.....
558 (1), (2)	" 14	9 55	0	226.0	0.973	0.025	23	Good	.....	Very steady
561 (3), (4)	" 14	10 40	0	225.5	0.976	0.025	22	Fair	.....
562 (1), (2)	" 14	11 30	0	225.5	0.976	0.025	22	"	.....
565 (3), (4)	" 14	12 18	0	225.5	0.976	0.025	25	Poor	Hazy	
566 (1), (2)	" 16	11 10	0	225.5	0.976	0.025	20	Good	.....
569 (3), (4)	" 16	12 31	0	225.5	0.976	0.025	20	Fair	.....
570 (1), (2)	" 19	10 59	0	226-	0.974	0.025	20	"	.....	Clouds intervened; (2) at 11.35
573 (1)-(4)	" 25	7 15	0	226.0	0.973	0.025	30	"	.....	Varying exposures
574 (1)-(4)	" 25	7 40	0	226.0	0.973	0.025	40	"	.....	" "
575 (1)-(4)	" 25	9 35	0	225.7	0.975	0.025	27	"	.....	" "
576 (1)-(4)	" 25	9 55	0	225.7	0.975	0.025	35	"	.....	" "
578 (1), (4)	" 25	10 25	0	225.7	0.975	0.025	33	"	.....

TABLE V—THE SPECTRUM LINES MEASURED AND THEIR VELOCITY FACTORS, F , FOR
1 mm. DISPLACEMENT

λ		Element	Intensity			Height	Penumbral displacement		II Order		III Order
Rowland	I.A.		Disc	Spot	Flash				Scale	F	F
Å						km.	Å	km./sec.	Å./mm.	km./sec.	
4376.942	.784	Fe-Cr	1	2	1d	400	0.026	1.76	0.9816	67.25	
4379.927	.771	Zr+Cr	0	1	2	400	0.029	2.01	0.9812	67.18	
4383.720s	.559	Fe	15	15	15	1600	-0.013	-0.91	0.9810	67.10	
4404.927s	.763	Fe	10	10	12	1200	-0.004	-0.30	0.9793	66.67	
4415.293s	.137	Fe	8	8	8	800	-0.003	-0.22	0.9784	66.45	
4416.636	.477	V	0	3	1	350	0.035	2.35	0.9783	66.42	
4554.211s	.038	Ba ⁺	8	10	50	2000	0.004	0.24	0.9732	64.08	39.55
4554.626	.462	Fe	1	2	.....	(400)	0.025	1.65	0.9732	64.07	39.55
4561.591	.419	.....	1	1	0	350	0.023	1.53	0.9726	63.94	39.46
4563.939s	.768	Ti ⁺	4	3	30	2500	0.005	0.32	0.9723	63.88	39.43
4572.156s	1.982	Ti ⁺	6	4	35	2500	0.006	0.38	0.9716	63.72	39.33
4574.396	.227	Fe	1	1	0	350	0.029	1.90	0.9713	63.67	39.30

TABLE VI—RESULTS FROM INDIVIDUAL OBSERVATIONS, 12 SPECTRUM LINES

Plate:	L527 (1) June 30, 10:30, E.S.T.											
De L on T												
" "	$\alpha = 0^\circ \quad \beta = 6^\circ 7' \quad \gamma = 12^\circ 8'$											
O'C.	$r = 0.976 \quad \epsilon = 0.260 \quad \phi = 0^\circ 6'$											
" "	$B_o = 2^\circ 9' \quad 0.5127v = V$											
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376.942	0.0512	1.851	1.898	0.0525	1.895	1.943	0.0485	1.761	1.806	0.0483	1.754	1.799
4379.927	0.0511	1.848	1.893	0.0530	1.910	1.959	0.0448	1.635	1.677	0.0487	1.766	1.811
4383.720	0.0477	1.732	1.774	0.0524	1.888	1.936	0.0490	1.774	1.819	0.0401	1.475	1.513
4404.927	0.0472	1.703	1.746	0.0482	1.737	1.781	0.0440	1.597	1.638	0.0463	1.673	1.716
4415.293	0.0520	1.857	1.904	0.0512	1.839	1.886	0.0480	1.725	1.769	0.0569	2.020	2.072
4416.636	0.0507	1.814	1.860	0.0479	1.721	1.765	0.0555	1.973	2.023	0.0494	1.771	1.816
4554.211	0.0549	1.889	1.937	0.0508	1.758	1.803	0.0523	1.706	1.750	0.0523	1.806	1.852
4554.626	0.0562	1.931	1.980	0.0509	1.761	1.806	0.0557	1.915	1.964	0.0541	1.863	1.911
4561.591	0.0575	1.968	2.018	0.0577	1.975	2.025	0.0560	1.820	1.866	0.0560	1.920	1.969
4563.939	0.0569	1.947	1.997	0.0528	1.816	1.862	0.0556	1.906	1.955	0.0525	1.807	1.853
4572.156	0.0514	1.768	1.813	0.0523	1.796	1.842	0.0545	1.866	1.914	0.0474	1.640	1.682
4574.396	0.0521	1.789	1.835	0.0496	1.709	1.753	0.0502	1.728	1.772	0.0518	1.779	1.824
Means:			1.888			1.863			1.829			1.818
						1.876						1.824

TABLE VI—RESULTS FROM INDIVIDUAL OBSERVATIONS, 12 SPECTRUM LINES—Continued

Plate:	L527 (2) June 30, 10:30, E.S.T.											
De L on T	$\alpha = 0^\circ \quad \beta = 6^\circ 7 \quad \gamma = 12^\circ 8$											
" "	$r = 0.976 \quad \epsilon = 0.260 \quad \phi = 0^\circ 6$											
O'C	$B_o = 2^\circ 9 \quad 0.5127v = V$											
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376.942	0.0484	1.757	1.802	0.0473	1.720	1.764	0.0481	1.747	1.792	0.0479	1.740	1.784
4379.927	0.0517	1.867	1.915	0.0554	1.991	2.042	0.0563	2.021	2.073	0.0576	2.085	2.138
4383.720	0.0549	1.972	2.022	0.0469	1.703	1.746	0.0492	1.781	1.826	0.0468	1.700	1.743
4404.927	0.0505	1.813	1.859	0.0456	1.650	1.692	0.0539	1.926	1.975	0.0483	1.740	1.784
4415.293	0.0571	2.027	2.079	0.0534	1.904	1.953	0.0504	1.804	1.850	0.0477	1.715	1.759
4416.636	0.0488	1.751	1.796	0.0431	1.561	1.601	0.0459	1.657	1.699	0.0500	1.791	1.837
4554.211	0.0552	1.899	1.947	0.0516	1.783	1.828	0.0535	1.844	1.891	0.0521	1.799	1.845
4554.626	0.0470	1.636	1.678	0.0611	2.088	2.141	0.0562	1.931	1.980	0.0502	1.738	1.782
4561.591	0.0512	1.767	1.812	0.0497	1.719	1.763	0.0575	1.968	2.018	0.0591	2.019	2.071
4563.939	0.0540	1.855	1.902	0.0485	1.679	1.722	0.0535	1.839	1.886	0.0514	1.772	1.817
4572.156	0.0571	1.949	1.999	0.0567	1.936	1.985	0.0514	1.768	1.813	0.0495	1.707	1.751
4574.396	0.0494	1.703	1.746	0.0527	1.808	1.854	0.0535	1.833	1.880	0.0485	1.674	1.717
Means:			1.880			1.841			1.891			1.836
						1.861						1.864
Plate:	L528 (1) July 5, 10:38, E.S.T.											
De L on T	$\alpha = 0^\circ \quad \beta = 6^\circ 4 \quad \gamma = 13^\circ 8$											
" "	$r = 0.973 \quad \epsilon = 0.259 \quad \phi = 0^\circ 8$											
O'C.	$B_o = 3^\circ 4 \quad 0.5148v = V$											
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376.942	0.0583	2.090	2.152	0.0521	1.882	1.938	0.0549	1.976	2.035	0.0479	1.740	1.792
4379.927	0.0576	2.064	2.125	0.0604	2.158	2.222	0.0500	1.809	1.863	0.0499	1.806	1.860
4383.720	0.0531	1.911	1.968	0.0508	1.834	1.888	0.0502	1.814	1.868	0.0534	1.922	1.979
4404.927	0.0591	2.099	2.161	0.0523	1.873	1.929	0.0524	1.876	1.932	0.0502	1.803	1.857
4415.293	0.0566	2.010	2.070	0.0578	2.050	2.111	0.0611	2.160	2.224	0.0531	1.894	1.950
4416.636	0.0589	2.085	2.147	0.0554	1.969	2.027	0.0576	2.043	2.104	0.0550	1.957	2.015
4554.211	0.0584	2.012	2.072	0.0591	2.035	2.095	0.0645	2.197	2.262	0.0642	2.187	2.252
4554.626	0.0618	2.122	2.185	0.0548	1.896	1.952	0.0634	2.161	2.225	0.0569	1.953	2.011
4561.591	0.0544	1.869	1.925	0.0505	1.744	1.796	0.0561	1.924	1.981	0.0521	1.796	1.849
4563.939	0.0613	2.087	2.149	0.0574	1.963	2.021	0.0588	2.008	2.068	0.0540	1.855	1.910
4572.156	0.0605	2.057	2.118	0.0553	1.891	1.947	0.0605	2.058	2.119	0.0668	2.258	2.325
4574.396	0.0560	1.912	1.969	0.0601	2.043	2.104	0.0597	2.031	2.091	0.0598	2.034	2.094
Means:			2.087			2.003			2.064			1.991
						2.045						2.028

TABLE VI—RESULTS FROM INDIVIDUAL OBSERVATIONS, 12 SPECTRUM LINES—Continued

Plate:	L528 (2) July 5, 10:39, E.S.T.											
De L on T " " O'C. " " " " "	$\alpha = 0^\circ \quad \beta = 6^\circ 4' \quad \gamma = 13^\circ 8'$ $r = 0.973 \quad \epsilon = 0.259 \quad \phi = 0^\circ 8'$ $B_0 = 3^\circ 4' \quad 0.5148v = V$											
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376-942	0.0530	1.912	1.960	0.0525	1.895	1.951	0.0555	1.996	2.055	0.0520	1.878	1.934
4379-927	0.0545	1.960	2.018	0.0517	1.866	1.921	0.0494	1.789	1.842	0.0521	1.880	1.936
4383-720	0.0510	1.841	1.896	0.0516	1.861	1.916	0.0518	1.868	1.923	0.0451	1.643	1.692
4404-927	0.0602	2.136	2.199	0.0590	2.096	2.158	0.0570	2.030	2.090	0.0559	1.993	2.052
4415-293	0.0499	1.788	1.841	0.0532	1.897	1.953	0.0513	1.834	1.888	0.0533	1.901	1.957
4416-636	0.0601	2.125	2.188	0.0570	2.022	2.082	0.0574	2.036	2.096	0.0514	1.837	1.892
4554-211	0.0573	1.977	2.036	0.0580	2.000	2.059	0.0593	2.030	2.090	0.0527	1.819	1.873
4554-626	0.0644	2.206	2.272	0.0611	2.100	2.162	0.0626	2.136	2.199	0.0573	1.966	2.024
4561-591	0.0626	2.128	2.191	0.0627	2.135	2.198	0.0597	2.039	2.100	0.0572	1.959	2.017
4563-939	0.0560	1.919	1.976	0.0579	1.980	2.039	0.0529	1.820	1.874	0.0524	1.804	1.858
4572-156	0.0572	1.953	2.011	0.0580	1.978	2.037	0.0561	1.917	1.974	0.0536	1.838	1.893
4574-396	0.0594	2.022	2.082	0.0607	2.063	2.124	0.0596	2.028	2.088	0.0543	1.859	1.914
Means:		2.057			2.050			2.018			1.920	
					2.054						1.969	
	L531 (1) July 5, 2:45, E.S.T.											
De L. on T " " O'C. " " " " "	$\alpha = 0^\circ \quad \beta = 6^\circ 4' \quad \gamma = 13^\circ 8'$ $r = 0.973 \quad \epsilon = 0.259 \quad \phi = 0^\circ 8'$ $B_0 = 3^\circ 4' \quad 0.5148v = V$											
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376-942	0.0550	1.979	2.038	0.0604	2.161	2.225	0.0599	2.144	2.208	0.0568	2.040	2.101
4379-927	0.0574	2.059	2.120	0.0518	1.870	1.926	0.0563	2.021	2.081	0.0587	2.108	2.171
4383-720	0.0543	1.952	2.010	0.0557	1.999	2.058	0.0527	1.898	1.954	0.0544	1.955	2.013
4404-927	0.0581	2.066	2.127	0.0551	1.966	2.024	0.0623	2.206	2.272	0.0537	1.920	1.977
4415-293	0.0596	2.110	2.173	0.0589	2.087	2.149	0.0540	1.924	1.981	0.0550	1.957	2.015
4416-636	0.0576	2.043	2.104	0.0598	2.116	2.179	0.0492	1.764	1.816	0.0502	1.797	1.850
4554-211	0.0598	2.049	2.110	0.0610	2.087	2.149	0.0534	1.841	1.896	0.0541	1.863	1.918
4554-626	0.0610	2.087	2.149	0.0592	2.030	2.090	0.0552	1.899	1.955	0.0547	1.883	1.939
4561-591	0.0542	1.863	1.918	0.0555	1.905	1.962	0.0566	1.940	1.998	0.0581	1.987	2.046
4563-939	0.0546	1.874	1.930	0.0552	1.894	1.950	0.0580	1.983	2.042	0.0562	1.925	1.982
4572-156	0.0594	2.023	2.083	0.0564	1.927	1.984	0.0581	1.981	2.040	0.0614	2.086	2.148
4574-396	0.0583	1.986	2.045	0.0578	1.970	2.029	0.0587	1.999	2.058	0.0590	2.009	2.069
Means:		2.067			2.060			2.025			2.019	
					2.064						2.022	

TABLE VI—RESULTS FROM INDIVIDUAL OBSERVATIONS, 12 SPECTRUM LINES—Continued

Plate:		L531 (2) July 5, 2:46, E.S.T.											
De L. on T		$\alpha = 0^\circ \quad \beta = 6^\circ 4' \quad \gamma = 13^\circ 8'$ $r = 0.973 \quad e = 0.259 \quad \phi = 0^\circ$ $B_0 = 3^\circ 4' \quad 0.5148v = V$											
λ		d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
		mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376.942		0.0570	2.046	2.107	0.0547	1.969	2.027	0.0534	1.925	1.982	0.0538	1.939	1.997
4379.927		0.0546	1.964	2.022	0.0547	1.967	2.025	0.0534	1.924	1.981	0.0576	2.065	2.126
4383.720		0.0569	2.039	2.100	0.0589	2.106	2.169	0.0550	1.975	2.034	0.0510	1.841	1.896
4404.927		0.0569	2.026	2.086	0.0547	1.953	2.011	0.0535	1.913	1.970	0.0513	1.840	1.895
4415.293		0.0560	1.990	2.049	0.0563	2.000	2.059	0.0575	2.040	2.101	0.0520	1.857	1.912
4416.636		0.0590	2.089	2.151	0.0629	2.219	2.285	0.0540	1.923	1.980	0.0470	1.691	1.741
4554.211		0.0583	2.001	2.060	0.0563	1.937	1.995	0.0587	2.011	2.070	0.0545	1.876	1.932
4554.626		0.0581	1.994	2.053	0.0591	2.027	2.087	0.0635	2.165	2.229	0.0544	1.873	1.929
4561.591		0.0574	1.966	2.024	0.0608	2.074	2.136	0.0604	2.061	2.122	0.0572	1.959	2.017
4563.939		0.0595	2.031	2.091	0.0593	2.025	2.085	0.0575	1.967	2.025	0.0552	1.893	1.949
4572.156		0.0598	2.036	2.096	0.0578	1.972	2.031	0.0615	2.089	2.151	0.0584	1.991	2.050
4574.396		0.0578	1.970	2.029	0.0598	2.034	2.094	0.0563	1.923	1.980	0.0555	1.897	1.953
Means:				2.072				2.084			2.052		1.950
								2.078					2.001
Plate:		L538 (1) July 11, 10:18, E.S.T.											
De L. on T		$\alpha = 0^\circ \quad \beta = 6^\circ 0' \quad \gamma = 21^\circ 7'$ $r = 0.931 \quad e = 0.248 \quad \phi = 1^\circ 5'$ $B_0 = 4^\circ 0' \quad 0.5381v = V$											
λ		d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
		mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376.942		0.0540	1.940	2.088	0.0500	1.806	1.944	0.0484	1.751	1.885	0.0521	1.876	2.019
4379.927		0.0558	1.999	2.152	0.0481	1.740	1.873	0.0440	1.602	1.724	0.0432	1.575	1.695
4383.720		0.0513	1.846	1.987	0.0480	1.735	1.867	0.0497	1.791	1.928	0.0494	1.781	1.917
4404.927		0.0486	1.745	1.878	0.0527	1.881	2.025	0.0522	1.864	2.006	0.0490	1.757	1.891
4415.293		0.0469	1.683	1.811	0.0502	1.792	1.929	0.0475	1.702	1.832	0.0513	1.828	1.967
4416.636		0.0555	1.968	2.118	0.0555	1.968	2.118	0.0520	1.851	1.992	0.0481	1.721	1.852
4554.211		0.0563	1.928	2.075	0.0504	1.739	1.872	0.0471	1.633	1.758	0.0460	1.598	1.720
4554.626		0.0544	1.867	2.009	0.0546	1.873	2.016	0.0496	1.713	1.844	0.0517	1.780	1.916
4561.591		0.0491	1.694	1.823	0.0493	1.701	1.831	0.0533	1.828	1.967	0.0535	1.834	1.974
4563.939		0.0470	1.628	1.750	0.0473	1.635	1.760	0.0509	1.750	1.884	0.0440	1.529	1.646
4572.156		0.0490	1.686	1.815	0.0513	1.759	1.893	0.0449	1.555	1.674	0.0483	1.663	1.790
4574.396		0.0516	1.767	1.902	0.0467	1.611	1.734	0.0496	1.703	1.833	0.0484	1.665	1.792
Means:				1.951				1.905			1.861		1.848
								1.928					1.855

TABLE VI—RESULTS FROM INDIVIDUAL OBSERVATIONS, 12 SPECTRUM LINES—Continued

Plate:	L538 (2) July 11, 10:19, E.S.T.											
De L. on T " " O'C. " " " "	$\alpha = 0^\circ \quad \beta = 6^\circ 0' \quad \gamma = 21^\circ 7'$ $r = 0.931 \quad \epsilon = 0.248 \quad \phi = 1^\circ 5'$ $B_0 = 4^\circ 0' \quad 0.5381v = V$											
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376.942	0.0505	1.823	1.962	0.0505	1.823	1.962	0.0489	1.768	1.903	0.0514	1.852	1.993
4379.927	0.0500	1.804	1.942	0.0472	1.710	1.840	0.0480	1.736	1.868	0.0531	1.908	2.054
4383.720	0.0495	1.785	1.921	0.0457	1.647	1.773	0.0429	1.563	1.682	0.0457	1.657	1.783
4404.927	0.0508	1.818	1.957	0.0517	1.848	1.989	0.0480	1.724	1.856	0.0456	1.644	1.769
4415.293	0.0450	1.620	1.744	0.0431	1.556	1.675	0.0483	1.729	1.861	0.0443	1.596	1.718
4416.636	0.0421	1.523	1.639	0.0490	1.752	1.886	0.0467	1.675	1.803	0.0487	1.741	1.874
4554.211	0.0474	1.643	1.768	0.0449	1.563	1.682	0.0521	1.793	1.930	0.0500	1.726	1.858
4554.626	0.0528	1.816	1.955	0.0476	1.650	1.776	0.0520	1.790	1.927	0.0517	1.780	1.916
4561.591	0.0515	1.771	1.906	0.0483	1.669	1.796	0.0508	1.748	1.881	0.0535	1.834	1.974
4563.939	0.0479	1.655	1.781	0.0536	1.837	1.977	0.0531	1.820	1.959	0.0528	1.810	1.948
4572.156	0.0541	1.849	1.990	0.0539	1.842	1.983	0.0518	1.774	1.909	0.0504	1.730	1.862
4574.396	0.0480	1.653	1.779	0.0549	1.873	2.016	0.0550	1.875	2.018	0.0501	1.719	1.850
Means:		1.862			1.863			1.883			1.883	
					1.863						1.883	
Plate:	L541 (1) July 11, 11:33, E.S.T.											
De L. on T " " O'C. " " " "	$\alpha = 0^\circ \quad \beta = 6^\circ 0' \quad \gamma = 21^\circ 7'$ $r = 0.931 \quad \epsilon = 0.248 \quad \phi = 1^\circ 5'$ $B_0 = 4^\circ 0' \quad 0.5381v = V$											
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376.942	0.0518	1.867	2.009	0.0509	1.837	1.977	0.0555	1.990	2.142	0.0537	1.929	2.076
4379.927	0.0565	2.023	2.177	0.0463	1.680	1.808	0.0515	1.854	1.995	0.0529	1.901	2.046
4383.720	0.0555	1.987	2.139	0.0511	1.840	1.980	0.0449	1.630	1.754	0.0442	1.607	1.730
4404.927	0.0542	1.932	2.079	0.0470	1.692	1.821	0.0474	1.704	1.834	0.0514	1.837	1.977
4415.293	0.0526	1.873	2.016	0.0485	1.736	1.868	0.0505	1.802	1.939	0.0538	1.911	2.057
4416.636	0.0488	1.746	1.879	0.0460	1.653	1.779	0.0489	1.748	1.881	0.0478	1.711	1.842
4554.211	0.0588	2.008	2.161	0.0499	1.723	1.854	0.0510	1.758	1.892	0.0442	1.540	1.658
4554.626	0.0595	2.030	2.185	0.0560	1.918	2.064	0.0531	1.825	1.964	0.0534	1.835	1.975
4561.591	0.0480	1.659	1.786	0.0472	1.633	1.758	0.0520	1.786	1.922	0.0490	1.691	1.820
4563.939	0.0567	1.936	2.084	0.0512	1.760	1.894	0.0582	1.983	2.134	0.0487	1.679	1.807
4572.156	0.0545	1.861	2.003	0.0472	1.628	1.752	0.0548	1.870	2.013	0.0461	1.593	1.715
4574.396	0.0515	1.764	1.899	0.0516	1.767	1.902	0.0519	1.776	1.912	0.0536	1.831	1.971
Means:		2.035			1.871			1.949			1.890	
					1.871						1.920	

TABLE VI—RESULTS FROM INDIVIDUAL OBSERVATIONS, 12 SPECTRUM LINES—Continued

Plate:	L541 (2) July 11, 11:34, E.S.T.											
De L. on T. " " O'C. " " " "	$\alpha = 0^\circ \quad \beta = 6^\circ 0' \quad \gamma = 21^\circ 7'$ $r = 0.931 \quad \epsilon = 0.248 \quad \phi = 1^\circ 6'$ $B_o = 4^\circ 0' \quad 0.5381v = V$											
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376.942	0.0515	1.857	1.999	0.0520	1.874	2.017	0.0526	1.892	2.036	0.0460	1.671	1.798
4379.927	0.0561	2.009	2.162	0.0574	2.053	2.210	0.0515	1.854	1.995	0.0468	1.696	1.825
4383.720	0.0557	1.994	2.146	0.0556	1.991	2.143	0.0501	1.805	1.943	0.0580	2.070	2.228
4404.927	0.0591	2.095	2.255	0.0531	1.895	2.040	0.0516	1.844	1.985	0.0534	1.904	2.049
4415.293	0.0528	1.879	2.022	0.0499	1.783	1.919	0.0500	1.785	1.921	0.0547	1.941	2.089
4416.636	0.0564	1.998	2.150	0.0494	1.766	1.901	0.0497	1.775	1.910	0.0455	1.635	1.760
4554.211	0.0532	1.829	1.969	0.0546	1.874	2.017	0.0568	1.944	2.092	0.0533	1.832	1.972
4554.626	0.0563	1.928	2.075	0.0614	2.092	2.252	0.0590	2.014	2.168	0.0529	1.819	1.958
4561.591	0.0520	1.787	1.923	0.0523	1.797	1.934	0.0556	1.902	2.047	0.0535	1.834	1.974
4563.939	0.0552	1.888	2.032	0.0581	1.971	2.121	0.0530	1.817	1.956	0.0491	1.691	1.821
4572.156	0.0508	1.744	1.877	0.0563	1.919	2.065	0.0487	1.676	1.804	0.0524	1.793	1.930
4574.396	0.0556	1.895	2.040	0.0540	1.844	1.985	0.0524	1.792	1.929	0.0486	1.671	1.798
Means:		2.054			2.050				1.982			1.934
					2.052							1.958
Plate:	L544 (1) July 12, 10:54, E.S.T.											
De L. on T. " " O'C. " " " "	$\alpha = 0^\circ \quad \beta = 6^\circ 0' \quad \gamma = 21^\circ 5'$ $r = 0.933 \quad \epsilon = 0.249 \quad \phi = 1^\circ 5'$ $B_o = 4^\circ 1' \quad 0.5374v = V$											
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376.942	0.0468	1.698	1.825	0.0441	1.607	1.727	0.0496	1.785	1.919	0.0504	1.818	1.954
4379.927	0.0548	1.965	2.112	0.0574	2.053	2.207	0.0542	1.945	2.090	0.0545	1.955	2.101
4383.720	0.0501	1.805	1.940	0.0488	1.762	1.894	0.0506	1.822	1.958	0.0464	1.681	1.807
4404.927	0.0497	1.781	1.914	0.0452	1.631	1.753	0.0559	1.987	2.136	0.0438	1.584	1.702
4415.293	0.0476	1.706	1.834	0.0411	1.490	1.601	0.0492	1.758	1.889	0.0438	1.579	1.697
4416.636	0.0559	1.981	2.129	0.0504	1.798	1.932	0.0535	1.801	1.936	0.0463	1.662	1.786
4554.211	0.0494	1.707	1.835	0.0508	1.752	1.883	0.0522	1.796	1.930	0.0527	1.813	1.949
4554.626	0.0539	1.851	1.989	0.0499	1.723	1.852	0.0524	1.803	1.938	0.0480	1.662	1.786
4561.591	0.0548	1.877	2.017	0.0514	1.768	1.900	0.0503	1.732	1.862	0.0511	1.758	1.889
4563.939	0.0523	1.796	1.930	0.0507	1.744	1.874	0.0550	1.881	2.022	0.0563	1.922	2.066
4572.156	0.0473	1.632	1.754	0.0474	1.635	1.757	0.0505	1.733	1.863	0.0530	1.813	1.949
4574.396	0.0459	1.586	1.705	0.0455	1.573	1.691	0.0512	1.754	1.885	0.0537	1.834	1.971
Means:		1.915			1.839				1.952			1.888
					1.877							1.920

TABLE VI—RESULTS FROM INDIVIDUAL OBSERVATIONS, 12 SPECTRUM LINES—Continued

Plate:	L544 (2) July 12, 10:55, E.S.T.											
De L. on T												
" "	$\alpha = 0^\circ \beta = 6^\circ 0 \gamma = 21^\circ 5$ $r = 0.933 \epsilon = 0.249 \phi = 1^\circ 5$ $B_o = 4^\circ 1 \quad 0.5374v = V$											
O'C. "												
" "												
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376-942	0.0572	2.048	2.201	0.0551	1.977	2.125	0.0539	1.936	2.081	0.0530	1.906	2.049
4379-927	0.0476	1.723	1.852	0.0501	1.807	1.942	0.0531	1.908	2.051	0.0509	1.834	1.971
4383-720	0.0505	1.819	1.955	0.0535	1.919	2.063	0.0489	1.765	1.897	0.0515	1.852	1.991
4404-927	0.0569	2.021	2.172	0.0540	1.924	2.068	0.0525	1.874	2.014	0.0509	1.820	1.956
4415-293	0.0504	1.799	1.934	0.0534	1.898	2.040	0.0504	1.798	1.932	0.0502	1.792	1.926
4416-636	0.0524	1.865	2.005	0.0527	1.875	2.015	0.0489	1.748	1.879	0.0491	1.755	1.886
4554-211	0.0559	1.916	2.059	0.0569	1.948	2.094	0.0547	1.877	2.017	0.0528	1.816	1.952
4554-626	0.0501	1.730	1.859	0.0502	1.733	1.863	0.0569	1.947	2.093	0.0499	1.723	1.852
4561-591	0.0570	1.947	2.093	0.0539	1.848	1.986	0.0521	1.790	1.924	0.0580	1.978	2.126
4563-939	0.0506	1.741	1.871	0.0536	1.837	1.974	0.0522	1.791	1.925	0.0523	1.794	1.928
4572-156	0.0489	1.683	1.809	0.0460	1.590	1.709	0.0523	1.790	1.924	0.0491	1.688	1.814
4574-396	0.0570	1.939	2.084	0.0578	1.965	2.112	0.0533	1.821	1.957	0.0536	1.831	1.968
Means:		1.991			1.999			1.975			1.952	
							1.955				1.963	
Plate:	L550 (1) July 13, 10:27, E.S.T.											
De L. on T												
" "	$\alpha = 0^\circ \beta = 5^\circ 9 \gamma = 21^\circ 5$ $r = 0.933 \epsilon = 0.249 \phi = 1^\circ 6$ $B_o = 4^\circ 2 \quad 0.5374v = V$											
O'C. "												
" "												
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376-942	0.0545	1.958	2.104	0.0516	1.860	1.999	0.0506	1.825	1.962	0.0484	1.751	1.882
4379-927	0.0572	2.046	2.199	0.0546	1.959	2.106	0.0533	1.914	2.057	0.0543	1.881	2.022
4383-720	0.0539	1.934	2.079	0.0508	1.930	2.074	0.0535	1.919	2.063	0.0479	1.731	1.860
4404-927	0.0639	2.256	2.425	0.0616	2.179	2.342	0.0561	1.994	2.143	0.0533	1.900	2.042
4415-293	0.0535	1.903	2.045	0.0535	1.903	2.045	0.0559	1.981	2.129	0.0496	1.772	1.905
4416-636	0.0554	1.965	2.112	0.0551	1.956	2.102	0.0501	1.788	1.922	0.0519	1.848	1.986
4554-211	0.0607	2.069	2.224	0.0613	2.089	2.245	0.0566	1.937	2.082	0.0544	1.867	2.007
4554-626	0.0530	1.823	1.959	0.0524	1.803	1.938	0.0546	1.873	2.013	0.0510	1.758	1.889
4561-591	0.0595	2.027	2.179	0.0553	1.892	2.034	0.0532	1.825	1.962	0.0544	1.863	2.002
4563-939	0.0576	1.965	2.112	0.0536	1.837	1.974	0.0528	1.810	1.945	0.0557	1.903	2.045
4572-156	0.0539	1.842	1.980	0.0537	1.836	1.973	0.0559	1.905	2.047	0.0574	1.953	2.099
4574-396	0.0598	2.029	2.181	0.0551	1.879	2.020	0.0564	1.920	2.064	0.0593	2.012	2.162
Means:		2.133			2.071			2.032			1.992	
					2.102						2.012	

TABLE VI—RESULTS FROM INDIVIDUAL OBSERVATIONS, 12 SPECTRUM LINES—Continued

Plate:	L550 (2) July 13, 10:28, E.S.T.											
De L. on T												
" "	$\alpha = 0^\circ \quad \beta = 5^\circ 9 \quad \gamma = 21^\circ 5$ $r = 0.933 \quad \epsilon = 0.249 \quad \phi = 1^\circ 6$ $B_o = 4^\circ 2 \quad 0.5374v = V$											
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376.942	0.0550	1.975	2.123	0.0533	1.918	2.061	0.0525	1.889	2.030	0.0536	1.926	2.070
4379.927	0.0474	1.717	1.845	0.0530	1.905	2.047	0.0466	1.689	1.815	0.0511	1.840	1.978
4383.720	0.0513	1.847	1.985	0.0490	1.769	1.901	0.0498	1.795	1.929	0.0443	1.610	1.730
4404.927	0.0597	2.116	2.274	0.0511	1.829	1.966	0.0525	1.874	2.014	0.0465	1.674	1.799
4415.293	0.0622	2.192	2.356	0.0501	1.790	1.924	0.0473	1.695	1.822	0.0525	1.868	2.008
4416.636	0.0527	1.876	2.016	0.0514	1.833	1.970	0.0503	1.794	1.928	0.0473	2.027	2.179
4554.211	0.0551	1.890	2.031	0.0501	1.730	1.859	0.0551	1.889	2.030	0.0522	1.796	1.930
4554.626	0.0570	1.951	2.097	0.0533	1.832	1.969	0.0586	2.002	2.152	0.0540	1.854	1.993
4561.591	0.0544	1.864	2.003	0.0523	1.797	1.931	0.0546	1.870	2.010	0.0555	1.898	2.040
4563.939	0.0530	1.818	1.954	0.0611	2.077	2.232	0.0535	1.833	1.970	0.0471	1.628	1.750
4572.156	0.0555	1.893	2.035	0.0554	1.890	2.031	0.0577	1.962	2.109	0.0556	1.901	2.043
4574.396	0.0591	2.006	2.156	0.0581	1.974	2.122	0.0509	1.745	1.876	0.0511	1.751	1.882
Means:		2.073			2.001				1.974			1.950
					2.037							1.962
Plate:	L554 (1) July 13, 11:43, E.S.T.											
De L. on T												
" "	$\alpha = 0^\circ \quad \beta = 5^\circ 9 \quad \gamma = 21^\circ 5$ $r = 0.933 \quad \epsilon = 0.249 \quad \phi = 1^\circ 6$ $B_o = 4^\circ 2 \quad 0.5374v = V$											
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376.942	0.0553	1.984	2.132	0.0535	1.923	2.067	0.0521	1.876	2.016	0.0517	1.862	2.001
4379.927	0.0533	1.915	2.058	0.0497	1.794	1.928	0.0581	2.076	2.231	0.0532	1.911	2.054
4383.720	0.0589	2.101	2.258	0.0558	1.997	2.146	0.0586	2.090	2.246	0.0508	1.828	1.965
4404.927	0.0548	1.951	2.097	0.0510	1.825	1.962	0.0559	1.987	2.135	0.0546	1.944	2.089
4415.293	0.0551	1.955	2.101	0.0539	1.915	2.058	0.0526	1.871	2.011	0.0565	2.001	2.151
4416.636	0.0574	2.031	2.183	0.0550	1.951	2.097	0.0513	1.828	1.965	0.0475	1.701	1.828
4554.211	0.0549	1.884	2.025	0.0569	1.948	2.094	0.0544	1.867	2.007	0.0517	1.780	1.913
4554.626	0.0562	1.925	2.069	0.0562	1.925	2.069	0.0585	1.998	2.147	0.0552	1.893	2.035
4561.591	0.0596	2.030	2.182	0.0537	1.841	1.979	0.0573	1.956	2.102	0.0519	1.783	1.916
4563.939	0.0586	1.997	2.146	0.0574	1.959	2.106	0.0560	1.913	2.056	0.0552	1.887	2.028
4572.156	0.0614	2.081	2.237	0.0557	1.900	2.042	0.0529	1.809	1.944	0.0545	1.860	1.999
4574.396	0.0593	2.013	2.164	0.0568	1.933	2.078	0.0547	1.866	2.006	0.0582	1.977	2.125
Means:		2.138			2.052				2.072			2.009
					2.095							2.041

TABLE VI—RESULTS FROM INDIVIDUAL OBSERVATIONS, 12 SPECTRUM LINES—Continued

Plate:	L554 (2) July 13, 11:44, E.S.T.											
De L. on T												
" "	$\alpha = 0^\circ \quad \beta = 5^\circ 9 \quad \gamma = 21^\circ 5$											
O'C. "	$r = 0.933 \quad e = 0.249 \quad \phi = 1^\circ 6$											
" "	$B_o = 4^\circ 2 \quad 0.5374v = V$											
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376-942	0.0554	1.987	2.136	0.0588	2.102	2.259	0.0505	1.822	1.958	0.0534	1.919	2.063
4379-927	0.0596	2.127	2.286	0.0537	1.929	2.073	0.0507	1.827	1.964	0.0558	1.998	2.147
4383-720	0.0543	1.947	2.093	0.0496	1.789	1.923	0.0473	1.711	1.839	0.0547	1.959	2.106
4404-927	0.0660	2.325	2.499	0.0610	2.158	2.319	0.0591	2.094	2.251	0.0566	2.010	2.160
4415-293	0.0465	1.669	1.794	0.0557	1.975	2.123	0.0601	2.121	2.280	0.0572	2.024	2.175
4416-636	0.0550	1.951	2.097	0.0526	1.872	2.012	0.0561	1.987	2.136	0.0520	1.851	1.989
4554-211	0.0562	1.925	2.069	0.0539	1.851	1.989	0.0514	1.771	1.903	0.0536	1.841	1.979
4554-626	0.0546	1.874	2.014	0.0564	1.932	2.077	0.0560	1.918	2.061	0.0561	1.921	2.065
4561-591	0.0554	1.896	2.038	0.0587	2.001	2.151	0.0571	1.949	2.095	0.0609	2.071	2.226
4563-939	0.0595	2.026	2.178	0.0562	1.920	2.064	0.0556	1.900	2.042	0.0544	1.862	2.001
4572-156	0.0549	1.874	2.014	0.0577	1.963	2.110	0.0569	1.937	2.082	0.0495	1.701	1.828
4574-396	0.0565	1.924	2.068	0.0568	1.933	2.078	0.0512	1.754	1.885	0.0532	1.818	1.954
Means:		2.107			2.098			2.041			2.058	
					2.013						2.050	
Plate:	L558 (1) July 14, 9:54, E.S.T.											
De L. on T												
" "	$\alpha = 0^\circ \quad \beta = 5^\circ 8 \quad \gamma = 14^\circ 0$											
O'C. "	$r = 0.973 \quad e = 0.259 \quad \phi = 1^\circ 1$											
" "	$B_o = 4^\circ 3 \quad 0.5153v = V$											
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376-942	0.0490	1.778	1.832	0.0503	1.822	1.878	0.0531	1.915	1.974	0.0525	1.895	1.953
4379-927	0.0532	1.918	1.977	0.0526	1.897	1.955	0.0535	1.927	1.986	0.0513	1.853	1.910
4383-720	0.0490	1.775	1.829	0.0461	1.678	1.729	0.0487	1.764	1.818	0.0520	1.875	1.932
4404-927	0.0527	1.888	1.948	0.0532	1.904	1.962	0.0556	1.983	2.044	0.0494	1.777	1.831
4415-293	0.0536	1.912	1.971	0.0552	1.965	2.025	0.0516	1.844	1.900	0.0560	1.990	2.051
4416-636	0.0553	1.968	2.028	0.0450	1.625	1.675	0.0612	2.162	2.228	0.0531	1.893	1.951
4554-211	0.0533	1.838	1.894	0.0545	1.876	1.933	0.0544	1.873	1.930	0.0595	2.036	2.098
4554-626	0.0618	2.110	2.175	0.0585	2.004	2.065	0.0541	1.863	1.920	0.0573	1.966	2.026
4561-591	0.0599	2.046	2.109	0.0552	1.895	1.953	0.0522	1.829	1.885	0.0555	1.904	1.962
4563-939	0.0567	1.942	2.001	0.0601	2.050	2.113	0.0540	1.855	1.912	0.0568	1.944	2.003
4572-156	0.0573	1.956	2.016	0.0535	1.835	1.891	0.0526	1.806	1.861	0.0565	1.930	1.989
4574-396	0.0547	1.872	1.929	0.0546	1.868	1.925	0.0586	1.996	2.057	0.0581	1.980	2.041
Means:		1.976			1.925			1.960			1.979	
					1.951						1.970	

TABLE VI—RESULTS FROM INDIVIDUAL OBSERVATIONS, 12 SPECTRUM LINES—Continued

Plate:	L558 (2) July 14, 9:55, E.S.T.											
De L. on T												
" "	$\alpha = 0^\circ \quad \beta = 5^\circ 8' \quad \gamma = 14^\circ 0'$ $r = 0.973 \quad \epsilon = 0.259 \quad \phi = 1^\circ 1'$ $B_o = 4^\circ 3' \quad 0.5153v = V$											
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376.942	0.0542	1.953	2.013	0.0511	1.848	1.905	0.0541	1.949	2.009	0.0522	1.885	1.943
4379.927	0.0500	1.810	1.865	0.0432	1.582	1.630	0.0526	1.897	1.955	0.0496	1.796	1.851
4383.720	0.0538	1.936	1.995	0.0456	1.660	1.711	0.0502	1.814	1.870	0.0476	1.727	1.780
4404.927	0.0464	1.677	1.728	0.0484	1.737	1.790	0.0480	1.730	1.783	0.0483	1.740	1.793
4415.293	0.0554	1.971	2.031	0.0494	1.772	1.826	0.0514	1.838	1.894	0.0567	2.014	2.076
4416.636	0.0528	1.884	1.942	0.0476	1.711	1.763	0.0516	1.844	1.900	0.0494	1.771	1.825
4554.211	0.0574	1.970	2.030	0.0599	2.050	2.113	0.0580	1.988	2.049	0.0545	1.876	1.933
4554.626	0.0519	1.793	1.848	0.0566	1.944	2.003	0.0556	1.911	1.969	0.0552	1.899	1.957
4561.591	0.0505	1.745	1.798	0.0517	1.783	1.838	0.0534	1.837	1.893	0.0597	2.039	2.101
4563.939	0.0595	2.032	2.094	0.0568	1.945	2.005	0.0581	1.986	2.047	0.0537	1.846	1.902
4572.156	0.0581	1.982	2.043	0.0575	1.963	2.023	0.0600	2.042	2.104	0.0614	2.086	2.150
4574.396	0.0586	1.996	2.057	0.0622	2.111	2.176	0.0592	2.015	2.077	0.0560	1.913	1.972
Means:		1.954				1.899				1.963		1.940
						1.927						1.952
Plate:	L561 (3) July 14, 10:40, E.S.T.											
De L. on T												
" "	$\alpha = 0^\circ \quad \beta = 5^\circ 8' \quad \gamma = 13^\circ 3'$ $r = 0.976 \quad \epsilon = 0.260 \quad \phi = 1^\circ 0'$ $B_o = 4^\circ 3' \quad 0.5138v = V$											
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376.942	0.0542	1.953	2.007	0.0457	1.667	1.713	0.0535	1.929	1.982	0.0507	1.835	1.886
4379.927	0.0440	1.608	1.652	0.0410	1.508	1.550	0.0484	1.756	1.804	0.0474	1.722	1.770
4383.720	0.0510	1.842	1.893	0.0520	1.889	1.941	0.0564	2.022	2.078	0.0478	1.734	1.782
4404.927	0.0568	2.024	2.080	0.0550	1.964	2.018	0.0510	1.830	1.881	0.0515	1.846	1.897
4415.293	0.0412	1.499	1.540	0.0465	1.675	1.721	0.0523	1.867	1.919	0.0508	1.818	1.868
4416.636	0.0556	1.977	2.032	0.0441	1.595	1.639	0.0540	1.923	1.976	0.0536	1.910	1.963
4554.211	0.0510	1.765	1.814	0.0537	1.851	1.902	0.0545	1.876	1.928	0.0580	1.988	2.043
4554.626	0.0583	1.999	2.054	0.0535	1.845	1.896	0.0556	1.911	1.964	0.0583	1.998	2.053
4561.591	0.0502	1.735	1.783	0.0567	1.943	1.997	0.0570	1.952	2.006	0.0527	1.815	1.865
4563.939	0.0578	1.977	2.032	0.0559	1.917	1.970	0.0560	1.919	1.972	0.0598	2.040	2.096
4572.156	0.0538	1.845	1.896	0.0537	1.842	1.893	0.0531	1.822	1.872	0.0595	2.026	2.082
4574.396	0.0578	1.971	2.025	0.0608	2.066	2.123	0.0545	1.865	1.916	0.0596	2.028	2.084
Means:		1.901				1.864				1.942		1.949
						1.883						1.946

TABLE VI—RESULTS FROM INDIVIDUAL OBSERVATIONS, 12 SPECTRUM LINES—Continued

Plate:	L561 (4) July 14, 10:41, E.S.T.											
De L. on T												
" "	$\alpha = 0^\circ \quad \beta = 5^\circ 8' \quad \gamma = 13^\circ 3'$ $r = 0.976 \quad \epsilon = 0.260 \quad \phi = 1^\circ 0'$ $B_o = 4^\circ 3' \quad 0.5138v = V$											
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376.942	0.0589	2.111	2.169	0.0517	1.869	1.921	0.0560	2.013	2.069	0.0537	1.935	1.988
4379.927	0.0516	1.864	1.915	0.0538	1.938	1.991	0.0554	1.991	2.046	0.0604	2.159	2.219
4383.720	0.0555	1.993	2.048	0.0443	1.617	1.662	0.0537	1.932	1.985	0.0470	1.707	1.754
4404.927	0.0575	2.047	2.103	0.0544	1.944	1.998	0.0582	2.070	2.127	0.0521	1.866	1.918
4415.293	0.0561	1.994	2.049	0.0585	2.074	2.131	0.0529	1.887	1.939	0.0516	1.844	1.895
4416.636	0.0605	2.140	2.199	0.0584	2.070	2.127	0.0477	1.714	1.761	0.0578	1.717	1.764
4554.211	0.0571	1.959	2.013	0.0539	1.857	1.908	0.0554	1.905	1.958	0.0540	1.860	1.911
4554.626	0.0543	1.870	1.922	0.0503	1.742	1.790	0.0609	2.081	2.138	0.0630	2.149	2.208
4561.591	0.0631	2.148	2.207	0.0634	2.158	2.218	0.0600	2.048	2.105	0.0657	2.230	2.292
4563.939	0.0599	2.044	2.100	0.0552	1.894	1.946	0.0564	1.931	1.984	0.0582	1.989	2.044
4572.156	0.0602	2.049	2.106	0.0620	2.106	2.164	0.0732	2.462	2.530	0.0632	2.144	2.203
4574.396	0.0606	2.060	2.117	0.0606	2.060	2.117	0.0596	2.028	2.084	0.0593	2.018	2.074
Means:		2.079			1.998				2.061			2.023
					2.039							2.041
Plate:	L562 (1) July 14, 11:30, E.S.T.											
De L. on T												
" "	$\alpha = 0^\circ \quad \beta = 5^\circ 8' \quad \gamma = 13^\circ 3'$ $r = 0.976 \quad \epsilon = 0.260 \quad \phi = 1^\circ 0'$ $B_o = 4^\circ 3' \quad 0.5138v = V$											
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376.942	0.0549	1.976	2.031	0.0481	1.748	1.796	0.0545	1.962	2.016	0.0553	1.989	2.044
4379.927	0.0590	2.112	2.170	0.0595	2.129	2.188	0.0565	2.028	2.084	0.0508	1.836	1.887
4383.720	0.0579	2.073	2.130	0.0567	2.033	2.089	0.0566	2.029	2.085	0.0524	1.888	1.940
4404.927	0.0567	2.020	2.076	0.0597	2.120	2.179	0.0561	2.000	2.055	0.0574	2.043	2.099
4415.293	0.0531	1.895	1.947	0.0548	1.951	2.005	0.0510	1.824	1.874	0.0542	1.931	1.984
4416.636	0.0464	1.671	1.717	0.0488	1.751	1.799	0.0481	1.727	1.775	0.0481	1.727	1.775
4554.211	0.0598	2.046	2.102	0.0604	2.065	2.122	0.0569	1.953	2.007	0.0546	1.879	1.931
4554.626	0.0668	2.270	2.333	0.0623	2.126	2.185	0.0605	2.068	2.125	0.0541	1.863	1.914
4561.591	0.0515	1.777	1.826	0.0503	1.739	1.787	0.0544	1.869	1.921	0.0520	1.792	1.841
4563.939	0.0566	1.938	1.991	0.0575	1.967	2.021	0.0539	1.852	1.903	0.0556	1.906	1.959
4572.156	0.0524	1.800	1.850	0.0529	1.816	1.866	0.0530	1.819	1.869	0.0526	1.806	1.856
4574.396	0.0529	1.814	1.864	0.0573	1.954	2.008	0.0546	1.868	1.920	0.0543	1.859	1.910
Means:		2.003			2.004				1.970			1.928
					2.004							1.949

TABLE VI—RESULTS FROM INDIVIDUAL OBSERVATIONS, 12 SPECTRUM LINES—Continued

Plate:	L562 (2) July 14, 11:30. E.S.T.											
De L. on T												
" "	$\alpha = 0^\circ \beta = 5^\circ 8' \gamma = 13^\circ 3'$ $r = 0.976 \epsilon = 0.260 \phi = 1^\circ 0'$ $B_0 = 4^\circ 3' 0.5138\pi = V$											
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376-942	0.0523	1.889	1.941	0.0461	1.680	1.726	0.0509	1.841	1.892	0.0519	1.875	1.927
4379-927	0.0534	1.924	1.977	0.0490	1.776	1.825	0.0519	1.873	1.925	0.0511	1.846	1.897
4383-720	0.0551	1.979	2.034	0.0570	2.043	2.099	0.0539	1.938	1.991	0.0518	1.868	1.920
4404-927	0.0523	1.874	1.926	0.0456	1.650	1.696	0.0555	1.980	2.035	0.0563	2.006	2.061
4415-293	0.0607	2.147	2.206	0.0545	1.941	1.995	0.0581	2.060	2.117	0.0546	1.944	1.998
4416-636	0.0490	1.758	1.807	0.0454	1.638	1.683	0.0441	1.595	1.639	0.0457	1.648	1.693
4554-211	0.0525	1.813	1.863	0.0530	1.829	1.879	0.0580	1.988	2.043	0.0532	1.835	1.886
4554-626	0.0557	1.915	1.968	0.0593	2.031	2.087	0.0588	2.014	2.070	0.0520	1.796	1.846
4561-591	0.0547	1.879	1.931	0.0567	1.943	1.997	0.0554	1.901	1.953	0.0474	1.645	1.690
4563-939	0.0570	1.952	2.006	0.0538	1.849	1.900	0.0527	1.813	1.863	0.0551	1.890	1.942
4572-156	0.0529	1.816	1.866	0.0536	1.839	1.890	0.0602	2.048	2.105	0.0550	1.882	1.934
4574-396	0.0532	1.824	1.874	0.0513	1.764	1.813	0.0556	1.900	1.952	0.0561	1.916	1.969
Means:		1.950			1.883			1.965			1.897	
					1.917						1.931	
Plate:	L565 (3) July 14, 12:18. E.S.T.											
De L. on T												
" "	$\alpha = 0^\circ \beta = 5^\circ 8' \gamma = 13^\circ 3'$ $r = 0.976 \epsilon = 0.260 \phi = 1^\circ 0'$ $B_0 = 4^\circ 3' 0.5138\pi = V$											
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376-942	0.0536	1.933	1.986	0.0506	1.832	1.883	0.0530	1.912	1.965	0.0547	1.969	2.023
4379-927	0.0572	2.052	2.109	0.0510	1.844	1.895	0.0521	1.880	1.932	0.0445	1.625	1.670
4383-720	0.0585	2.094	2.152	0.0547	1.966	2.020	0.0523	1.885	1.937	0.0491	1.777	1.826
4404-927	0.0576	2.051	2.108	0.0549	1.961	2.015	0.0596	2.116	2.174	0.0611	2.166	2.226
4415-293	0.0498	1.785	1.834	0.0499	1.789	1.838	0.0505	1.808	1.858	0.0555	1.974	2.028
4416-636	0.0496	1.778	1.827	0.0462	1.665	1.711	0.0497	1.781	1.830	0.0483	1.734	1.782
4554-211	0.0544	1.874	1.926	0.0573	1.966	2.020	0.0593	2.030	2.086	0.0569	1.953	2.007
4554-626	0.0569	1.954	2.008	0.0566	1.944	1.998	0.0565	1.940	1.994	0.0589	2.017	2.073
4561-591	0.0552	1.895	1.947	0.0528	1.819	1.869	0.0589	2.013	2.069	0.0524	1.805	1.855
4563-939	0.0600	2.048	2.015	0.0650	2.207	2.268	0.0498	1.721	1.768	0.0614	2.091	2.149
4572-156	0.0584	1.992	2.047	0.0576	1.966	2.020	0.0584	1.991	2.046	0.0581	1.981	2.036
4574-396	0.0545	1.866	1.918	0.0535	1.834	1.885	0.0529	1.814	1.864	0.0550	1.881	1.933
Means:		1.997			1.952			1.960			1.967	
					1.975						1.964	

TABLE VI—RESULTS FROM INDIVIDUAL OBSERVATIONS, 12 SPECTRUM LINES—Continued

Plate:	L565 (4) July 14, 12:18, E.S.T.											
De L. on T												
" "	$\alpha = 0^\circ \quad \beta = 5^\circ 8' \quad \gamma = 13^\circ 3'$											
O'C. "	$r = 0.976 \quad \epsilon = 0.260 \quad \phi = 1^\circ 1'$											
" "	$B_o = 4^\circ 3' \quad 0.5138v = V$											
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376.942	0.0548	1.973	2.027	0.0517	1.869	1.921	0.0502	1.818	1.868	0.0507	1.835	1.886
4379.927	0.0544	1.958	2.012	0.0539	1.941	1.995	0.0502	1.816	1.866	0.0485	1.759	1.808
4383.720	0.0508	1.835	1.886	0.0491	1.772	1.821	0.0503	1.818	1.868	0.0513	1.851	1.902
4404.927	0.0527	1.888	1.940	0.0523	1.874	1.926	0.0443	1.607	1.651	0.0502	1.803	1.853
4415.293	0.0562	1.998	2.053	0.0529	1.888	1.940	0.0510	1.824	1.874	0.0515	1.841	1.892
4416.636	0.0553	1.968	2.022	0.0501	1.795	1.845	0.0550	1.957	2.011	0.0565	2.006	2.061
4554.211	0.0597	2.043	2.099	0.0540	1.860	1.911	0.0540	1.860	1.911	0.0567	1.947	2.001
4554.626	0.0495	1.716	1.763	0.0531	1.831	1.882	0.0506	1.751	1.799	0.0551	1.895	1.947
4561.591	0.0586	2.003	2.058	0.0584	1.997	2.052	0.0578	1.978	2.033	0.0561	1.924	1.977
4563.939	0.0600	2.046	2.102	0.0519	1.788	1.837	0.0544	1.868	1.920	0.0521	1.794	1.844
4572.156	0.0584	1.991	2.046	0.0555	1.898	1.950	0.0558	1.908	1.961	0.0567	1.936	1.989
4574.396	0.0617	2.095	2.153	0.0574	1.958	2.012	0.0518	1.779	1.828	0.0563	1.923	1.976
Means:		2.013			1.924				1.883			1.928
						1.969						1.906
Plate:	L566 (1) July 16, 11:10, E.S.T.											
De L. on T												
" "	$\alpha = 0^\circ \quad \beta = 5^\circ 7' \quad \gamma = 13^\circ 3'$											
O'C. "	$r = 0.976 \quad \epsilon = 0.260 \quad \phi = 1^\circ 1'$											
" "	$B_o = 4^\circ 5' \quad 0.5138v = V$											
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376.942	0.0529	1.910	1.963	0.0514	1.859	1.910	0.0551	1.982	2.037	0.0561	2.016	2.072
4379.927	0.0565	2.028	2.084	0.0513	1.854	1.905	0.0504	1.823	1.873	0.0541	1.947	2.001
4383.720	0.0481	1.745	1.793	0.0435	1.590	1.634	0.0556	1.995	2.050	0.0505	1.824	1.874
4404.927	0.0562	2.004	2.059	0.0489	1.694	1.741	0.0466	1.683	1.729	0.0507	1.820	1.870
4415.293	0.0502	1.799	1.849	0.0504	1.805	1.855	0.0560	1.990	2.045	0.0543	1.934	1.987
4416.636	0.0562	1.998	2.053	0.0484	1.672	1.718	0.0483	1.734	1.782	0.0511	1.827	1.877
4554.211	0.0510	1.765	1.814	0.0512	1.771	1.820	0.0553	1.902	1.954	0.0531	1.831	1.882
4554.626	0.0542	1.867	1.919	0.0601	2.056	2.113	0.0567	1.947	2.001	0.0563	1.934	1.987
4561.591	0.0567	1.943	1.997	0.0563	1.930	1.983	0.0504	1.741	1.789	0.0545	1.872	1.924
4563.939	0.0553	1.897	1.949	0.0600	2.048	2.105	0.0529	1.820	1.870	0.0534	1.836	1.887
4572.156	0.0520	1.788	1.837	0.0492	1.698	1.745	0.0529	1.815	1.865	0.0516	1.774	1.823
4574.396	0.0519	1.783	1.832	0.0539	1.847	1.898	0.0569	1.942	1.996	0.0547	1.872	1.924
Means:		1.929			1.869				1.916			1.926
					1.899							1.921

TABLE VI—RESULTS FROM INDIVIDUAL OBSERVATIONS, 12 SPECTRUM LINES—Continued

Plate:	L566 (2) July 16, 11·10, E.S.T.											
De L. on T												
" "	$\alpha = 0^\circ \quad \beta = 5^\circ 7' \quad \gamma = 13^\circ 3'$											
O'C. "	$r = 0.976 \quad \epsilon = 0.260 \quad \phi = 1^\circ 1'$											
" "	$B_o = 4^\circ 5' \quad 0.5138v = V$											
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376·942	0.0541	1.950	2.004	0.0572	2.054	2.111	0.0599	2.144	2.203	0.0535	1.929	1.982
4379·927	0.0482	1.750	1.798	0.0496	1.797	1.847	0.0512	1.850	1.901	0.0480	1.742	1.790
4383·720	0.0531	1.913	1.966	0.0529	1.906	1.959	0.0565	2.026	2.082	0.0582	2.083	2.140
4404·927	0.0571	2.034	2.090	0.0657	2.321	2.385	0.0579	2.060	2.117	0.0508	1.823	1.873
4415·293	0.0533	1.902	1.954	0.0537	1.915	1.968	0.0559	1.987	2.042	0.0564	2.004	2.059
4416·636	0.0595	2.107	2.165	0.0565	2.007	2.062	0.0573	2.033	2.089	0.0554	1.970	2.024
4554·211	0.0529	1.825	1.875	0.0569	1.954	2.008	0.0588	2.014	2.070	0.0511	1.767	1.816
4554·626	0.0537	1.851	1.902	0.0559	1.922	1.975	0.0558	1.918	1.971	0.0515	1.780	1.829
4561·591	0.0596	2.036	2.092	0.0622	2.119	2.177	0.0536	1.844	1.895	0.0565	1.936	1.989
4563·939	0.0559	1.917	1.970	0.0611	2.083	2.140	0.0569	1.947	2.001	0.0535	1.839	1.890
4572·156	0.0552	1.890	1.942	0.0587	2.001	2.056	0.0588	2.003	2.058	0.0542	1.857	1.908
4574·396	0.0585	1.993	2.048	0.0592	2.016	2.072	0.0579	1.974	2.028	0.0543	1.859	1.910
Means:		1.984			2.063				2.038			1.934
					2.024							1.986
Plate:	L569 (3) July 16, 12·31, E.S.T.											
De L. on T												
" "	$\alpha = 0^\circ \quad \beta = 5^\circ 7' \quad \gamma = 13^\circ 3'$											
O'C. "	$r = 0.976 \quad \epsilon = 0.260 \quad \phi = 1^\circ 1'$											
" "	$B_o = 4^\circ 5' \quad 0.5138v = V$											
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376·942	0.0534	1.928	1.979	0.0566	2.034	2.090	0.0531	1.915	1.968	0.0563	2.023	2.079
4379·927	0.0570	2.045	2.101	0.0536	1.931	1.984	0.0634	2.260	2.322	0.0607	2.169	2.229
4383·720	0.0551	1.980	2.035	0.0550	1.976	2.031	0.0564	2.022	2.078	0.0507	1.831	1.882
4404·927	0.0522	1.871	1.923	0.0525	1.881	1.933	0.0569	2.026	2.082	0.0521	1.866	1.918
4415·293	0.0539	1.922	1.975	0.0543	1.935	1.988	0.0516	1.844	1.895	0.0545	1.940	1.994
4416·636	0.0599	2.120	2.179	0.0616	2.177	2.237	0.0535	1.907	1.960	0.0529	1.887	1.939
4554·211	0.0536	1.848	1.899	0.0552	1.899	1.951	0.0554	1.905	1.958	0.0529	1.825	1.875
4554·626	0.0555	1.909	1.962	0.0519	1.793	1.842	0.0549	1.889	1.941	0.0528	1.822	1.872
4561·591	0.0569	1.950	2.004	0.0550	1.889	1.941	0.0525	2.128	2.187	0.0619	2.109	2.167
4563·939	0.0638	2.169	2.229	0.0611	2.083	2.140	0.0576	1.970	2.024	0.0591	2.018	2.074
4572·156	0.0563	1.925	1.978	0.0560	1.915	1.968	0.0617	2.096	2.154	0.0581	1.981	2.036
4574·396	0.0535	1.834	1.885	0.0479	1.656	1.702	0.0579	1.974	2.028	0.0571	1.948	2.002
Means:		2.012			1.984				2.050			2.006
					1.998							2.028

TABLE VI—RESULTS FROM INDIVIDUAL OBSERVATIONS, 12 SPECTRUM LINES—Continued

Plate:	L569 (4) July 16, 12:31, E.S.T.											
De L. on T												
" "	$\alpha = 0^\circ \quad \beta = 5^\circ 7 \quad \gamma = 13^\circ 3$ $r = 0.976 \quad \epsilon = 0.260 \quad \phi = 1^\circ 1$ $B_0 = 4^\circ 5 \quad 0.5138v = V$											
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376.942	0.0518	1.873	1.925	0.0485	1.762	1.811	0.0487	1.767	1.816	0.0542	1.952	2.006
4379.927	0.0444	1.622	1.667	0.0446	1.629	1.674	0.0480	1.742	1.790	0.0572	2.051	2.108
4383.720	0.0474	1.721	1.768	0.0545	1.960	2.014	0.0557	1.999	2.054	0.0504	1.821	1.871
4404.927	0.0515	1.848	1.899	0.0539	1.928	1.981	0.0579	2.060	2.117	0.0535	1.913	1.966
4415.293	0.0556	1.978	2.033	0.0514	1.839	1.890	0.0534	1.904	1.957	0.0500	1.791	1.840
4416.636	0.0532	1.898	1.950	0.0553	1.968	2.022	0.0550	1.957	2.011	0.0525	1.907	1.960
4554.211	0.0567	1.947	2.001	0.0579	1.986	2.041	0.0594	2.033	2.089	0.0536	1.847	1.898
4554.626	0.0587	2.011	2.067	0.0515	1.781	1.830	0.0504	1.745	1.793	0.0550	1.892	1.944
4561.591	0.0546	1.876	1.928	0.0563	1.930	1.983	0.0563	1.930	1.983	0.0530	1.824	1.874
4563.939	0.0580	1.984	2.039	0.0659	2.236	2.298	0.0559	1.915	1.968	0.0556	1.906	1.959
4572.156	0.0484	1.673	1.719	0.0565	1.931	1.984	0.0565	1.930	1.983	0.0523	1.796	1.846
4574.396	0.0522	1.793	1.842	0.0518	1.780	1.829	0.0535	1.833	1.884	0.0559	1.910	1.963
Means:		1.903			1.946			1.954			1.936	
					1.925						1.945	
Plate:	L570 (1) July 19, 10:59, E.S.T.											
De L. on T												
" "	$\alpha = 0^\circ \quad \beta = 5^\circ 4 \quad \gamma = 13^\circ 8$ $r = 0.974 \quad \epsilon = 0.260 \quad \phi = 1^\circ 2$ $B_0 = 4^\circ 8 \quad 0.5149v = V$											
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376.942	0.0509	1.842	1.897	0.0523	1.889	1.945	0.0531	1.915	1.972	0.0513	1.855	1.910
4379.927	0.0519	1.874	1.930	0.0493	1.786	1.839	0.0476	1.729	1.780	0.0534	1.924	1.981
4383.720	0.0454	1.654	1.703	0.0503	1.819	1.873	0.0524	1.888	1.944	0.0481	1.744	1.796
4404.927	0.0485	1.747	1.799	0.0545	1.948	2.006	0.0511	1.833	1.887	0.0496	1.783	1.836
4415.293	0.0456	1.646	1.695	0.0481	1.729	1.780	0.0549	1.954	2.012	0.0462	1.665	1.714
4416.636	0.0526	1.878	1.934	0.0529	1.888	1.944	0.0439	1.588	1.635	0.0490	1.757	1.809
4554.211	0.0533	1.838	1.893	0.0518	1.790	1.843	0.0506	1.751	1.803	0.0521	1.799	1.852
4554.626	0.0455	1.588	1.635	0.0605	2.068	2.129	0.0559	1.921	1.978	0.0555	1.908	1.965
4561.591	0.0509	1.750	1.802	0.0522	1.799	1.852	0.0560	1.920	1.977	0.0501	1.732	1.783
4563.939	0.0476	1.651	1.700	0.0549	1.884	1.940	0.0513	1.769	1.822	0.0518	1.778	1.831
4572.156	0.0566	1.934	1.991	0.0574	1.959	2.017	0.0506	1.742	1.794	0.0521	1.790	1.843
4574.396	0.0517	1.776	1.829	0.0528	1.811	1.865	0.0530	1.818	1.872	0.0540	1.849	1.904
Means:		1.817			1.919			1.873			1.852	
					1.868						1.863	

TABLE VI—RESULTS FROM INDIVIDUAL OBSERVATIONS, 12 SPECTRUM LINES—Continued

Plate:	L570 (2) July 19, 11:35, E.S.T.											
De L. on T												
" "												
O'C. "												
" "												
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376·942	0.0519	1.876	1.932	0.0428	1.570	1.617	0.0541	1.949	2.007	0.0531	1.915	1.972
4379·927	0.0418	1.534	1.580	0.0424	1.555	1.601	0.0505	1.826	1.880	0.0469	1.705	1.756
4383·720	0.0457	1.664	1.713	0.0496	1.795	1.848	0.0476	1.727	1.778	0.0470	1.707	1.758
4404·927	0.0531	1.901	1.957	0.0564	2.011	2.071	0.0526	1.883	1.939	0.0501	1.800	1.853
4415·293	0.0491	1.762	1.814	0.0545	1.942	2.000	0.0493	1.768	1.821	0.0492	1.764	1.816
4416·636	0.0479	1.722	1.773	0.0467	1.682	1.732	0.0579	2.053	2.114	0.0565	2.006	2.066
4554·211	0.0514	1.777	1.830	0.0525	1.812	1.866	0.0503	1.742	1.794	0.0462	1.610	1.658
4554·626	0.0479	1.665	1.714	0.0474	1.649	1.698	0.0540	1.860	1.915	0.0491	1.703	1.754
4561·591	0.0518	1.787	1.840	0.0542	1.863	1.918	0.0492	1.703	1.754	0.0565	1.937	1.995
4563·939	0.0471	1.635	1.684	0.0539	1.852	1.907	0.0511	1.762	1.814	0.0534	1.836	1.891
4572·156	0.0532	1.825	1.879	0.0559	1.912	1.969	0.0567	1.936	1.993	0.0485	1.675	1.725
4574·396	0.0512	1.760	1.812	0.0495	1.706	1.757	0.0507	1.744	1.796	0.0502	1.728	1.779
Means:		1.794				1.832			1.884			1.835
						1.813						1.860
Plate:	L578 (1) July 25, 10:23, E.S.T.											
De L. on T												
" "												
O'C. "												
" "												
λ	d''	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376·942	0.0508	1.839	1.894	0.0502	1.819	1.873	0.0488	1.771	1.824	0.0501	1.814	1.868
4379·927	0.0504	1.823	1.877	0.0515	1.860	1.915	0.0520	1.877	1.933	0.0542	1.951	2.009
4383·720	0.0437	1.597	1.644	0.0557	2.000	2.059	0.0465	1.690	1.740	0.0481	1.744	1.796
4404·927	0.0533	1.908	1.965	0.0481	1.734	1.785	0.0508	1.823	1.877	0.0545	1.946	2.004
4415·293	0.0613	2.168	2.232	0.0551	1.962	2.020	0.0548	1.950	2.008	0.0513	1.834	1.888
4416·636	0.0621	2.194	2.259	0.0576	2.044	2.105	0.0529	1.887	1.943	0.0546	1.943	2.001
4554·211	0.0524	1.809	1.863	0.0537	1.851	1.906	0.0539	1.857	1.912	0.0559	1.921	1.978
4554·626	0.0556	1.911	1.968	0.0585	2.004	2.064	0.0596	2.040	2.101	0.0556	1.911	1.968
4561·591	0.0534	1.838	1.893	0.0574	1.966	2.024	0.0575	1.968	2.026	0.0565	1.936	1.993
4563·939	0.0584	1.996	2.055	0.0539	1.852	1.907	0.0555	1.903	1.960	0.0596	2.034	2.094
4572·156	0.0529	1.816	1.870	0.0561	1.918	1.975	0.0538	1.844	1.899	0.0528	1.812	1.866
4574·396	0.0557	1.903	1.960	0.0512	1.760	1.812	0.0515	1.770	1.823	0.0569	1.942	2.000
Means:		1.957				1.954			1.921			1.955
						1.956						1.938

TABLE VI—RESULTS FROM INDIVIDUAL OBSERVATIONS, 12 SPECTRUM LINES—Concluded

Plate:	L578 (4) July 25, 10:26, E.S.T.											
De L. on T " " O'C. " " "	$\alpha = 0^\circ \quad \beta = 4^\circ 9 \quad \gamma = 13^\circ 8$ $r = 0.975 \quad \epsilon = 0.260 \quad \phi = 1^\circ 2$ $B_0 = 5^\circ 3 \quad 0.5149v = V$											
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4376.942	0.0527	1.903	1.960	0.0498	1.805	1.859	0.0470	1.710	1.761	0.0561	2.016	2.076
4379.927	0.0512	1.850	1.905	0.0485	1.760	1.812	0.0576	2.065	2.126	0.0484	1.756	1.808
4383.720	0.0561	2.013	2.073	0.0567	2.033	2.093	0.0490	1.774	1.827	0.0446	1.626	1.674
4404.927	0.0539	1.928	1.985	0.0583	2.074	2.136	0.0597	2.120	2.183	0.0533	1.906	1.963
4415.203	0.0461	1.662	1.711	0.0526	1.878	1.934	0.0494	1.771	1.824	0.0581	2.060	2.121
4416.636	0.0588	2.017	2.077	0.0474	1.705	1.756	0.0494	1.771	1.824	0.0506	1.810	1.884
4554.211	0.0536	1.848	1.903	0.0545	1.877	1.933	0.0511	1.767	1.819	0.0531	1.831	1.885
4554.626	0.0493	1.710	1.761	0.0559	1.922	1.979	0.0522	1.802	1.856	0.0527	1.819	1.873
4561.591	0.0556	1.908	1.965	0.0547	1.879	1.935	0.0518	1.786	1.839	0.0548	1.882	1.938
4563.939	0.0524	1.805	1.859	0.0557	1.910	1.967	0.0492	1.701	1.752	0.0541	1.858	1.913
4572.156	0.0508	1.750	1.802	0.0542	1.858	1.913	0.0539	1.847	1.902	0.0525	1.803	1.857
4574.396	0.0524	1.799	1.852	0.0522	1.793	1.846	0.0547	1.872	1.928	0.0538	1.843	1.898
Means:		1.904			1.930			1.887			1.906	
					1.917						1.897	

TABLE VII—RESULTS FROM INDIVIDUAL OBSERVATIONS, 6 SPECTRUM LINES

Plate:	L493 (1)-(2) June 21, 11.00 E.S.T.	L497 (1)-(2) June 21, 12.05 E.S.T.	L502 (1)-(2) June 23, 10.14, E.S.T.	L505 (1) June 23, 11.10, E.S.T.								
O'C. on T	$\alpha=0^\circ \quad \beta=7^\circ 0 \quad \gamma=12^\circ 2$ $r=0.978 \quad \epsilon=0.260 \quad \phi=0^\circ 3$ $B_0=1^\circ 9 \quad 0.5116v = V$	$\alpha=0^\circ \quad \beta=7^\circ 0 \quad \gamma=12^\circ 2$ $r=0.978 \quad \epsilon=0.260 \quad \phi=0^\circ 3$ $B_0=1^\circ 9 \quad 0.5116v = V$	$\alpha=0^\circ \quad \beta=6^\circ 9 \quad \gamma=12^\circ 8$ $r=0.976 \quad \epsilon=0.260 \quad \phi=0^\circ 4$ $B_0=2^\circ 1 \quad 0.5127v = V$	$\alpha=0^\circ \quad \beta=6^\circ 9 \quad \gamma=12^\circ 8$ $r=0.976 \quad \epsilon=0.260 \quad \phi=0^\circ 4$ $B_0=2^\circ 1 \quad 0.5127v = V$								
λ	d''	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4554.211	0.0562	1.929	1.974	0.0841	1.793	1.835	0.0813	1.738	1.782	0.0832	1.775	1.820
4554.626	0.0583	2.012	2.059	0.0881	1.872	1.915	0.0932	1.975	2.025	0.0866	1.843	1.890
4561.626	0.0556	2.064	2.112	0.0908	1.921	1.966	0.0912	1.930	1.980	0.0984	2.072	2.125
4563.939	0.0557	1.938	1.983	0.0801	1.709	1.748	0.0844	1.796	1.841	0.0863	1.831	1.878
4572.156	0.0567	1.935	1.980	0.0874	1.849	1.891	0.0830	1.762	1.807	0.0850	1.801	1.847
4574.396	0.0555	1.895	1.939	0.0846	1.791	1.832	0.0813	1.730	1.773	0.0801	1.704	1.747
Means:		2.008			1.864			1.868			1.887	

TABLE VII—RESULTS FROM INDIVIDUAL OBSERVATIONS, 6 SPECTRUM LINES—Continued

Plate:	L508 (3) June 23, 12.00, E.S.T.			L509 (1) June 23, 2.55, E.S.T.			L510 (1) June 23, 3.14, E.S.T.			L511 (1)–(4) June 24, 10.01, E.S.T.		
O'C. on T	$\alpha=0^\circ \beta=6^\circ 9 \gamma=13^\circ 5$ $r=0.973 \epsilon=0.259 \phi=0^\circ 5$ $B_o=2^\circ 1 0.5142v = V$			$\alpha=0^\circ \beta=6^\circ 9 \gamma=13^\circ 5$ $r=0.973 \epsilon=0.259 \phi=0^\circ 5$ $B_o=2^\circ 1 0.5142v = V$			$\alpha=0^\circ \beta=6^\circ 9 \gamma=13^\circ 5$ $r=0.973 \epsilon=0.259 \phi=0^\circ 5$ $B_o=2^\circ 1 0.5142v = V$			$\alpha=0^\circ \beta=6^\circ 9 \gamma=13^\circ 5$ $r=0.973 \epsilon=0.259 \phi=0^\circ 5$ $B_o=2^\circ 2 0.5142v = V$		
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
4554-211	mm. 0.0710	km./sec. 1.529	km./sec. 1.572	mm. 0.0843	km./sec. 1.796	km./sec. 1.847	mm. 0.0865	km./sec. 1.840	km./sec. 1.892	mm. 0.0815	km./sec. 1.740	km./sec. 1.789
4554-626	0.0935	1.978	2.034	0.0942	1.991	2.048	0.0904	1.917	1.972	0.0923	1.954	2.010
4561-591	0.0847	1.801	1.852	0.1009	2.119	2.179	0.0889	1.883	1.937	0.0883	1.871	1.924
4563-939	0.0691	1.491	1.533	0.0859	1.822	1.874	0.0935	1.973	2.029	0.0849	1.803	1.854
4572-156	0.0717	1.539	1.583	0.0880	1.859	1.912	0.0910	1.919	1.974	0.0860	1.819	1.870
4574-396	0.0850	1.800	1.851	0.0916	1.929	1.984	0.1029	2.151	2.212	0.0878	1.853	1.906
Means:			1.738			1.974			2.003			1.892
Plate:	L512 (1)–(4) June 24, 10.01, E.S.T.			L519 (1)–(4) June 28, 3.55, E.S.T.			L520 (1)–(2) June 28, 4.14, E.S.T.			L522 (1)–(2) June 29, 10.00, E.S.T.		
O'C. on T	$\alpha=0^\circ \beta=6^\circ 9 \gamma=13^\circ 6$ $r=0.973 \epsilon=0.259 \phi=0^\circ 5$ $B_o=2^\circ 2 0.5144v = V$			$\alpha=0^\circ \beta=6^\circ 7 \gamma=12^\circ 3$ $r=0.978 \epsilon=0.260 \phi=0^\circ 5$ $B_o=2^\circ 7 0.5117v = V$			$\alpha=0^\circ \beta=6^\circ 7 \gamma=12^\circ 3$ $r=0.978 \epsilon=0.260 \phi=0^\circ 5$ $B_o=2^\circ 7 0.5117v = V$			$\alpha=0^\circ \beta=6^\circ 7 \gamma=12^\circ 3$ $r=0.976 \epsilon=0.260 \phi=0^\circ 6$ $B_o=2^\circ 8 0.5127v = V$		
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
4554-211	mm. 0.0890	km./sec. 1.891	km./sec. 1.945	mm. 0.0849	km./sec. 1.810	km./sec. 1.852	mm. 0.0919	km./sec. 1.947	km./sec. 1.993	mm. 0.0885	km./sec. 1.881	km./sec. 1.929
4554-626	0.0882	1.875	1.929	0.0948	2.004	2.051	0.0842	1.797	1.839	0.0881	1.871	1.919
4561-591	0.0836	1.780	1.831	0.0904	1.915	1.960	0.0944	1.993	2.040	0.0838	1.785	1.830
4563-939	0.0939	1.981	2.030	0.0917	1.937	1.983	0.0797	1.701	1.741	0.0859	1.824	1.870
4572-156	0.0928	1.954	2.010	0.0907	1.913	1.958	0.0863	1.829	1.871	0.0890	1.881	1.929
4574-396	0.0901	1.901	1.956	0.0952	2.002	2.049	0.0954	2.005	2.052	0.0831	1.764	1.809
Means:			1.950			1.976			1.923			1.881
Plate:	L525 (1)–(2) June 29, 11.30, E.S.T.			L526 (1)–(2) June 30, 9.30, E.S.T.			L527 (1)–(4) July 25, 7.15, E.S.T.			L574 (1)–(4) July 25, 7.40, E.S.T.		
O'C. on T	$\alpha=0^\circ \beta=6^\circ 7 \gamma=12^\circ 8$ $r=0.976 \epsilon=0.260 \phi=0^\circ 6$ $B_o=2^\circ 8 0.5127v = V$			$\alpha=0^\circ \beta=6^\circ 6 \gamma=12^\circ 8$ $r=0.976 \epsilon=0.260 \phi=0^\circ 6$ $B_o=2^\circ 9 0.5127v = V$			$\alpha=0^\circ \beta=4^\circ 9 \gamma=14^\circ 3$ $r=0.973 \epsilon=0.259 \phi=1^\circ 2$ $B_o=5^\circ 3 0.5160v = V$			$\alpha=0^\circ \beta=4^\circ 9 \gamma=14^\circ 3$ $r=0.973 \epsilon=0.259 \phi=1^\circ 2$ $B_o=5^\circ 3 0.5160v = V$		
λ	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
4554-211	mm. 0.0870	km./sec. 1.851	km./sec. 1.898	mm. 0.0858	km./sec. 1.826	km./sec. 1.873	mm. 0.0555	km./sec. 1.909	km./sec. 1.970	mm. 0.0556	km./sec. 1.912	km./sec. 1.973
4554-626	0.0913	1.936	1.986	0.0897	1.904	1.952	0.0569	1.953	2.015	0.0537	1.849	1.908
4561-591	0.0885	1.872	1.919	0.0894	1.895	1.944	0.0531	1.828	1.887	0.0530	1.824	1.882
4563-939	0.0884	1.873	1.921	0.0850	1.805	1.851	0.0544	1.870	1.929	0.0576	1.970	2.034
4572-156	0.0932	1.963	2.013	0.0904	1.907	1.956	0.0562	1.922	1.983	0.0544	1.864	1.924
4574-396	0.0910	1.918	1.967	0.0886	1.872	1.920	0.0525	1.798	1.861	0.0510	1.755	1.811
Means:			1.951			1.916			1.941			1.922

TABLE VII—RESULTS FROM INDIVIDUAL OBSERVATIONS, 6 SPECTRUM LINES—*Concluded*

Plate:	L575 (1)–(4) July 25, 9:35, E.S.T.			L576 (1)–(4) July 25, 9:55, E.S.T.		
	$\alpha=0^\circ$	$\beta=4^\circ 9$	$\gamma=13^\circ 8$	$\alpha=0^\circ$	$\beta=4^\circ 9$	$\gamma=13^\circ 8$
O'C. on T	$r=0.975$	$e=0.260$	$\phi=1^\circ 2$	$r=0.975$	$e=0.260$	$\phi=1^\circ 2$
	$B_o=5^\circ 3$		$0.5149v = V$	$B_o=5^\circ 3$		$0.5149v = V$
λ	d'	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
4554.211	0.0555	1.910	1.967	0.0568	1.951	2.009
4554.626	0.0558	1.917	1.974	0.0540	1.858	1.913
4561.591	0.0532	1.831	1.886	0.0544	1.870	1.925
4563.939	0.0556	1.907	1.963	0.0565	1.936	1.993
4572.156	0.0559	1.912	1.967	0.0581	1.980	2.039
4574.396	0.0554	1.893	1.949	0.0543	1.840	1.915
Means:			1.951			1.966

DISCUSSION OF RESULTS

Mean Velocity.—In Table VIII is given a summary of the mean velocities derived from the measurements of 12 spectrum lines on the 32 observations detailed in Table VI. The summary includes the values for each plate measured violet left and violet right and their means for each of the two observers. In Table IX is a summary of the mean velocities for the 46 additional observations of Table VII, on which O'Connor measured 6 spectrum lines with the plate either violet right or violet left. The values for the individual observations of this latter group are not given in Table VII, where, to save space, only the means of all the observations on each plate are detailed for each spectrum line.

From Table VIII it is evident that there is a systematic difference between the measurements of the plates in the violet left and right positions of about 0.03 km. per sec. for each observer. This, as previously explained, is attributable to the relative motion between the image of the spectrum line and the spider thread of the micrometer, during the time the settings are made, caused by capillary action of the oil between the micrometer thread and nut. Since the rate of this motion is not the same after the micrometer screw has gone into the nut as after it has been screwed in the reverse direction, the mean of the two measurements is not quite the true value of the displacement. Furthermore, the particular method of making the settings of the spectrum line image on the spider thread may introduce irregularities as evident in the settings on plate L569 (4) given above. However, the variety of methods of making the settings in the measurements of these 32 observations reveals the extent of the oil error. As mentioned previously, De Lury measured the first 16 plates in the usual way by making 4 settings on the spectrum line in the middle strip of spectrum followed by 2 settings on the line in each of the outside strips of spectrum; while in the measurements of the second 16 observations, the first settings were made on the middle and outside strips

TABLE VIII—SUMMARY OF MEAN VELOCITIES, 32 OBSERVATIONS, 12 SPECTRUM LINES

Observation		De Lury			O'Connor			De L. and O'C.
		V km./sec.			V km./sec.			
L	1910	(Left)	(Right)	Mean	(Left)	(Right)	Mean	Mean
527 (1)	June 30	1.888	1.863	1.876	1.829	1.818	1.824	1.849
(2)	" 30	1.880	1.841	1.861	1.891	1.836	1.864	1.862
528 (1)	July 5	2.087	2.003	2.045	2.064	1.991	2.028	2.036
(2)	" 5	2.057	2.050	2.054	2.018	1.920	1.969	2.011
531 (1)	" 5	2.067	2.060	2.064	2.025	2.019	2.022	2.043
(2)	" 5	2.072	2.084	2.078	2.052	1.950	2.001	2.040
538 (1)	" 11	1.951	1.905	1.928	1.861	1.848	1.855	1.891
(2)	" 11	1.862	1.863	1.863	1.883	1.883	1.883	1.873
541 (1)	" 11	2.035	1.871	1.953	1.949	1.890	1.920	1.936
(2)	" 11	2.054	2.050	2.052	1.982	1.934	1.958	2.005
544 (1)	" 12	1.915	1.839	1.877	1.952	1.888	1.920	1.899
(2)	" 12	1.991	1.999	1.995	1.975	1.952	1.963	1.979
550 (1)	" 13	2.133	2.071	2.101	2.032	1.992	2.012	2.057
(2)	" 13	2.073	2.001	2.037	1.974	1.950	1.962	2.000
554 (1)	" 13	2.138	2.052	2.095	2.072	2.009	2.041	2.068
(2)	" 13	2.107	2.098	2.103	2.041	2.058	2.050	2.076
558 (1)	" 14	1.976	1.925	1.951	1.969	1.979	1.970	1.960
(2)	" 14	1.954	1.899	1.927	1.963	1.940	1.952	1.939
561 (3)	" 14	1.901	1.864	1.883	1.942	1.949	1.946	1.914
(4)	" 14	2.079	1.998	2.039	2.061	2.023	2.041	2.040
562 (1)	" 14	2.003	2.004	2.004	1.970	1.928	1.949	1.976
(2)	" 14	1.950	1.883	1.917	1.965	1.897	1.931	1.924
565 (3)	" 14	1.997	1.952	1.975	1.960	1.967	1.964	1.969
(4)	" 14	2.013	1.924	1.969	1.883	1.928	1.906	1.937
566 (1)	" 16	1.929	1.869	1.899	1.916	1.926	1.921	1.910
(2)	" 16	1.984	2.063	2.024	2.038	1.934	1.986	2.005
569 (3)	" 16	2.012	1.984	1.998	2.050	2.006	2.028	2.013
(4)	" 16	1.903	1.946	1.925	1.954	1.936	1.945	1.935
570 (1)	" 19	1.817	1.919	1.888	1.873	1.852	1.863	1.865
(2)	" 19	1.794	1.832	1.813	1.884	1.835	1.860	1.836
578 (1)	" 25	1.957	1.954	1.956	1.921	1.955	1.938	1.947
(4)	" 25	1.904	1.930	1.917	1.887	1.906	1.897	1.907
Means:		1.984	1.956	1.970	1.963	1.934	1.949	1.959

on alternate spectrum lines. On the other hand, O'Connor throughout the series set on the line in one outside strip, then on the middle strip followed by settings on the line in the other outside strip. De Lury's settings were made rapidly, usually requiring a little over a minute to complete the 8 settings for each spectrum line, during which time the plate or its image was moving most rapidly relatively to the spider thread. O'Connor's measurements were among his first and were naturally a little more deliberate, requiring usually over two minutes for the set of settings on the three strips, by which time the rate of motion of the plate was considerably reduced. The means of the two groups of 16 observations are as follows:

1st 16 observations, De Lury, 1.998 km./sec., O'Connor, 1.955 km./sec.
 2nd 16 " " 1.942 " " 1.945 "

Since the method employed by De Lury in the second group insured the elimination of the systematic error in the mean, and since the two measures practically agree for this group, it may be supposed that O'Connor's measurements in the mean of the whole group are practically free from this systematic error, and also that the difference between the two in the first group is mainly due to the effect of the systematic oil error in De Lury's measurements. Consequently it would seem that the mean, 1.959 km. per sec., of all the measurements of the 32 observations should be corrected to 1.950 km. per sec.

TABLE IX—SUMMARY OF MEAN VELOCITIES, 46 OBSERVATIONS, 6 SPECTRUM LINES

Observation			O'Connor		Observation			O'Connor	
			V km./sec.					V km./sec.	
L	1910		(Left)	(Right)	L	1910		(Left)	(Right)
493 (1)	June	21	.....	2.033	520 (2)	June	28	1.927	
(2)	"	21	.....	1.983	522 (1)	"	29	1.834	
497 (1)	"	21	.....	1.886	(2)	"	29	1.929	
(2)	"	21	.....	1.843	525 (1)	"	29	.....	1.960
502 (1)	"	23	1.892	.....	(2)	"	29	.....	1.942
(2)	"	23	1.844	.....	526 (1)	"	30	1.888	
505 (1)	"	23	.....	1.887	(2)	"	30	1.943	
508 (3)	"	23	1.738	.....	573 (1)	July	25	1.931	
509 (1)	"	23	.....	1.974	(2)	"	25	1.905	
510 (1)	"	23	2.003	.....	(3)	"	25	1.898	
511 (1)	"	24	.....	1.975	(4)	"	25	2.029	
(2)	"	24	.....	1.975	574 (1)	"	25	.....	1.874
(3)	"	24	.....	1.788	(2)	"	25	.....	1.989
(4)	"	24	.....	1.930	(3)	"	25	.....	1.875
512 (1)	"	24	1.953	.....	(4)	"	25	.....	1.950
(2)	"	24	1.909	.....	575 (1)	"	25	2.038	
(3)	"	24	1.935	.....	(2)	"	25	1.929	
(4)	"	24	2.009	.....	(3)	"	25	1.972	
519 (1)	"	28	.....	2.003	(4)	"	25	1.866	
(2)	"	28	.....	2.012	576 (1)	"	25	1.944	
(3)	"	28	.....	1.890	(2)	"	25	1.949	
(4)	"	28	.....	1.997	(3)	"	25	1.973	
520 (1)	"	28	1.919	.....	(4)	"	25	1.998	
Means:								1.929	1.933

The mean of the additional group of 46 observations, derived from Table IX, is 1.931 km. per sec. The mean of the whole series of 78 observations is $1.943 \pm .005$ km. per sec.; and it would seem that this mean should be corrected to about 1.940 km. per sec. as representing the equatorial velocity of the solar rotation in the $\lambda 4500$ region of the spectrum from June 21 to July 25.

The Bearing of the Results on the Question of Variation of the Rotational Velocity with Elevation in the Solar Atmosphere.—The spectrum lines measured in the present series of observations were selected, as previously explained, in order to throw more light on the interesting and important findings of Dr. Walter S. Adams at Mount Wilson Observatory concerning the increase of rotational velocity with elevation in the sun's atmosphere.

Six lines having large penumbral displacements in sunspot spectra were chosen as representing the lower levels and six with small or negative displacements representing the higher levels, giving about the maximum range in elevation of the elements producing easily measurable spectrum lines in the $\lambda 4500$ region. Later, reliable chromospheric elevations were published by Mitchell, for all but one of the selected lines. The elevation of this line may be inferred from its penumbral displacement. The mean velocity for each spectrum line from the four measurements of each of the 32 observations, two by each observer, is given in Table X, along with groupings as to elevation and as to strengthening in the flash spectrum. In Table XI similar means are given for the measurements of six lines on the additional 46 observations.

TABLE X—SUMMARY OF THE MEAN VALUES OF THE EQUATORIAL VELOCITY OF ROTATION FOR 12 SPECTRUM LINES, 32 OBSERVATIONS

Sun				Chromosphere		Sunspot			Rotational velocity					
λ Rowland	λ I.A.	Element	Int.	Int.	Height	Int.	Penumbral displacement	Mean	Heights		Strength in flash			
				km.					High	Low	Strong	Weak		
\AA							\AA	km./sec.	km./sec.	km./sec.	km./sec.	km./sec.		
4376.942	.784	Fe-Cr	1	1d	400	2	0.026	1.76	1.970	.....	1.970	.....	1.970
4379.927	.771	Zr ⁺ Cr	0	2	400	1	0.029	2.01	1.956	.....	.....	1.956	.....
4383.720s	.559	Fe	15	15	1600	15	-0.013	-0.91	1.925	1.925	.....	.....	1.925
4404.927s	.763	Fe	10	12	1200	10	-0.004	-0.30	1.988	1.988	.....	1.988	.....
4415.293	.137	Fe	8	8	800	8	-0.003	-0.22	1.952	1.952	.....	.....	1.952
4416.636	.477	V	0	1	350	3	0.035	2.35	1.939	.....	1.939	1.939	.....
4554.211s	.038	Ba ⁺	8	50	2000	10	0.004	0.24	1.954	1.954	.....	1.954	.....
4554.626	.462	Fe	1	—	(400)	2	0.025	1.65	1.983	.....	1.983	.....	.....
4561.591	.419	—	1	0	350	1	0.023	1.53	1.969	.....	1.969	.....	1.969
4563.939s	.768	Ti ⁺	4	30	2500	3	0.005	0.32	1.970	1.970	.....	1.970	.....
4572.156s	1.982	Ti ⁺	6	35	2500	4	0.006	0.38	1.956	1.956	.....	1.956	.....
4574.396	.227	Fe	1	0	350	1	0.029	1.90	1.952	.....	1.952	.....	1.952
Means:									1.959	1.957	1.961	1.961	1.954	

From Table X, it is seen that 6 spectrum lines of average chromospheric elevation, 1,767 km., and average penumbral displacement, -0.001 \AA or $-0.008 \text{ km. per sec.}$, yield a mean velocity of rotation of $1.957 \text{ km. per sec.}$; while the other 6 lines, average elevation, 375 km., and average penumbral displacement, 0.028 \AA or $1.87 \text{ km. per sec.}$, have a mean rotational velocity of $1.961 \text{ km. per sec.}$. Thus for a difference in elevation of 1,400 km. no appreciable difference in the velocity of rotation is indicated from the present series of observations.

From Table XI, 3 spectrum lines of average elevation, 2333 km., and average penumbral displacement, 0.005 \AA or $0.31 \text{ km. per sec.}$, show a mean velocity of rotation of $1.923 \text{ km. per sec.}$; while the other 3 lines, average elevation, 367 km., and average penumbral displacement, 0.026 \AA or $1.69 \text{ km. per sec.}$, indicate a mean rotational velocity of $1.939 \text{ km. per sec.}$. Thus for this group of 46 observations, an average difference of elevation of 1,966 km. is accompanied by a difference in rotational velocity of $0.016 \text{ km. per sec.}$, with the higher velocity at the lower level. Coupling these results

with those for the same 6 spectrum lines in Table X, the resulting mean velocities for the 78 observations yield means of 1.939 and 1.951 km. per sec. respectively for the higher and lower levels, with a difference of 0.013 km. per sec. Thus the results are at variance with the findings at Mount Wilson Observatory that increased rotational velocity accompanies increase in elevation in the solar atmosphere.

TABLE XI—SUMMARY OF THE MEAN VALUES OF THE EQUATORIAL VELOCITY OF ROTATION FOR 6 SPECTRUM LINES, 46 OBSERVATIONS

Sun				Chromosphere		Sunspot			Rotational velocity				
λ Rowland	λ I.A.	Element	Int.	Int.	Height	Int.	Penumbral displacement	Mean	Heights		Strength in flash		
					km.				High	Low	Strong	Weak	
Å					km.		Å	km./sec.	km./sec.	km./sec.	km./sec.	km./sec.	
4554.211s	.038	Ba ⁺	8	50	2000	10	0.004	0.24	1.907	1.907	.....	1.907	
4554.626	.462	Fe	1	—	(400)	2	0.025	1.65	1.968	.....	1.968	.....
4561.591	.419	—	1	0	350	1	0.023	1.53	1.932	.....	1.932	.....	1.932
4563.939s	.768	Ti ⁺	4	30	2500	3	0.005	0.32	1.921	1.921	.....	1.921	
4572.156s	1.982	Ti ⁺	6	35	2500	4	0.006	0.38	1.940	1.940	.....	1.940	
4574.396	.227	Fe	1	0	350	1	0.029	1.90	1.917	.....	1.917	.....	1.917
Means:								1.931	1.923	1.938	1.923	1.925	

In view of the fact that in the green and yellow green region of the spectrum higher velocities have been found for spectrum lines not greatly weakened at the limb of the sun relatively to the centre of the solar disc than for lines considerably weakened at the limb, in amounts varying with terrestrial haziness, it was considered advisable to group, in Table X, the velocities of the various spectrum lines in accordance with their strengthening or not in the flash spectrum. Six strengthened lines exhibit a mean rotational velocity of 1.961 km. per sec., and five unstrengthened lines yield a mean velocity of 1.954 km. per sec. The difference, 0.007 km. per sec., is too small to be regarded as significant; while the corresponding difference for the 5 lines of Table XI whose chromospheric intensities are known is still smaller, namely 0.002 km. per sec.

SOLAR ROTATION

SECTION 3—DETERMINATIONS OF THE EQUATORIAL VELOCITY FROM OBSERVATIONS AT $\lambda 5600$ IN 1910

BY

RALPH E. DE LURY

The region of the spectrum from $\lambda 5500$ to $\lambda 5700$ for the observation of the solar rotation was assigned to the Dominion Observatory at the 1910 meeting¹ of the International Union for Co-operation in Solar Research. This part of the spectrum is not of particular interest: the range in intensity of the spectrum lines is small; the difference in elevation in the solar atmosphere of the materials producing the spectrum lines is very small for lines of sufficient intensity for easy measurement in the limb spectrum; not many elements are represented among the lines suitable for rotation measurements; and few lines of ionized elements are present. However, it was desirable that this region of the spectrum be represented in the co-operative attack on the problem of the solar rotation, and since the initiation of the program a goodly number of observations have been made yearly. While lines due to the terrestrial atmosphere are present in this part of the spectrum, they are scarcely intense enough to serve for accurate measurement of observational or mensurational errors in the determinations of the rotational displacements of the solar spectrum lines; but, from 1913 on, some of the advantages of the terrestrial lines were provided by strips of iodine absorption spectrum. The yellow-green region of the spectrum is probably relatively sensitive to the influence of general sunlight from terrestrial haze in depressing the measured values of the solar rotation, since water droplets and cirrus ice crystals selectively reflect or transmit green light. Evidence of such an influence in lessening the values of the solar rotation will be shown in the following discussion of the preliminary observations at $\lambda 5600$ made in November and December, 1910.

Observations.—Using the same equipment as employed in making the observations at $\lambda 4500$, discussed in the preceding Section, the same observers obtained about 150 spectrograms recording the rotational line-displacements in spectra from opposite points within the solar limb at various latitudes from the equator to the pole. The record of 68 of these observations, made at the equator, is given in Table XII.

Measurements.—Early measurements² of some of the observations at $\lambda 5600$, like those at $\lambda 4500$ already referred to, exhibited serious systematic errors. Having finally detected the systematic errors of measurement caused by the micrometer oil, the writer returned to the measurement of these early observations. A group of 32 observations of the equatorial velocity, L609 (1)-L629 (1), were chosen, and the 10 spectrum lines given in the first group of Table XIII were selected for measurement (see Figure 1).

¹ Trans. Int. Union for Solar Res., Vol. III, p. 83.

² Rept. Chief Astronomer, 1911, 129 and 264.

To eliminate the systematic error, the split nut of the micrometer was tightened, and the lines were alternately measured commencing with the central strip of spectrum (east limb) or the outside strips of spectrum (west limb). Thus, by reversing the order of the alternations on every other observation, the mean value for each observation and the means for each line in the whole series of observations are freed from the systematic error of measurement. The results are given in Table XIV, where, as in the previous Sections, d' denotes the measured displacement, plate violet left, and d'' , plate violet right. Since in many later observations 6 lines (the second group in Table XIII) were measured, and their behaviour known in blended spectra of limb and haze or limb and centre of the solar disc, the 32 observations were re-measured using these 6 lines, and in addition the 36 other equatorial observations of less uniform quality were measured with plate either left or right. The results of these measurements are given in Table XV.

TABLE XII—RECORD OF OBSERVATIONS OF THE SOLAR ROTATION, $\lambda 5600$

Plate	1910		Position			Slit width	Exposure	Observing conditions and remarks		
	Date	E.S.T.	α	Disc	r			D	B	
L		h. m.	°	mm.		mm.	sec.			Exposures:
600 (1)–(5)	Nov. 9	3 20	0	223.0	0.950	0.025	15–50	Fair	Fair	15, 20, 30, 40, 50 sec.
601 (1)–(6)	" 9	3 37	0	233.0	0.950	0.025	20–32			20, 20, 25, 25, 32, 30 sec.
602 (1)–(6)	" 9	3 50	0	233.0	0.950	0.025	25–50			25, 35, 45, 30, 40, 50 sec.
603 (1)–(5)	" 27	2 03	0	233.5	0.948	0.025	30–60			30, 35, 40, 45, 60 sec.
606 (1)–(4)	Dec. 5	2 30	0.3	233.8	0.947	0.025	25–50			25, 30, 40, 50 sec.
607 (1)–(5)	" 5	2 40	0.3	233.8	0.947	0.025	30–60			30, 35, 40, 60, 50 sec.
608 (1)–(5)	" 6	1 25	0	234.5	0.946	0.025	20–40			20, 30, 25, 35, 40 sec.
609 (1), (2)	" 6	1 45	0	234.5	0.946	0.025	30	Fair	Fair	Steady clock driving
610 (4), (5)	" 6	1 55	0	234.5	0.946	0.025	30			
611 (1), (2)	" 6	2 50	0	233.0	0.952	0.025	40			
613 (1), (6)	" 8	1 20	0	234.8	0.945	0.025	40			
614 (1), (2)	" 8	1 38	0	235.2	0.943	0.025	40			
614a (1)	" 8	2 02	0	235.0	0.944	0.025	45			
616 (1), (2)	" 9	12 42	0	236.0	0.940	0.025	35			
617 (1), (2)	" 9	12 52	0	236.0	0.940	0.025	35			
618 (1), (2)	" 9	1 12	0	236.0	0.940	0.025	35			
619 (1), (2)	" 9	1 20	0	236.0	0.940	0.025	35			
622 (1), (2)	" 10	12 32	0	235.3	0.943	0.025	35			
623 (1), (2)	" 10	12 42	0	236.0	0.940	0.025	35			
624 (1), (2)	" 10	1 02	0	236.0	0.940	0.025	35			
625 (1)	" 10	1 10	0	236.0	0.940	0.025	35			
627 (1), (2)	" 12	1 02	0	236.0	0.939	0.025	30			
628 (1), (2)	" 12	1 08	0	236.0	0.939	0.025	30			
629 (1)	" 12	1 40	0	236.0	0.939	0.025	60	Fair		

(1) Unsteady

TABLE XIII—THE SPECTRUM LINES MEASURED AND THEIR VELOCITY FACTORS, F , FOR
1 mm. DISPLACEMENT

Rowland	I.A.	Element	Intensity			Height	Scale	F
			Disc	Spot	Flash			
Å						km.	Å/mm.	km./sec.
5528-641s	.420	Mg	8	8	8	400	0.9494	51.49
5535-061s	4.849	Fe ⁺	2	0	15	600	0.9488	51.40
5562-933	.718	Fe	2	1	2	350	0.9477	51.08
5569-848s	.633	Fe	6	7	7	600	0.9476	51.02
5576-320s	.101	Fe	4	4	6	500	0.9468	50.91
5578-946	.731	Ni	1	2	4	500	0.9466	50.88
5586-991	.773	Fe	7	8	8	600	0.9460	50.77
5588-985s	.766	Ca	6	10	6	600	0.9458	50.74
5590-343s	.128	Ca	3	7	1	400	0.9457	50.73
5593-961	.748	Ni	0	-1	1d	400	0.9455	50.68
5586-991	.773	Fe	7	8	8	600		
5587-800	.583	Fe	0	0	1	300		
5588-084	7.870	Ni	1	2	4	400	0.9459	50.76
5588-985s	.766	Ca	6	10	6	600		
5589-582	.368	Ni	0	0	1	300		
5590-343s °	.128	Ca	3	7	1	400		

TABLE XIV—RESULTS FROM INDIVIDUAL OBSERVATIONS, 10 SPECTRUM LINES

Plate	L609 (1) Dec. 6, 1:45, E.S.T.							L609 (2) Dec. 6, 1:46, E.S.T.						
De L. on T	$\alpha=0^\circ$ $\beta=7^\circ 2'$ $\gamma=18^\circ 9'$ $r=0.946$ $\epsilon=0.267$ $\phi=0^\circ 0'$ $B_0=0^\circ 1'$ $0.5285v = V$							$\alpha=0^\circ$ $\beta=7^\circ 2'$ $\gamma=18^\circ 9'$ $r=0.946$ $\epsilon=0.267$ $\phi=0^\circ 0'$ $B_0=0^\circ 1'$ $0.5285v = V$						
	λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	
		mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	
5528-641	0.0631	1.759	1.859	0.0635	1.769	1.870	0.0608	1.700	1.797	0.0650	1.808	1.911		
5535-061	0.0695	1.920	2.029	0.0685	1.894	2.002	0.0732	2.015	1.130	0.0714	1.969	2.081		
5562-933	0.0637	1.761	1.861	0.0641	1.771	1.872	0.0640	1.769	1.870	0.0645	1.781	1.883		
5569-848	0.0673	1.851	1.957	0.0681	1.871	1.978	0.0631	1.744	1.843	0.0703	1.927	2.037		
5576-320	0.0637	1.758	1.856	0.0651	1.791	1.893	0.0663	1.822	1.926	0.0652	1.794	1.896		
5578-946	0.0657	1.805	1.908	0.0700	1.915	2.024	0.0645	1.775	1.876	0.0657	1.805	1.908		
5586-991	0.0642	1.764	1.865	0.0655	1.797	1.899	0.0656	1.800	1.903	0.0676	1.850	1.955		
5588-985	0.0692	1.890	1.998	0.0667	1.826	1.930	0.0705	1.923	2.033	0.0673	1.841	1.946		
5590-343	0.0692	1.889	1.997	0.0683	1.866	1.972	0.0671	1.836	1.941	0.0679	1.856	1.962		
5593-961	0.0711	1.936	2.046	0.0625	1.718	1.816	0.0724	1.969	2.081	0.0684	1.867	1.973		
Means:			1.938			1.926			1.940			1.955		
							1.932						1.948	

TABLE XIV—RESULTS FROM INDIVIDUAL OBSERVATIONS, 10 SPECTRUM LINES—Continued

Plate:	L610 (4) Dec. 6, 1:55, E.S.T.						L610 (5) Dec. 6, 1:56, E.S.T.					
De L. on T	$\alpha=0^\circ \beta=7^\circ 2' \gamma=18^\circ 9'$ $r=0.946 \epsilon=0.267 \phi=0^\circ 0'$ $B_o=0^\circ 1' 0.5285v = V$						$\alpha=0^\circ \beta=7^\circ 2' \gamma=18^\circ 9'$ $r=0.946 \epsilon=0.267 \phi=0^\circ 0'$ $B_o=0^\circ 1' 0.5285v = V$					
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
5528.641	0.0695	1.924	2.034	0.0700	1.937	2.047	0.0686	1.900	2.008	0.0750	2.065	2.183
5535.061	0.0679	1.879	1.986	0.0724	1.995	2.109	0.0703	1.941	2.052	0.0730	2.010	2.125
5562.933	0.0695	1.909	2.018	0.0743	2.032	2.148	0.0657	1.812	1.915	0.0634	1.753	1.853
5569.848	0.0685	1.881	1.988	0.0687	1.887	1.995	0.0641	1.769	1.870	0.0655	1.805	1.908
5576.320	0.0684	1.875	1.982	0.0649	1.786	1.888	0.0694	1.901	2.009	0.0690	1.891	1.999
5578.946	0.0716	1.956	2.067	0.0685	1.877	1.984	0.0680	1.864	1.970	0.0648	1.783	1.885
5586.991	0.0655	1.797	1.899	0.0675	1.848	1.953	0.0657	1.802	1.905	0.0678	1.855	1.961
5588.985	0.0677	1.852	1.958	0.0681	1.862	1.968	0.0656	1.798	1.900	0.0648	1.778	1.879
5590.343	0.0642	1.762	1.862	0.0602	1.661	1.756	0.0705	1.922	2.032	0.0643	1.765	1.866
5593.961	0.0682	1.862	1.968	0.0699	1.905	2.014	0.0691	1.885	1.992	0.0697	1.900	2.008
Means:		1.976			1.986			1.965			1.967	
					1.981						1.966	
Plate:	L611 (1) Dec. 6, 2:48, E.S.T.						L611 (2) Dec. 6, 2:49, E.S.T.					
De L. on T	$\alpha=0^\circ \beta=7^\circ 2' \gamma=17^\circ 8'$ $r=0.952 \epsilon=0.269 \phi=0^\circ 0'$ $B_o=0^\circ 1' 0.5251v = V$						$\alpha=0^\circ \beta=7^\circ 2' \gamma=17^\circ 8'$ $r=0.952 \epsilon=0.269 \phi=0^\circ 0'$ $B_o=0^\circ 1' 0.5251v = V$					
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
5528.641	0.0529	1.497	1.572	0.0608	1.701	1.787	0.0675	1.873	1.967	0.0709	1.961	2.060
5535.061	0.0715	1.973	2.072	0.0644	1.790	1.880	0.0704	1.944	2.042	0.0744	2.047	2.150
5562.933	0.0699	1.920	2.017	0.0714	1.959	2.058	0.0708	1.943	2.041	0.0705	1.936	2.033
5569.848	0.0667	1.837	1.920	0.0707	1.939	2.037	0.0692	1.900	1.996	0.0708	1.941	2.039
5576.320	0.0645	1.777	1.866	0.0690	1.892	1.987	0.0674	1.851	1.944	0.0675	1.854	1.947
5578.946	0.0712	1.946	2.044	0.0684	1.875	1.969	0.0722	1.972	2.071	0.0702	1.921	2.018
5586.991	0.0655	1.798	1.888	0.0642	1.765	1.854	0.0687	1.879	1.974	0.0744	2.024	2.126
5588.985	0.0677	1.853	1.946	0.0739	2.010	2.111	0.0658	1.804	1.895	0.0679	1.858	1.951
5590.343	0.0677	1.852	1.945	0.0697	1.903	1.999	0.0662	1.814	1.905	0.0720	1.961	2.060
5593.961	0.0690	1.883	1.978	0.0698	1.904	2.000	0.0693	1.891	1.986	0.0649	1.780	1.870
Means:		1.925			1.968			1.982			2.025	
					1.947						2.004	

TABLE XIV—RESULTS FROM INDIVIDUAL OBSERVATIONS, 10 SPECTRUM LINES—Continued

Plate:	L613 (1) Dec. 8, 1:18, E.S.T.						L613 (2) Dec. 8, 1:22, E.S.T.					
	$\alpha=0^\circ \beta=7^\circ 2' \gamma=19^\circ 1'$ $r=0.945 \epsilon=0.267 \phi=0^\circ 0'$ $B_o=-0.2^{\circ} 0.5291v = V$						$\alpha=0^\circ \beta=7^\circ 2' \gamma=19^\circ 1'$ $r=0.945 \epsilon=0.267 \phi=0^\circ 0'$ $B_o=-0.2^{\circ} 0.5291v = V$					
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
5528·641	0.0625	1.743	1.845	0.0733	2.023	2.141	0.0643	1.790	1.894	0.0615	1.718	1.818
5535·061	0.0699	1.930	2.043	0.0665	1.843	1.950	0.0676	1.871	1.980	0.0703	1.941	2.054
5562·933	0.0704	1.932	2.045	0.0704	1.932	2.045	0.0675	1.858	1.966	0.0630	1.743	1.845
5569·848	0.0684	1.879	1.989	0.0727	1.989	2.105	0.0705	1.932	2.045	0.0689	1.892	1.002
5576·320	0.0757	2.061	2.181	0.0678	1.860	1.968	0.0584	1.621	1.716	0.0511	1.435	1.519
5578·946	0.0696	1.905	2.016	0.0695	1.902	2.013	0.0726	1.981	2.096	0.0676	1.854	1.962
5586·991	0.0672	1.840	1.947	0.0688	1.881	1.991	0.0654	1.795	1.900	0.0660	1.810	1.916
5588·985	0.0725	1.973	2.088	0.0724	1.971	2.086	0.0648	1.778	1.882	0.0635	1.745	1.847
5590·343	0.0683	1.866	1.975	0.0697	1.902	2.013	0.0647	1.775	1.878	0.0577	1.597	1.690
5593·961	0.0708	1.928	2.040	0.0632	1.735	1.836	0.0726	1.974	2.089	0.0734	1.994	2.110
Means:		2.017			2.015			1.945			1.876	
						2.016					1.911	
Plate:	L614 (1) Dec. 8, 1:38, E.S.T.						L614 (2) Dec. 8, 1:39, E.S.T.					
De L. on T	$\alpha=0^\circ \beta=7^\circ 2' \gamma=19^\circ 4'$ $r=0.943 \epsilon=0.267 \phi=0^\circ 0'$ $B_o=-0.2^{\circ} 0.5301v = V$						$\alpha=0^\circ \beta=7^\circ 2' \gamma=19^\circ 4'$ $r=0.943 \epsilon=0.267 \phi=0^\circ 0'$ $B_o=-0.2^{\circ} 0.5301v = V$					
	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
5528·641	0.0743	2.046	2.169	0.0740	2.039	2.162	0.0684	1.894	2.008	0.0697	1.928	2.044
5535·061	0.0669	1.852	1.963	0.0669	1.852	1.963	0.0574	1.608	1.705	0.0598	1.670	1.771
5562·933	0.0653	1.801	1.909	0.0703	1.928	2.044	0.0647	1.785	1.892	0.0653	1.801	1.909
5569·848	0.0689	1.891	2.005	0.0571	1.590	1.686	0.0649	1.789	1.897	0.0707	1.937	2.054
5576·320	0.0688	1.885	1.998	0.0683	1.872	1.985	0.0640	1.762	1.868	0.0672	1.844	1.955
5578·946	0.0659	1.809	1.918	0.0681	1.865	1.977	0.0571	1.586	1.681	0.0714	1.949	2.066
5586·991	0.0657	1.801	1.909	0.0665	1.821	1.931	0.0614	1.692	1.794	0.0674	1.844	1.955
5588·985	0.0656	1.797	1.905	0.0631	1.734	1.838	0.0710	1.934	2.050	0.0675	1.871	1.984
5590·343	0.0672	1.837	1.948	0.0645	1.769	1.875	0.0630	1.731	1.835	0.0650	1.781	1.888
5593·961	0.0674	1.841	1.952	0.0618	1.699	1.801	0.0689	1.879	1.992	0.0651	1.783	1.890
Means:		1.968			1.926			1.872			1.952	
					1.947						1.912	

TABLE XIV—RESULTS FROM INDIVIDUAL OBSERVATIONS, 10 SPECTRUM LINES—Continued

Plate:	L614a (1) Dec. 8, 2:02, E.S.T.						L615 (1) Dec. 8, 2:15, E.S.T.					
De L. on T	$\alpha=0^\circ \beta=7^\circ 2' \gamma=19^\circ 3'$ $r=0.944 \epsilon=0.267 \phi=0^\circ 0'$ $B_o=-0^\circ 2' 0.5298v = V$						$\alpha=0^\circ \beta=7^\circ 2' \gamma=19^\circ 1'$ $r=0.945 \epsilon=0.267 \phi=0^\circ 0'$ $B_o=-0^\circ 2' 0.5291v = V$					
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
5528-641	0.0654	1.817	1.925	0.0645	1.794	1.901	0.0744	2.050	2.170	0.0766	2.106	2.229
5535-061	0.0764	2.096	2.221	0.0678	1.875	1.987	0.0729	2.008	2.125	0.0738	2.031	2.149
5562-933	0.0626	1.732	1.835	0.0628	1.737	1.841	0.0691	1.899	2.010	0.0675	1.858	1.966
5569-848	0.0632	1.745	1.849	0.0670	1.842	1.952	0.0668	1.838	1.945	0.0698	1.915	2.027
5576-320	0.0781	2.119	2.245	0.0736	2.007	2.127	0.0705	1.929	2.041	0.0687	1.883	1.993
5578-946	0.0741	2.018	2.138	0.0791	2.145	2.273	0.0656	1.803	1.908	0.0632	1.742	1.844
5586-991	0.0624	1.717	1.819	0.0701	1.913	2.027	0.0638	1.754	1.856	0.0661	1.812	1.918
5588-985	0.0654	1.792	1.899	0.0726	1.975	2.093	0.0697	1.902	2.013	0.0694	1.895	2.005
5590-343	0.0631	1.733	1.836	0.0644	1.766	1.871	0.0704	1.919	2.031	0.0705	1.922	2.034
5593-961	0.0645	1.767	1.872	0.0594	1.638	1.736	0.0749	2.033	2.152	0.0683	1.865	1.974
Means:			1.964			1.981			2.025			2.014
						1.973						2.020
Plate:	L616 (1) Dec. 9, 12:42, E.S.T.						L616 (2) Dec. 9, 12:43, E.S.T.					
De L. on T	$\alpha=0^\circ \beta=7^\circ 2' \gamma=19^\circ 9'$ $r=0.940 \epsilon=0.266 \phi=0^\circ 1'$ $B_o=-0^\circ 3' 0.5318v = V$						$\alpha=0^\circ \beta=7^\circ 2' \gamma=19^\circ 9'$ $r=0.940 \epsilon=0.266 \phi=0^\circ 1'$ $B_o=-0^\circ 3' 0.5318v = V$					
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
5528-641	0.0618	1.724	1.833	0.0610	1.704	1.812	0.0694	1.920	2.042	0.0644	1.791	1.905
5535-061	0.0624	1.737	1.847	0.0618	1.721	1.830	0.0592	1.654	1.759	0.0633	1.760	1.872
5562-933	0.0604	1.676	1.782	0.0581	1.617	1.720	0.0593	1.648	1.753	0.0616	1.706	1.814
5569-848	0.0636	1.755	1.866	0.0621	1.717	1.826	0.0585	1.625	1.728	0.0668	1.837	1.954
5576-320	0.0614	1.696	1.804	0.0607	1.678	1.785	0.0649	1.785	1.898	0.0658	1.788	1.902
5578-946	0.0638	1.756	1.868	0.0632	1.741	1.852	0.0680	1.863	1.981	0.0705	1.927	2.049
5586-991	0.0679	1.857	1.975	0.0671	1.837	1.954	0.0628	1.727	1.837	0.0634	1.743	1.854
5588-985	0.0679	1.856	1.974	0.0693	1.891	2.011	0.0702	1.914	2.036	0.0663	1.815	1.930
5590-343	0.0672	1.837	1.954	0.0629	1.728	1.838	0.0680	1.857	1.975	0.0675	1.845	1.962
5593-961	0.0657	1.798	1.912	0.0717	1.950	2.074	0.0743	2.016	2.144	0.0708	1.927	2.049
Means:			1.882			1.870			1.915			1.929
						1.876						1.922

TABLE XIV—RESULTS FROM INDIVIDUAL OBSERVATIONS, 10 SPECTRUM LINES—Continued

Plate:	L617 (1) Dec. 9, 12:52, E.S.T.							L617 (2) Dec. 9, 12:53, E.S.T.						
De L. on T	$\alpha=0^\circ$ $\beta=7^\circ 2'$ $\gamma=19^\circ 9'$ $r=0.940$ $\epsilon=0.266$ $\phi=0^\circ 1'$ $B_0=-0^\circ 3'$ $0.5318v = V$							$\alpha=0^\circ$ $\beta=7^\circ 2'$ $\gamma=19^\circ 9'$ $r=0.940$ $\epsilon=0.266$ $\phi=0^\circ 1'$ $B_0=-0^\circ 3'$ $0.5318v = V$						
	λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	
		mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	
5528-641	0.0646	1.796	1.910	0.0661	1.835	1.952	0.0633	1.763	1.875	0.0642	1.786	1.899		
5535-061	0.0600	1.675	1.781	0.0570	1.598	1.699	0.0658	1.824	1.940	0.0654	1.814	1.929		
5562-933	0.0612	1.696	1.804	0.0678	1.865	1.983	0.0602	1.671	1.777	0.0661	1.821	1.937		
5569-848	0.0687	1.886	2.006	0.0683	1.875	1.994	0.0646	1.781	1.894	0.0644	1.776	1.889		
5576-320	0.0646	1.778	1.891	0.0657	1.806	1.921	0.0692	1.895	2.015	0.0660	1.813	1.928		
5578-946	0.0606	1.675	1.781	0.0613	1.692	1.799	0.0627	1.728	1.838	0.0625	1.723	1.832		
5586-991	0.0654	1.794	1.908	0.0626	1.722	1.831	0.0655	1.796	1.910	0.0673	1.842	1.959		
5588-985	0.0622	1.711	1.820	0.0658	1.802	1.916	0.0676	1.848	1.965	0.0625	1.719	1.828		
5590-343	0.0661	1.809	1.924	0.0666	1.822	1.938	0.0659	1.804	1.919	0.0608	1.675	1.781		
5593-961	0.0598	1.648	1.753	0.0617	1.696	1.804	0.0742	2.013	2.141	0.0741	2.011	2.139		
Means:			1.858			1.884			1.927				1.912	
							1.871						1.920	
Plate:	L618 (1) Dec. 9, 1:12, E.S.T.							L618 (2) Dec. 9, 1:14, E.S.T.						
De L. on T	$\alpha=0^\circ$ $\beta=7^\circ 2'$ $\gamma=19^\circ 9'$ $r=0.940$ $\epsilon=0.266$ $\phi=0^\circ 1'$ $B_0=-0^\circ 3'$ $0.5318v = V$							$\alpha=0^\circ$ $\beta=7^\circ 2'$ $\gamma=19^\circ 9'$ $r=0.940$ $\epsilon=0.266$ $\phi=0^\circ 1'$ $B_0=-0^\circ 3'$ $0.5318v = V$						
	λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	
		mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	
5528-641	0.0613	1.711	1.820	0.0620	1.730	1.840	0.0614	1.714	1.823	0.0613	1.711	1.820		
5535-061	0.0693	1.914	2.036	0.0654	1.814	1.929	0.0725	1.996	2.123	0.0685	1.893	2.013		
5562-933	0.0587	1.632	1.736	0.0663	1.826	1.942	0.0643	1.775	1.888	0.0590	1.640	1.744		
5569-848	0.0635	1.753	1.864	0.0644	1.776	1.889	0.0643	1.773	1.886	0.0670	1.842	1.959		
5576-320	0.0643	1.770	1.882	0.0660	1.813	1.928	0.0599	1.658	1.763	0.0614	1.696	1.804		
5578-946	0.0730	1.990	2.116	0.0640	1.761	1.873	0.0659	1.809	1.924	0.0635	1.748	1.859		
5586-991	0.0662	1.814	1.929	0.0660	1.809	1.924	0.0648	1.778	1.891	0.0667	1.827	1.943		
5588-985	0.0666	1.823	1.939	0.0663	1.815	1.930	0.0671	1.835	1.952	0.0672	1.838	1.955		
5590-343	0.0724	1.969	2.094	0.0659	1.804	1.919	0.0650	1.781	1.894	0.0615	1.693	1.801		
5593-961	0.0619	1.702	1.810	0.0611	1.681	1.788	0.0707	1.925	2.047	0.0633	1.737	1.847		
Means:			1.923			1.896			1.919				1.875	
							1.910						1.897	

TABLE XIV—RESULTS FROM INDIVIDUAL OBSERVATIONS, 10 SPECTRUM LINES—Continued

Plate:	L619 (1) Dec. 9, 1:20, E.S.T.						L620 (1) Dec. 9, 1:35, E.S.T.					
De L. on T	$\alpha=0^\circ \beta=7^\circ 2' \gamma=19^\circ 9'$ $r=0.940 \epsilon=0.266 \phi=0^\circ 1'$ $B_o=-0^\circ 3' 0.5318v =V$						$\alpha=0^\circ \beta=7^\circ 2' \gamma=19^\circ 4'$ $r=0.943 \epsilon=0.267 \phi=0^\circ 1'$ $B_o=-0^\circ 3' 0.5301v =V$					
	λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$
		mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.
5528·641	0.0661	1.835	1.952	0.0701	1.938	2.061	0.0609	1.702	1.804	0.0650	1.808	1.917
5535·061	0.0697	1.924	2.046	0.0633	1.760	1.872	0.0609	1.699	1.801	0.0656	1.820	1.930
5562·933	0.0586	1.885	2.005	0.0618	1.711	1.820	0.0628	1.738	1.843	0.0656	1.809	1.918
5569·848	0.0622	1.720	1.829	0.0651	1.794	1.908	0.0613	1.698	1.800	0.0626	1.731	1.835
5576·320	0.0667	1.831	1.947	0.0621	1.714	1.823	0.0668	1.835	1.945	0.0683	1.873	1.986
5578·946	0.0646	1.776	1.889	0.0669	1.835	1.952	0.0522	1.462	1.555	0.0649	1.785	1.892
5586·991	0.0592	1.636	1.740	0.0608	1.677	1.783	0.0631	1.736	1.841	0.0617	1.701	1.803
5588·985	0.0648	1.777	1.890	0.0658	1.802	1.916	0.0635	1.745	1.850	0.0590	1.631	1.729
5590·343	0.0653	1.789	1.903	0.0661	1.809	1.924	0.0691	1.886	2.000	0.0673	1.841	1.952
5593·961	0.0546	1.770	1.882	0.0662	1.709	1.818	0.0612	1.685	1.786	0.0585	1.616	1.713
Means:			1.908			1.888			1.823			1.868
						1.898						1.846
Plate:	L622 (1) Dec. 10, 12:32, E.S.T.						L622 (2) Dec. 10, 12:33, E.S.T.					
De L. on T	$\alpha=0^\circ \beta=7^\circ 2' \gamma=19^\circ 4'$ $r=0.943 \epsilon=0.267 \phi=0^\circ 1'$ $B_o=-0^\circ 4' 0.5301v =V$						$\alpha=0^\circ \beta=7^\circ 2' \gamma=19^\circ 4'$ $r=0.943 \epsilon=0.267 \phi=0^\circ 1'$ $B_o=-0^\circ 4' 0.5301v =V$					
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
5528·641	0.0696	1.926	2.042	0.0705	1.949	2.066	0.0669	1.857	1.969	0.0659	1.831	1.941
5535·061	0.0651	1.807	1.916	0.0634	1.763	1.869	0.0659	1.828	1.938	0.0665	1.843	1.954
5562·933	0.0711	1.950	2.067	0.0711	1.950	2.067	0.0643	1.776	1.883	0.0663	1.827	1.937
5569·848	0.0682	1.874	1.987	0.0674	1.853	1.965	0.0662	1.823	1.933	0.0663	1.825	1.935
5576·320	0.0705	1.929	2.045	0.0693	1.898	2.012	0.0658	1.809	1.918	0.0667	1.832	1.942
5578·946	0.0653	1.795	1.903	0.0631	1.739	1.844	0.0654	1.798	1.906	0.0708	1.935	2.051
5586·991	0.0688	1.881	1.994	0.0680	1.861	1.973	0.0647	1.777	1.884	0.0631	1.736	1.841
5588·985	0.0675	1.846	1.957	0.0683	1.867	1.979	0.0660	1.808	1.917	0.0642	1.763	1.869
5590·343	0.0669	1.831	1.941	0.0683	1.866	1.978	0.0645	1.770	1.877	0.0653	1.790	1.898
5593·961	0.0634	1.741	1.846	0.0640	1.756	1.862	0.0622	1.710	1.813	0.0593	1.637	1.736
Means:			1.970			1.962			1.904			1.910
						1.966						1.907

TABLE XIV—RESULTS FROM INDIVIDUAL OBSERVATIONS, 10 SPECTRUM LINES—Continued

Plate:	L623 (1) Dec. 10, 12:42, E.S.T.						L623 (2) Dec. 10, 12:43, E.S.T.					
De L. on T	$\alpha=0^\circ \quad \beta=7^\circ 2' \quad \gamma=19^\circ 9'$ $r=0.940 \quad \epsilon=0.266 \quad \phi=0^\circ 1'$ $B_0=-0^\circ 4' \quad 0.5318v = V$						$\alpha=0^\circ \quad \beta=7^\circ 2' \quad \gamma=10^\circ 9'$ $r=0.940 \quad \epsilon=0.266 \quad \phi=0^\circ 1'$ $B_0=-0^\circ 4' \quad 0.5318v = V$					
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}t$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
5528-641	0.0600	1.678	1.785	0.0644	1.791	1.905	0.0660	1.833	1.949	0.0638	1.776	1.889
5535-061	0.0674	1.865	1.983	0.0664	1.839	1.956	0.0675	1.868	1.987	0.0740	2.035	2.164
5562-933	0.0721	1.974	2.099	0.0681	1.872	1.991	0.0621	1.719	1.828	0.0620	1.716	1.825
5569-848	0.0726	1.985	2.111	0.0687	1.887	2.007	0.0726	1.985	2.111	0.0707	1.937	2.060
5576-320	0.0687	1.882	2.002	0.0703	1.923	2.045	0.0677	1.857	1.975	0.0679	1.862	1.980
5578-946	0.0671	1.840	1.957	0.0695	1.901	2.022	0.0717	1.957	2.081	0.0700	1.914	2.036
5586-991	0.0695	1.898	2.019	0.0702	1.915	2.037	0.0695	1.898	2.019	0.0649	1.781	1.894
5588-985	0.0650	1.782	1.895	0.0680	1.858	1.976	0.0731	1.988	2.114	0.0702	1.914	2.036
5590-343	0.0708	1.928	2.050	0.0680	1.857	1.975	0.0655	1.794	1.908	0.0622	1.710	1.819
5593-961	0.0687	1.874	1.993	0.0679	1.854	1.972	0.0656	1.795	1.909	0.0660	1.805	1.920
Means:		1.989				1.989			1.988			1.962
						1.989						1.975
Plate:	L624 (1) Dec. 10, 1:02, E.S.T.						L624 (2) Dec. 10, 1:03, E.S.T.					
De L. on T	$\alpha=0^\circ \quad \beta=7^\circ 2' \quad \gamma=10^\circ 9'$ $r=0.940 \quad \epsilon=0.266 \quad \phi=0^\circ 1'$ $B_0=-0^\circ 4' \quad 0.5318v = V$						$\alpha=0^\circ \quad \beta=7^\circ 2' \quad \gamma=19^\circ 9'$ $r=0.940 \quad \epsilon=0.262 \quad \phi=0^\circ 1'$ $B_0=-0^\circ 4' \quad 0.5318v = V$					
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}t$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
5528-641	0.0628	1.750	1.861	0.0634	1.766	1.878	0.0636	1.771	1.883	0.0593	1.660	1.765
5535-061	0.0707	1.950	2.074	0.0717	1.976	2.101	0.0614	1.711	1.820	0.0649	1.801	1.915
5562-933	0.0577	1.607	1.708	0.0628	1.737	1.847	0.0643	1.775	1.888	0.0646	1.783	1.896
5569-848	0.0666	1.832	1.948	0.0675	1.855	1.973	0.0692	1.898	2.019	0.0696	1.908	2.029
5576-320	0.0680	1.864	1.982	0.0634	1.747	1.858	0.0684	1.874	1.993	0.0717	1.958	2.082
5578-946	0.0677	1.855	1.973	0.0719	1.962	2.087	0.0644	1.771	1.883	0.0653	1.794	1.908
5586-991	0.0638	1.753	1.864	0.0662	1.814	1.929	0.0678	1.854	1.972	0.0661	1.811	1.926
5588-985	0.0673	1.840	1.956	0.0636	1.747	1.858	0.0700	1.909	2.030	0.0688	1.878	1.997
5590-343	0.0646	1.771	1.883	0.0677	1.850	1.967	0.0668	1.827	1.943	0.0664	1.817	1.932
5593-961	0.0627	1.722	1.831	0.0623	1.712	1.821	0.0706	1.922	2.044	0.0700	1.907	2.028
Means:		1.908				1.932			1.948			1.948
						1.920						1.948

TABLE XIV—RESULTS FROM INDIVIDUAL OBSERVATIONS, 10 SPECTRUM LINES—Continued

Plate:	L625 (1) Dec. 10, 1:10, E.S.T.						L627 (1) Dec. 12, 1:02, E.S.T.					
	$\alpha=0^\circ \beta=7^\circ 2' \gamma=19^\circ 9'$ $r=0.940 \epsilon=0.266 \phi=0^\circ 1'$ $B_0=-0^\circ 4' 0.5318v = V$						$\alpha=0^\circ \beta=6^\circ 8' \gamma=20^\circ 1'$ $r=0.939 \epsilon=0.267 \phi=0^\circ 1'$ $B_0=-2^\circ 6' 0.5324v = V$					
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
5528-641	0.0662	1.838	1.955	0.0728	2.008	2.136	0.0607	1.696	1.806	0.0721	1.990	2.119
5535-061	0.0663	1.837	1.954	0.0697	1.924	2.046	0.0668	1.850	1.970	0.0626	1.742	1.855
5562-933	0.0673	1.852	1.970	0.0628	1.737	1.847	0.0643	1.775	1.890	0.0639	1.765	1.880
5569-848	0.0624	1.725	1.835	0.0690	1.893	2.013	0.0615	1.702	1.812	0.0633	1.748	1.861
5576-320	0.0635	1.750	1.861	0.0650	1.788	1.902	0.0717	1.958	2.085	0.0616	1.701	1.811
5578-946	0.0637	1.754	1.865	0.0608	1.680	1.787	0.0655	1.799	1.916	0.0643	1.769	1.884
5586-991	0.0667	1.827	1.943	0.0688	1.880	1.999	0.0646	1.773	1.888	0.0653	1.791	1.907
5588-985	0.0626	1.721	1.830	0.0693	1.891	2.011	0.0595	1.643	1.750	0.0652	1.787	1.903
5590-343	0.0604	1.665	1.771	0.0628	1.726	1.836	0.0694	1.893	2.016	0.0665	1.819	1.937
5593-961	0.0620	1.704	1.812	0.0683	1.864	1.982	0.0640	1.755	1.889	0.0658	1.800	1.917
Means:		1.880			1.956			1.900			1.907	
					1.918						1.904	
Plate:	L627 (2) Dec. 12, 1:03, E.S.T.						L628 (1) Dec. 12, 1:08, E.S.T.					
De L. on T	$\alpha=0^\circ \beta=6^\circ 8' \gamma=20^\circ 1'$ $r=0.939 \epsilon=0.267 \phi=0^\circ 1'$ $B_0=-2^\circ 6' 0.5324v = V$						$\alpha=0^\circ \beta=6^\circ 8' \gamma=20^\circ 1'$ $r=0.939 \epsilon=0.267 \phi=0^\circ 1'$ $B_0=-2^\circ 6' 0.5324v = V$					
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
5528-641	0.0650	1.807	1.924	0.0651	1.809	1.926	0.0652	1.811	1.929	0.0668	1.852	1.972
5535-061	0.0629	1.750	1.864	0.0666	1.845	1.965	0.0616	1.716	1.827	0.0610	1.700	1.810
5562-933	0.0655	1.806	1.923	0.0616	1.706	1.817	0.0642	1.772	1.887	0.0648	1.787	1.903
5569-848	0.0592	1.643	1.750	0.0612	1.694	1.804	0.0618	1.709	1.820	0.0674	1.852	1.972
5576-320	0.0618	1.706	1.817	0.0661	1.816	1.934	0.0666	1.828	1.946	0.0650	1.787	1.903
5578-946	0.0629	1.733	1.845	0.0625	1.723	1.835	0.0678	1.857	1.978	0.0714	1.949	2.075
5586-991	0.0685	1.872	1.993	0.0642	1.763	1.877	0.0747	2.029	2.161	0.0683	1.866	1.987
5588-985	0.0757	1.800	1.917	0.0664	1.818	1.936	0.0612	1.685	1.794	0.0538	1.497	1.594
5590-343	0.0632	1.736	1.849	0.0618	1.700	1.810	0.0556	1.542	1.642	0.0590	1.629	1.735
5593-961	0.0638	1.750	1.864	0.0671	1.833	1.952	0.0690	1.881	2.003	0.0665	1.817	1.935
Means:		1.875			1.886			1.899			1.889	
					1.881						1.894	

TABLE XIV—RESULTS FROM INDIVIDUAL OBSERVATIONS, 10 SPECTRUM LINES—Concluded

Plate:	L628 (2) Dec. 12, 1:09, E.S.T.							L629 (1) Dec. 12, 1:40, E.S.T.							
	$\alpha=0^\circ \beta=6^\circ 8 \gamma=20^\circ 1$			$\alpha=0^\circ \beta=6^\circ 8 \gamma=20^\circ 1$			$\alpha=0^\circ \beta=6^\circ 8 \gamma=20^\circ 1$			$\alpha=0^\circ \beta=6^\circ 8 \gamma=20^\circ 1$			$\alpha=0^\circ \beta=6^\circ 8 \gamma=20^\circ 1$		
De L. on T	$r=0.939 \epsilon=0.267 \phi=0^\circ 1$							$r=0.939 \epsilon=0.267 \phi=0^\circ 1$							
	$B_o=-2^\circ 6 0.5324v -V$			$B_o=-2^\circ 6 0.5324v -V$			$B_o=-2^\circ 6 0.5324v -V$			$B_o=-2^\circ 6 0.5324v -V$			$B_o=-2^\circ 6 0.5324v -V$		
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
5528·641	0.0684	1.894	2.017	0.0685	1.897	2.020	0.0561	1.578	1.680	0.0779	2.139	2.278			
5535·061	0.0620	1.726	1.838	0.0620	1.726	1.838	0.0684	1.891	2.014	0.0678	1.875	1.997			
5562·933	0.0624	1.727	1.839	0.0621	1.719	1.831	0.0639	1.765	1.880	0.0670	1.844	1.964			
5569·848	0.0643	1.773	1.888	0.0639	1.763	1.877	0.0699	1.916	2.040	0.0697	1.911	2.035			
5576·320	0.0573	1.592	1.695	0.0641	1.765	1.880	0.0650	1.788	1.904	0.0677	1.857	1.978			
5578·946	0.0611	1.687	1.796	0.0597	1.652	1.759	0.0668	1.832	1.951	0.0674	1.848	1.968			
5586·991	0.0711	1.938	2.064	0.0746	2.027	2.159	0.0659	1.806	1.923	0.0704	1.920	2.045			
5588·985	0.0683	1.866	1.987	0.0678	1.853	1.973	0.0676	1.848	1.988	0.0699	1.906	2.030			
5590·343	0.0697	1.901	2.024	0.0699	1.906	2.030	0.0627	1.723	1.835	0.0646	1.771	1.886			
5593·961	0.0533	1.484	1.580	0.0675	1.843	1.963	0.0709	1.930	2.055	0.0665	1.818	1.936			
Means:		1.873			1.933				1.925			2.012			
					1.903							1.969			

TABLE XV—RESULTS FROM OBSERVATIONS, 6 SPECTRUM LINES

Plate:	L600 (1)–(5), Nov. 9, 3:20, E.S.T.				L601 (1)–(6), Nov. 9, 3:37, E.S.T.				L602 (1)–(6), Nov. 9, 3:50, E.S.T.						
	$\alpha=0^\circ \beta=6^\circ 4 \gamma=18^\circ 5$			$\alpha=0^\circ \beta=6^\circ 4 \gamma=18^\circ 5$			$\alpha=0^\circ \beta=6^\circ 4 \gamma=18^\circ 5$			$\alpha=0^\circ \beta=6^\circ 4 \gamma=18^\circ 5$					
DeL.on-C	$r=0.950 \epsilon=0.268 \phi=1^\circ 1$			$r=0.950 \epsilon=0.268 \phi=1^\circ 1$			$r=0.950 \epsilon=0.268 \phi=1^\circ 1$			$r=0.950 \epsilon=0.268 \phi=1^\circ 1$					
	$B_o=3^\circ 4 0.52724v -V$			$B_o=3^\circ 4 0.52724v -V$			$B_o=3^\circ 4 0.52724v -V$			$B_o=3^\circ 4 0.52724v -V$					
λ	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
5586·991	0.0648	1.778	1.874	0.0676	1.849	1.949	0.0649	1.760	1.877	0.0697	1.902	2.005			
5587·800	0.0681	1.863	1.964	0.0674	1.844	1.944	0.0671	1.838	1.938	0.0689	1.883	1.986			
5588·084	0.0653	1.792	1.890	0.0663	1.814	1.912	0.0691	1.886	1.989	0.0667	1.826	1.925			
5588·985	0.0700	1.911	2.015	0.0652	1.788	1.885	0.0678	1.855	1.955	0.0687	1.878	1.980			
5589·582	0.0665	1.821	1.920	0.0675	1.848	1.948	0.0659	1.806	1.904	0.0662	1.813	1.912			
5590·343	0.0668	1.830	1.929	0.0677	1.851	1.952	0.0696	1.899	2.003	0.0690	1.886	1.989			
Means:		1.932			1.932				1.944			1.966			

TABLE XV—RESULTS FROM OBSERVATIONS, 6 SPECTRUM LINES—Continued

Plate:	L603 (1)–(5), Nov. 27, 2:02, E.S.T.			L606 (1)–(4), Dec. 5, 2:30, E.S.T.			L607 (1)–(5), Dec. 5, 2:40, E.S.T.			L608 (1)–(5), Dec. 6, 1:25, E.S.T.		
De L. on —C	$\alpha=0^\circ$ $r=0.948$ $B_o=1^\circ 2'$	$\beta=7^\circ 2'$ $\epsilon=0.268$ $0.5276v = V$	$\gamma=18^\circ 6'$ $\phi=0^\circ 4'$ $B_o=0^\circ 2'$	$\alpha=0^\circ 3$ $r=0.947$ $B_o=0^\circ 2$	$\beta=7^\circ 0$ $\epsilon=0.268$ $0.5276v = V$	$\gamma=18^\circ 6$ $\phi=0^\circ 3$ $B_o=0^\circ 2$	$\alpha=0$ $r=0.947$ $B_o=0^\circ 2$	$\beta=7^\circ 2$ $\epsilon=0.268$ $0.5276v = V$	$\gamma=18^\circ 6$ $\phi=0^\circ 0$ $B_o=0^\circ 2$	$\alpha=0^\circ$ $r=0.946$ $B_o=0^\circ 1$	$\beta=7^\circ 2$ $\epsilon=0.268\phi = 0^\circ 0$ $0.5285v = V$	$\gamma=18^\circ 6$ $\phi=0^\circ 0$ $B_o=0^\circ 1$
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
5586-991	0.0639	1.756	1.852	0.0643	1.766	1.863	0.0636	1.748	1.845	0.0671	1.838	1.943
5587-800	0.0643	1.726	1.864	0.0652	1.792	1.891	0.0630	1.737	1.829	0.0656	1.779	1.880
5588-084	0.0660	1.808	1.908	0.0607	1.674	1.766	0.0629	1.731	1.827	0.0673	1.841	1.946
5588-985	0.0679	1.857	1.959	0.0648	1.778	1.876	0.0654	1.774	1.872	0.0685	1.872	1.979
5589-582	0.0705	1.923	2.029	0.0656	1.801	1.900	0.0664	1.819	1.919	0.0620	1.728	1.826
5590-343	0.0700	1.910	2.015	0.0652	1.789	1.887	0.0622	1.713	1.807	0.0678	1.854	1.960
Means:		1.938			1.864			1.850			1.923	
Plate:	L609 (1) Dec. 6, 1:45, E.S.T.			L609 (2) Dec. 6, 1:46, E.S.T.			L610 (4) Dec. 6, 1:55, E.S.T.			L610 (5) Dec. 6, 1:56, E.S.T.		
De L. on —C	$\alpha=0^\circ$ $r=0.946$ $B_o=0^\circ 1$	$\beta=7^\circ 2$ $\epsilon=0.267$ $0.5285v = V$	$\gamma=18^\circ 9$ $\phi=0^\circ 0$ $B_o=0^\circ 1$	$\alpha=0^\circ$ $r=0.946$ $B_o=0^\circ 1$	$\beta=7^\circ 2$ $\epsilon=0.267$ $0.5285v = V$	$\gamma=18^\circ 9$ $\phi=0^\circ 0$ $B_o=0^\circ 1$	$\alpha=0^\circ$ $r=0.946$ $B_o=0^\circ 1$	$\beta=7^\circ 2$ $\epsilon=0.267$ $0.5285v = V$	$\gamma=18^\circ 9$ $\phi=0^\circ 0$ $B_o=0^\circ 1$	$\alpha=0^\circ$ $r=0.946$ $B_o=0^\circ 1$	$\beta=7^\circ 2$ $\epsilon=0.267$ $0.5285v = V$	$\gamma=18^\circ 9$ $\phi=0^\circ 0$ $B_o=0^\circ 1$
λ	d''	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
5586-991	0.0640	1.758	1.858	0.0656	1.799	1.902	0.0678	1.855	1.961	0.0633	1.741	1.840
5587-800	0.0716	1.951	2.062	0.0736	2.002	2.116	0.0677	1.852	1.958	0.0597	1.649	1.743
5588-084	0.0727	1.970	2.092	0.0681	1.862	1.968	0.0640	1.758	1.858	0.0666	1.824	1.928
5588-985	0.0725	1.974	2.087	0.0646	1.774	1.875	0.0692	1.890	1.998	0.0708	1.930	2.040
5589-582	0.0656	1.799	1.902	0.0566	1.571	1.661	0.0701	1.913	2.022	0.0708	1.930	2.040
5590-343	0.0656	1.799	1.902	0.0679	1.857	1.963	0.0678	1.855	1.961	0.0689	1.883	1.990
Means:		1.984			1.914			1.960			1.930	
Plate:	L611 (1) Dec. 6, 2:48, E.S.T.			L611 (2) Dec. 6, 2:49, E.S.T.			L613 (1) Dec. 8, 1:18, E.S.T.			L613 (6) Dec. 8, 1:19, E.S.T.		
De L. on —C	$\alpha=0^\circ$ $r=0.952$ $B_o=0^\circ 1$	$\beta=7^\circ 2$ $\epsilon=0.269$ $0.5251v = V$	$\gamma=17^\circ 8$ $\phi=0^\circ 0$ $B_o=0^\circ 1$	$\alpha=0^\circ$ $r=0.952$ $B_o=0^\circ 1$	$\beta=7^\circ 2$ $\epsilon=0.269$ $0.5251v = V$	$\gamma=17^\circ 8$ $\phi=0^\circ 0$ $B_o=0^\circ 1$	$\alpha=0^\circ$ $r=0.945$ $B_o=0^\circ 2$	$\beta=7^\circ 2$ $\epsilon=0.267$ $0.5291v = V$	$\gamma=19^\circ 1$ $\phi=0^\circ 0$ $B_o=0^\circ 2$	$\alpha=0^\circ$ $r=0.945$ $B_o=0^\circ 2$	$\beta=7^\circ 2$ $\epsilon=0.267$ $0.5291v = V$	$\gamma=19^\circ 1$ $\phi=0^\circ 0$ $B_o=0^\circ 2$
λ	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
5586-991	0.0680	1.861	1.954	0.0678	1.856	1.949	0.0684	1.870	1.979	0.0691	1.888	1.998
5587-800	0.0688	1.881	1.975	0.0655	1.797	1.887	0.0561	1.812	1.917	0.0630	1.733	1.834
5588-084	0.0665	1.823	1.915	0.0742	2.018	2.119	0.0681	1.862	1.970	0.0654	1.794	1.898
5588-985	0.0693	1.894	1.989	0.0720	1.962	2.060	0.0681	1.862	1.970	0.0650	1.784	1.888
5589-582	0.0774	2.099	2.024	0.0710	1.937	2.034	0.0681	1.862	1.970	0.0745	2.025	2.143
5590-343	0.0695	1.899	1.994	0.0708	1.932	2.029	0.0661	1.812	1.917	0.0647	1.776	1.879
Means:		2.005			2.013			1.954			1.940	

TABLE XV—RESULTS FROM OBSERVATIONS, 6 SPECTRUM LINES—Continued

Plate:	L614 (1) Dec. 8, 1:38, E.S.T.			L614 (2) Dec. 8, 1:39, E.S.T.			L614a (1) Dec. 8, 2:02, E.S.T.			L615 (1) Dec. 8, 2:15, E.S.T.		
	$\alpha=0^\circ$	$\beta=7^\circ 2$	$\gamma=19^\circ 4$	$\alpha=0^\circ$	$\beta=7^\circ 2$	$\gamma=19^\circ 4$	$\alpha=0^\circ$	$\beta=7^\circ 2$	$\gamma=19^\circ 3$	$\alpha=0^\circ$	$\beta=7^\circ 2$	$\gamma=19^\circ 1$
De L. on -C	r=0.943	$\epsilon=0.267$	$\phi=0^\circ 0$	r=0.943	$\epsilon=0.267$	$\phi=0^\circ 0$	r=0.944	$\epsilon=0.267$	$\phi=0^\circ 0$	r=0.945	$\epsilon=0.267$	$\phi=0^\circ 0$
	$B_o=0^\circ 2$	$0.5301v = V$		$B_o=0^\circ 2$	$0.5301v = V$		$B_o=0^\circ 2$	$0.5298v = V$		$B_o=0^\circ 2$	$0.5291v = V$	
λ	d'	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
5586.991	0.0690	1.885	1.998	0.0645	1.771	1.878	0.0652	1.789	1.896	0.0632	1.738	1.839
5587.800	0.0655	1.796	1.904	0.0682	1.865	1.977	0.0650	1.784	1.890	0.0728	1.982	2.097
5588.084	0.0614	1.692	1.794	0.0683	1.867	1.979	0.0652	1.789	1.896	0.0701	1.913	2.024
5588.985	0.0628	1.728	1.832	0.0628	1.728	1.832	0.0716	1.951	2.067	0.0688	1.880	1.989
5589.582	0.0579	1.604	1.701	0.0631	1.735	1.839	0.0645	1.771	1.877	0.0736	2.002	2.119
5590.343	0.0720	1.983	2.102	0.0616	1.697	1.799	0.0692	1.890	2.003	0.0709	1.933	2.046
Means:		1.889			1.884			1.938			2.019	
Plate:	L616 (1) Dec. 9, 9:12, E.S.T.			L616 (2) Dec. 9, 12:43, E.S.T.			L617 (1) Dec. 9, 12:52, E.S.T.			L617 (2) Dec. 9, 12:53, E.S.T.		
De L. on -C	$\alpha=0^\circ$	$\beta=7^\circ 2$	$\gamma=19^\circ 9$	$\alpha=0^\circ$	$\beta=7^\circ 2$	$\gamma=19^\circ 9$	$\alpha=0^\circ$	$\beta=7^\circ 2$	$\gamma=19^\circ 9$	$\alpha=0^\circ$	$\beta=7^\circ 2$	$\gamma=19^\circ 9$
	r=0.940	$\epsilon=0.266$	$\phi=0^\circ 1$	r=0.940	$\epsilon=0.266$	$\phi=0^\circ 1$	r=0.940	$\epsilon=0.266$	$\phi=0^\circ 1$	r=0.940	$\epsilon=0.266$	$\phi=0^\circ 1$
	$B_o=0^\circ 3$	$0.5318v = V$		$B_o=0^\circ 3$	$0.5318v = V$		$B_o=0^\circ 3$	$0.5318v = V$		$B_o=0^\circ 3$	$0.5318v = V$	
λ	d''	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
5586.991	0.0648	1.778	1.891	0.0605	1.668	1.774	0.0595	1.643	1.747	0.0651	1.785	1.899
5587.800	0.0591	1.633	1.737	0.0657	1.800	1.914	0.0644	1.767	1.879	0.0646	1.773	1.886
5588.084	0.0601	1.658	1.763	0.0636	1.747	1.858	0.0703	1.917	2.039	0.0732	1.991	2.118
5588.985	0.0613	1.691	1.799	0.0663	1.816	1.931	0.0595	1.643	1.747	0.0654	1.793	1.907
5589.582	0.0662	1.813	1.928	0.0710	1.935	2.058	0.0654	1.793	1.907	0.0652	1.788	1.902
5590.343	0.0658	1.803	1.918	0.0674	1.844	1.961	0.0698	1.905	2.026	0.0636	1.747	1.858
Means:		1.839			1.916			1.891			1.928	
Plate:	L618 (1) Dec. 9, 1:12, E.S.T.			L618 (2) Dec. 9, 1:14, E.S.T.			L619 (1) Dec. 9, 1:20, E.S.T.			L620 (1) Dec. 9, 1:35, E.S.T.		
De L. on -C	$\alpha=0^\circ$	$\beta=7^\circ 2$	$\gamma=19^\circ 9$	$\alpha=0^\circ$	$\beta=7^\circ 2$	$\gamma=19^\circ 9$	$\alpha=0^\circ$	$\beta=7^\circ 2$	$\gamma=19^\circ 9$	$\alpha=0^\circ$	$\beta=7^\circ 2$	$\gamma=19^\circ 9$
	r=0.940	$\epsilon=0.266$	$\phi=0^\circ 1$	r=0.940	$\epsilon=0.266$	$\phi=0^\circ 1$	r=0.940	$\epsilon=0.266$	$\phi=0^\circ 1$	r=0.940	$\epsilon=0.266$	$\phi=0^\circ 1$
	$B_o=-0^\circ 3$	$0.5318v = V$		$B_o=-0^\circ 3$	$0.5318v = V$		$B_o=-0^\circ 3$	$0.5318v = V$		$B_o=-0^\circ 3$	$0.5318v = V$	
λ	d''	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
5586.991	0.0669	1.831	1.947	0.0630	1.732	1.842	0.0584	1.615	1.718	0.0623	1.715	1.818
5587.800	0.0787	2.130	2.265	0.0644	1.767	1.879	0.0674	1.844	1.961	0.0664	1.819	1.929
5588.084	0.0754	2.047	2.177	0.0640	1.757	1.869	0.0678	1.854	1.972	0.0586	1.621	1.719
5588.985	0.0679	1.856	1.974	0.0685	1.872	1.991	0.0634	1.742	1.853	0.0655	1.796	1.904
5589.582	0.0670	1.833	1.950	0.0505	1.415	1.505	0.0782	2.118	2.253	0.0579	1.604	1.698
5590.343	0.0709	1.932	2.055	0.0608	1.676	1.783	0.0695	1.897	2.018	0.0688	1.880	1.993
Means:		2.061			1.812			1.963			1.844	

TABLE XV—RESULTS FROM OBSERVATIONS, 6 SPECTRUM LINES—Concluded

Plate:	L624 (1) Dec. 10, 1:02, E.S.T.			L624 (2) Dec. 10, 1:03, E.S.T.			L625 (1) Dec. 10, 1:10, E.S.T.			L627 (1) Dec. 12, 1:02, E.S.T.		
	$\alpha=0^\circ$ $r=0.940$ $B_o=-0.4$	$\beta=7^\circ 2'$ $\epsilon=0.266$ $0.5318v = V$	$\gamma=19^\circ 9'$ $\phi=0^\circ 1'$	$\alpha=0^\circ$ $r=0.940$ $B_o=-0.4$	$\beta=7^\circ 2'$ $\epsilon=0.266$ $0.5318v = V$	$\gamma=19^\circ 9'$ $\phi=0^\circ 1'$	$\alpha=0^\circ$ $r=0.940$ $B_o=-0.4$	$\beta=7^\circ 2'$ $\epsilon=0.266$ $0.5318v = V$	$\gamma=19^\circ 9'$ $\phi=0^\circ 1'$	$\alpha=0^\circ$ $r=0.939$ $B_o=-2^\circ 6$	$\beta=6^\circ 8'$ $\epsilon=0.267$ $0.5324v = V$	$\gamma=20^\circ 1'$ $\phi=0^\circ 1'$
λ	d'	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
De L. on -C	$\alpha=0^\circ$ $r=0.943$ $B_o=-0.4$	$\beta=7^\circ 2'$ $\epsilon=0.267$ $0.5301v = V$	$\gamma=19^\circ 4'$ $\phi=0^\circ 1'$	$\alpha=0^\circ$ $r=0.943$ $B_o=-0.4$	$\beta=7^\circ 2'$ $\epsilon=0.267$ $0.5301v = V$	$\gamma=19^\circ 4'$ $\phi=0^\circ 1'$	$\alpha=0^\circ$ $r=0.940$ $B_o=-0.4$	$\beta=7^\circ 2'$ $\epsilon=0.266$ $0.5318v = V$	$\gamma=19^\circ 9'$ $\phi=0^\circ 1'$	$\alpha=0^\circ$ $r=0.940$ $B_o=-0.4$	$\beta=7^\circ 2'$ $\epsilon=0.266$ $0.5318v = V$	$\gamma=19^\circ 9'$ $\phi=0^\circ 1'$
Means:		2.020				1.975				1.875		1.861
Plate:	L622 (1) Dec. 10, 12:32, E.S.T.			L622 (2) Dec. 10, 12:33, E.S.T.			L623 (1) Dec. 10, 12:42, E.S.T.			L623 (2) Dec. 10, 12:43, E.S.T.		
	$\alpha=0^\circ$ $r=0.943$ $B_o=-0.4$	$\beta=7^\circ 2'$ $\epsilon=0.267$ $0.5301v = V$	$\gamma=19^\circ 4'$ $\phi=0^\circ 1'$	$\alpha=0^\circ$ $r=0.943$ $B_o=-0.4$	$\beta=7^\circ 2'$ $\epsilon=0.267$ $0.5301v = V$	$\gamma=19^\circ 4'$ $\phi=0^\circ 1'$	$\alpha=0^\circ$ $r=0.940$ $B_o=-0.4$	$\beta=7^\circ 2'$ $\epsilon=0.266$ $0.5318v = V$	$\gamma=19^\circ 9'$ $\phi=0^\circ 1'$	$\alpha=0^\circ$ $r=0.940$ $B_o=-0.4$	$\beta=7^\circ 2'$ $\epsilon=0.266$ $0.5318v = V$	$\gamma=19^\circ 9'$ $\phi=0^\circ 1'$
λ	d'	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
De L. on -C	$\alpha=0^\circ$ $r=0.943$ $B_o=-0.4$	$\beta=7^\circ 2'$ $\epsilon=0.267$ $0.5301v = V$	$\gamma=19^\circ 4'$ $\phi=0^\circ 1'$	$\alpha=0^\circ$ $r=0.943$ $B_o=-0.4$	$\beta=7^\circ 2'$ $\epsilon=0.267$ $0.5301v = V$	$\gamma=19^\circ 4'$ $\phi=0^\circ 1'$	$\alpha=0^\circ$ $r=0.940$ $B_o=-0.4$	$\beta=7^\circ 2'$ $\epsilon=0.266$ $0.5318v = V$	$\gamma=19^\circ 9'$ $\phi=0^\circ 1'$	$\alpha=0^\circ$ $r=0.940$ $B_o=-0.4$	$\beta=7^\circ 2'$ $\epsilon=0.266$ $0.5318v = V$	$\gamma=19^\circ 9'$ $\phi=0^\circ 1'$
Means:		1.822				1.874				2.008		1.867
Plate:	L627 (2) Dec. 12, 1:03, E.S.T.			L628 (1) Dec. 12, 1:08, E.S.T.			L628 (2) Dec. 12, 1:09, E.S.T.			L629 (1) Dec. 12, 1:40, E.S.T.		
	$\alpha=0^\circ$ $r=0.939$ $B_o=-2^\circ 6$	$\beta=6^\circ 8'$ $\epsilon=0.267$ $0.5324v = V$	$\gamma=20^\circ 1'$ $\phi=0^\circ 1'$	$\alpha=0^\circ$ $r=0.939$ $B_o=-2^\circ 6$	$\beta=6^\circ 8'$ $\epsilon=0.267$ $0.5324v = V$	$\gamma=20^\circ 1'$ $\phi=0^\circ 1'$	$\alpha=0^\circ$ $r=0.939$ $B_o=-2^\circ 6$	$\beta=6^\circ 8'$ $\epsilon=0.267$ $0.5324v = V$	$\gamma=20^\circ 1'$ $\phi=0^\circ 1'$	$\alpha=0^\circ$ $r=0.939$ $B_o=-2^\circ 6$	$\beta=6^\circ 8'$ $\epsilon=0.267$ $0.5324v = V$	$\gamma=20^\circ 1'$ $\phi=0^\circ 1'$
λ	d'	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d''	$\frac{1}{2}v$	V	d'	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
De L. on -C	$\alpha=0^\circ$ $r=0.939$ $B_o=-2^\circ 6$	$\beta=6^\circ 8'$ $\epsilon=0.267$ $0.5324v = V$	$\gamma=20^\circ 1'$ $\phi=0^\circ 1'$	$\alpha=0^\circ$ $r=0.939$ $B_o=-2^\circ 6$	$\beta=6^\circ 8'$ $\epsilon=0.267$ $0.5324v = V$	$\gamma=20^\circ 1'$ $\phi=0^\circ 1'$	$\alpha=0^\circ$ $r=0.939$ $B_o=-2^\circ 6$	$\beta=6^\circ 8'$ $\epsilon=0.267$ $0.5324v = V$	$\gamma=20^\circ 1'$ $\phi=0^\circ 1'$	$\alpha=0^\circ$ $r=0.939$ $B_o=-2^\circ 6$	$\beta=6^\circ 8'$ $\epsilon=0.267$ $0.5324v = V$	$\gamma=20^\circ 1'$ $\phi=0^\circ 1'$
Means:		1.845				1.791				1.984		1.915

The order of the micrometer-settings on the spectrum lines in the measurements of these 68 observations was that used in many of the later observations containing 7 and 9 strips of spectrum. The settings are commenced on one of the outside strips of spectrum and carried through with 2 settings on each line in each strip, thus, top, middle, bottom, bottom, middle, top. If the "oil error" is present it will be detected, and the error in the measured displacement greatly reduced as compared to the method of making 4 settings on the middle strip followed by 2 settings on each of the outside strips. The difference between the measurements of the plate in the violet left and violet right positions will be small, and the mean of the two will be practically freed from the oil error if it be present. An inspection of the oil-error curves of motion of the plate with time, given in this Volume, Part I, p. 21, will make this clear, keeping in mind that the 6 settings involved required about 1 minute to make.

DISCUSSION OF RESULTS

Mean Velocity.—The mean velocities for the 32 observations on which 10 spectrum lines were measured, taken from Table XIV, are summarized in Table XVI, where the values for plate violet left and right are given together with the means of these. Thus, it is seen that the mean of the violet left and violet right measurements, 1.929 and 1.937 km. per sec., respectively, differ by only 0.008 km. per sec., a quantity so small that it may be assumed to be accidental, in other words, the oil error would seem to be practically eliminated from the mean measurements. The mean value of the equatorial velocity of rotation derived from the double measurement of 10 spectrum lines, of average intensity 3.9 and average chromospheric elevation 495 km., is 1.933 km. per sec. In Table XVII is a summary of mean velocities of the whole series of 68 plates

TABLE XVI—SUMMARY OF MEAN VELOCITIES, 32 OBSERVATIONS, 10 SPECTRUM LINES

Observation		V km./sec.			Observation		V km./sec.		
L	1910	(Left)	(Right)	Mean	L	1910	(Left)	(Right)	Mean
609 (1)	Dec. 6	1.938	1.926	1.932	618 (1)	Dec. 9	1.923	1.896	1.910
(2)	" 6	1.940	1.955	1.948	(2)	" 9	1.919	1.875	1.897
610 (4)	" 6	1.976	1.986	1.981	619 (1)	" 9	1.908	1.888	1.898
(5)	" 6	1.965	1.967	1.966	620 (1)	" 9	1.823	1.868	1.846
611 (1)	" 6	1.925	1.968	1.947	622 (1)	" 10	1.970	1.962	1.966
(2)	" 6	1.982	2.025	2.004	(2)	" 10	1.904	1.910	1.907
613 (1)	" 8	2.017	2.015	2.016	623 (1)	" 10	1.989	1.989	1.989
(6)	" 8	1.945	1.876	1.911	(2)	" 10	1.988	1.962	1.975
614 (1)	" 8	1.968	1.926	1.947	624 (1)	" 10	1.908	1.932	1.920
(2)	" 8	1.872	1.952	1.912	(2)	" 10	1.948	1.948	1.948
614a (1)	" 8	1.964	1.981	1.973	625 (1)	" 10	1.880	1.956	1.918
615 (1)	" 8	2.025	2.014	2.020	627 (1)	" 12	1.900	1.907	1.904
616 (1)	" 9	1.882	1.870	1.876	(2)	" 12	1.875	1.886	1.881
(2)	" 9	1.915	1.929	1.922	628 (1)	" 12	1.899	1.889	1.894
617 (1)	" 9	1.858	1.884	1.871	(2)	" 12	1.873	1.933	1.903
(2)	" 9	1.927	1.912	1.920	629 (1)	" 12	1.925	2.012	1.969
Means:							1.920	1.937	1.933

from 6 spectrum lines measured either violet left or right. In Table XV, the results for individual observations are given for the 32 observations only, L609 (1)–L629 (1), so that the measurements may be compared with the 10 line measurements of the same plates; while only the means for each plate, L600–L608, 4 to 6 observations on each plate, 36 observations in all, are given, to save printing space. In Table XVIII, the mean velocity for the series of 36 and 32 observations, and the combined series of 68 observations, along with the mean displacements and the derived velocities for the 6 spectrum lines, are given together with the mean observational quantities, since these vary little throughout the series. Thus, it is seen that the 32 observations, L609 (1)–L629 (1), using 6 spectrum lines of average intensity 2.8 and average chromospheric elevation 433 km., yield a mean value for the equatorial velocity of rotation of 1.923

TABLE XVII—SUMMARY OF MEAN VELOCITIES, 68 OBSERVATIONS, 6 SPECTRUM LINES

Observation			V km./sec.		Observation			V km./sec.	
L	1910		(Left)	(Right)	L	1910		(Left)	(Right)
600 (1)	Nov.	9	.....	1.991	608 (4)	Dec.	6	.....	1.877
(2)	"	9	.....	1.877	(5)	"	6	.....	1.970
(3)	"	9	.....	1.875	609 (1)	"	6	.....	1.984
(4)	"	9	.....	1.961	(2)	"	6	.....	1.914
(5)	"	9	.....	1.957	610 (4)	"	6	1.960	
601 (1)	"	9	1.953		(5)	"	6	1.930	
(2)	"	9	1.951		611 (1)	"	6	2.005	
(3)	"	9	1.912		(2)	"	6	2.013	
(4)	"	9	1.948		613 (1)	"	8	.....	1.954
(5)	"	9	1.915		(6)	"	8	.....	1.940
(6)	"	9	1.912		614 (1)	"	8	1.889	
602 (1)	"	9	.....	1.916	(2)	"	8	1.884	
(2)	"	9	.....	1.932	614a (1)	"	8	.....	1.938
(3)	"	9	.....	2.100	615 (1)	"	8	2.019	
(4)	"	9	.....	1.952	616 (1)	"	9	.....	1.839
(5)	"	9	.....	1.931	(2)	"	9	.....	1.916
(6)	"	9	.....	1.966	617 (1)	"	9	1.891	
603 (1)	"	27	1.953		(2)	"	9	1.928	
(2)	"	27	2.068		618 (1)	"	9	.....	2.061
(3)	"	27	1.809		(2)	"	9	.....	1.812
(4)	"	27	1.968		619 (1)	"	9	1.963	
(5)	"	27	1.891		620 (1)	"	9	.....	1.844
606 (1)	Dec.	5	.....	1.891	622 (1)	"	10	1.822	
(2)	"	5	.....	1.910	(2)	"	10	1.874	
(3)	"	5	.....	1.837	623 (1)	"	10	.....	2.008
(4)	"	5	.....	1.817	(2)	"	10	.....	1.867
607 (1)	"	5	1.834		624 (1)	"	10	2.020	
(2)	"	5	1.799		(2)	"	10	1.975	
(3)	"	5	1.862		625 (1)	"	10	.....	1.875
(4)	"	5	1.885		627 (1)	"	12	1.861	
(5)	"	5	1.869		(2)	"	12	1.845	
608 (1)	"	6	.....	1.894	628 (1)	"	12	.....	1.791
(2)	"	6	.....	1.950	(2)	"	12	.....	1.984
(3)	"	6	.....	1.922	629 (1)	"	12	1.915	
Means:								1.919	1.922

km. per sec., as compared with the value 1.933 km. per sec. noted above for the 10 spectrum lines. The other 36 observations yield a mean velocity of 1.918 km. per sec.; and the mean for the whole series of 68 observations is 1.920 km. per sec.

TABLE XVIII—SUMMARY OF MEAN DISPLACEMENTS AND DERIVED VELOCITIES FOR
6 SPECTRUM LINES, 36, 32, AND 68 OBSERVATIONS

Plates:	36 Observations			32 Observations			68 Observations		
	L600 (1) to L608 (5)			L609 (1) to L629 (1)			L660 (1) to 629 (1)		
	$\alpha = 0^\circ$	$\beta = 6^\circ 8$	$\gamma = 18^\circ 6$	$\alpha = 0^\circ$	$\beta = 7^\circ 1$	$\gamma = 19^\circ 5$	$\alpha = 0^\circ$	$\beta = 6^\circ 9$	$\gamma = 19^\circ 1$
De L. on -C	$r = 0.948$	$\epsilon = 0.268$	$\phi = 0^\circ 6$	$r = 0.942$	$\epsilon = 0.267$	$\phi = 0^\circ 1$	$r = 0.945$	$\epsilon = 0.268$	$\phi = 0^\circ 3$
	$B_0 = 1.98$	$0.5276v$	$= V$	$B_0 = 0.96$	$0.5306v$	$= V$	$B_0 = 0.96$	$0.5291v$	$= V$
λ	d	$\frac{1}{2}v$	V	d	$\frac{1}{2}v$	V	d	$\frac{1}{2}v$	V
	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.	mm.	km./sec.	km./sec.
5586.991	0.0660	1.810	1.910	0.0656	1.797	1.907	0.0658	1.804	1.909
5587.800	0.0662	1.813	1.912	0.0666	1.823	1.934	0.0664	1.818	1.923
5588.084	0.0652	1.789	1.887	0.0665	1.822	1.933	0.0658	1.804	1.910
5588.985	0.0673	1.838	1.939	0.0663	1.817	1.928	0.0668	1.829	1.934
5589.582	0.0664	1.823	1.923	0.0649	1.780	1.889	0.0657	1.801	1.906
5590.343	0.0671	1.834	1.937	0.0670	1.833	1.945	0.0670	1.834	1.942
Means:	0.0664	1.818	1.918	0.0662	1.812	1.923	0.0663	1.815	1.920
" 1, 4, 6:	0.0668	1.829	1.929	0.0663	1.816	1.927	0.0665	1.822	1.928
" 2, 3, 5:	0.0660	1.808	1.908	0.0660	1.808	1.919	0.0660	1.808	1.913
p.r. Single observation:			$\pm .043$			$\pm .047$			$\pm .045$
p.r. Mean:			$\pm .007$			$\pm .008$			$\pm .005$

Mean Velocities for Individual Spectrum Lines, and the Question of the Cause of Their Differences.—In Tables XIX and XX, are given summaries of the equatorial velocities of rotation, derived from individual spectrum lines, for the groups of 10 and 6 lines respectively. Groupings of the individual values with elevations and with different degrees of strengthening in the "flash" spectrum are given in the former table, and with elevations and intensities in the latter.

It is seen from Table XIX that for a range of elevations in the chromosphere from 600 to 350 km. the velocity of rotation is progressively lower from 1.943 km. per sec. to 1.906 km. per sec. This is rather surprising in view of the fact that for the $\lambda 4500$ observations (discussed in the preceding section) differences of about 1400 km. and 2000 km. made little difference in the rotational velocity of two groups of spectrum lines, and the slight difference found indicated the greater velocity for the lower level. One must therefore be skeptical of the interpretation that a difference of 250 km. in elevation would result in a difference of velocity of rotation of 0.037 km. per sec. in this $\lambda 5600$ region of the spectrum. By grouping the lines as to their relative strengthening in the flash spectrum another progression results, showing a difference of 0.024 km. per sec. in rotational velocity between lines greatly strengthened and those not strengthened or somewhat weakened in the flash. In Table XX, the group of 6 lines used in many later

TABLE XIX—SUMMARY OF THE MEAN VALUES OF THE EQUATORIAL VELOCITY OF ROTATION FOR 10 SPECTRUM LINES, 32 OBSERVATIONS, 1910

Sun				Chromo-sphere		Rotational velocity								
λ Rowland	λ I.A.	Element	Int.	Int.	Height	Mean	Heights in km.				Strength in flash			
							600	500	400	350	Strong	Medium	Weak	
\AA					km.	km./sec.	km./sec.	km./sec.	km./sec.	km./sec.	km./sec.	km./sec.	km./sec.	
5528.641	.420	Mg	8	8	400	1.945	.....	.....	1.945	.....	.....	.....	.....	1.945
5535.061	4.849	Fe ⁺	2	15	600	1.963	1.963	.....	.....	.....	1.963	.....	.....
5562.933	.718	Fe	2	2	350	1.906	.....	.....	.....	1.906	.....	.....	.....	1.906
5569.848	.633	Fe	6	7	600	1.938	1.938	.....	.....	.....	.....	.....	1.938	
5576.320	.101	Fe	4	6	500	1.931	.....	1.931	.....	.....	.....	.....	1.931	
5578.946	.731	Ni	1	4	500	1.937	.....	1.937	.....	.....	1.937	.....	.....
5586.991	.773	Fe	7	8	600	1.930	1.930	.....	.....	.....	.....	.....	1.930	
5588.985	.766	Ca	6	6	600	1.939	1.939	.....	.....	.....	.....	.....	.....	1.939
5590.343	.128	Ca	3	1	400	1.914	.....	.....	1.914	.....	.....	.....	.....	1.914
5593.961	.748	Ni	0	1d	400	1.930	.....	.....	1.930	.....	.....	.....	1.930	
Means:						1.933	1.943	1.934	1.930	1.906	1.950	1.932	1.926	

TABLE XX—SUMMARY OF THE MEAN VALUES OF THE EQUATORIAL VELOCITY OF ROTATION FOR 6 SPECTRUM LINES, 68 OBSERVATIONS, 1910

Sun				Chromosphere		Rotational velocity								
λ Rowland	λ I.A.	Element	Int.	Int.	Height	Mean	Heights in km.			Intensity				
							600	400	300	Strong	Weak			
\AA					km.	km./sec.	km./sec.	km./sec.	km./sec.	km./sec.	km./sec.	km./sec.	km./sec.	
5586.991	.773	Fe	7	8	600	1.909	1.909	.....	.....	.....	1.909	.....	.....
5587.800	.583	Fe	0	1	300	1.923	.....	.....	1.923	.....	.....	1.923	.....	1.923
5588.084	7.870	Ni	1	4	400	1.910	.....	1.910	.....	.....	.....	.....	.....	1.910
5588.985	.766	Ca	6	6	600	1.934	1.934	.....	.....	.....	1.934	.....	.....
5589.582	.368	Ni	0	1	300	1.906	.....	.....	1.906	.....	.....	1.906	.....	1.906
5590.343	.128	Ca	3	1	400	1.941	.....	1.941	.....	.....	1.941	.....	.....
Means:						1.920	1.922	1.926	1.915	1.928	1.913	.....	.....

rotation observations, and measured also in the artificial blends of centre and limb spectra, show the characteristic difference due to blended spectra in that the 3 strong lines yield an average velocity of 1.928 km. per sec., while the 3 weak lines have a mean value of 1.913 km. per sec. (An outline of results found in blended spectra has been given in the Introduction of Section 1, preceding.) The difference in velocity exhibited with elevation is not great enough to be significant for these 6 lines with a range of 300 km. in height. The conclusion must consequently be drawn that, in the main, the differences in velocity found for the different spectrum lines are due to the blended spectrum of haze, which is usually fairly bright in December.

In the results in Table XIX, a striking difference in velocity, 0.057 km. per sec., is seen for the lines $\lambda 5535$ and $\lambda 5562$, both of intensity 2, the former due to Fe^+ and the latter to Fe. The former line is greatly increased in intensity in the flash spectrum, relatively to the latter line. This difference in rotational velocity is surely not ascribable to the small difference of 250 km. in elevation. It may denote a real difference in velocity, but further work with these lines, particularly in blended spectra and with different degrees of haziness, is desirable.

Summary of the Determinations of the Equatorial Velocity of Rotation in 1909 and 1910.—The results of the measurements of the solar equatorial velocity in 1909 and 1910, the bridge years between the high values of preceding years and the low values of subsequent years, may be briefly outlined as follows:—

1. In 1909, 11 observations of poor quality at $\lambda 4250$ and $\lambda 4500$ yielded a mean value of the equatorial velocity of 1.94 km. per sec.
2. In 1910, 32 observations of fair quality at $\lambda 4500$ yielded a mean value of 1.950 km. per sec. for the equatorial velocity from the measurements of 12 spectrum lines made twice by each of two observers; while 46 observations of fair quality, 6 lines measured once for each observation by one observer, gave a mean value of 1.931 km. per sec.; and the mean of the 78 observations was 1.940 km. per sec.
3. In 1910, 32 observations of good quality at $\lambda 5600$ gave a mean value of 1.933 km. per sec. for the equatorial velocity derived from the measurement of 10 spectrum lines, twice for each observation, by one observer; and 68 observations of fair quality at $\lambda 5600$, 6 lines measured once for each observation, by one observer, yielded a mean equatorial velocity of 1.920 km. per sec.
4. The theory that increased velocity of rotation accompanies increased elevation in the solar atmosphere is not supported by the observations at $\lambda 4500$, but rather the reverse; while differences in velocity for different spectrum lines at $\lambda 5600$ are ascribable to the depressing influence of blended spectrum of terrestrial haze. A striking difference in velocity between an Fe^+ and an Fe line, both of intensity 2, may indicate a real difference in velocity of rotation, too great to be ascribed to the small difference in elevation of 250 km., though this difference may also be due to the blended spectrum of haze.

DOMINION OBSERVATORY,
OTTAWA,

June 1, 1936.

