Kodaikanal Observatory.

BULLETIN No. XXXII.

A NEW METHOD OF MEASURING SMALL DISPLACEMENTS OF SPECTRUM LINES.

In the course of measurement of many series of spectra photographed with the Kodaikanal grating spectrograph a new method of measuring suggested itself which seemed to give promise of appreciably reducing the accidental and systematic errors inherent in the ordinary method of bisecting a spectrum line with a straight spider thread.

The essence of the new method consists in placing a positive copy of the plate to be measured reversed, and almost in contact with the negative, film to film, and moving one with reference to the other so that the positive images are made to coincide successively with the negative images of the corresponding lines.

No spider thread is used, and the accuracy of the adjustment for coincidence depends on the sensitiveness of the eye in estimating the change from the bright and dark contiguous images of a line, to the perfectly uniform density which results when the positive image exactly coincides with the negative, and the positive copy has the same gradation of tone as the negative.

The delicacy of this adjustment is greater than might have been anticipated, and it is independent of the width of the lines. The displacement of the D lines for instance at the sun's limb due to the solar rotation can be measured almost, if not quite, as accurately as that of the much narrower lines of Fe etc. Experience has shown that given the same amount of training in the new method as in the old, the adjustment for coincidence of a positive and negative image of a solar line can be made with almost the same apparent accuracy as in bisecting the line with a thread. A good deal of course depends on the contrast in the original negative, and in the case of the sharply defined and very dense emission lines of the arc or spark spectrum the adjustment for coincidence can be made with greater accuracy than is possible in setting a thread central on the line.

The principal advantage claimed for the new method is in the reduction of the accidental errors by reason of the double intervals measured. It is in fact almost equivalent to doubling the linear dispersion of a plate without altering the width or definition of the lines. The method appears also to be entirely free from the large systematic bias which most observers become aware of when estimating displacements between the lines in an absorption spectrum and in a comparison spectrum of bright lines.

The detection of asymmetry in a spectrum line is of interest and importance in some researches. By the method of reversing a positive end for end on a negative the slightest want of symmetry is revealed, since the less refrangible edge of a line in the copy is superposed on the more refrangible edge of the negative and the condition of perfect uniformity of density when the centres coincide is destroyed if the edges of the line are not similar. This reversal end for end is not essential for the measurement of displacements and where the lines in a spectrum are thickly crowded, as in the violet and ultra violet solar spectrum, it is better to take the positive copy through the glass. It is then not necessary to reverse it end for end on the negative

The new method is applicable where the spectrum to be measured does not exceed 2–3 mm. in width with a comparison spectrum contiguous to it on one or both sides. It has been used successfully to measure the displacements between sun and arc spectra where the arc lines are impressed on both sides of the solar spectrum, and to solar spectra where the central strip represents the sun's limb and the side spectra represent the centre of the disc; also to solar rotation plates where east limb and west limb spectra form two contiguous strips, or east limb, centre of disc and west limb spectra form three contiguous strips.

Where the side spectra are the same as in the first two cases mentioned a positive copy may be taken in the ordinary way and reversed end for end on the negative and the lines brought successively into coincidence.

If there are only two contiguous spectra, or three dissimilar spectra, it is necessary to obtain a *reversed* positive to place on the negative. This may be done in several ways. A positive may be printed through the glass with parallel light, or without using a collimating lens, by exposing for a few seconds to a naked electric arc placed at a distance of not less than 50 feet, and screening the plate from scattered light. Another method is to take two contact copies in the ordinary way developing one as a positive, and reversing the other to a negative with ammonium persulphate or other bleaching agent. The negative so obtained can be used on the positive. A third method which I have found to be much the most satisfactory is to take a single copy of the original negative with a long focus photographic lens using a moderately fast plate and placing the negative with the glass side towards the lens. If the conjugate foci are made equal the positive can be used on the negative.

In many cases it is an advantage to enlarge the original about one and a half or two-fold In this case the procedure is as follows: an ordinary contact positive is made on a moderately fast plate and developed so that it has the same gradation of tone as the negative. The positive and the original negative are then copied with the enlarging camera, using lantern plates to increase the contrast In copying, the positive must be placed with the film side towards the lens, and the negative with the glass side towards the lens (or *vice versa*) care being taken to place the film in each case at precisely the same distance from the lens so that the scale of the two copies is the same. Very satisfactory results have been obtained by this method, the enlargement and increase of contrast being a distinct gain in measuring.

By the ordinary method of measuring I have found no advantage in enlarging a plate if the scale of the original is not less than one millimetre to the angstrom because the increased width of the spectrum lines in the copy and the more obtrusive irregularities of grain militate against the accurate bisection of a line with the spider thread With the new method neither the width of the lines nor the grain of the plate has very much effect on the accuracy of setting. With the spectrograph I have employed the scale of the original negatives is made as large as is consistent with reasonable exposure times. With a Rowland 3½-inch grating of 15,028 lines to the inch the scale ranges between 1·2 mm and 2·0 mm to the angstrom and these may be enlarged with advantage up to 3 or 4 mm. to the angstrom.

The photographically reversed positive may be placed on the negative film to film and either reversed end for end or not reversed. If the relative displacements between three different spectra are to be measured it must be so reversed, but for two spectra only it may be either way. When not reversed end for end the positive and negative images of all the lines on one spectrum come into coincidence simultaneously, and the entire spectrum assumes a uniform grey tint devoid of all details. In this way it is possible to obtain a generalized measurement of the displacements of all the lines of the two spectra by measuring the amount of movement required between the two plates in order to obtain this uniform tint, first in one spectrum and then in the other, half of this movement being equal to the mean displacement of the lines. A fairly accurate estimate of the mean result of a plate can in this way be made very rapidly.

In addition to the advantages already mentioned the following may also be claimed for the new method.

In measuring displacements of two contiguous spectra by the ordinary method a troublesome correction has to be applied for the inclination of the thread to the spectrum lines, this being determined by numerous subsidiary measures. This correction is entirely avoided by the new method if the spectrum lines may be assumed normal to the spectrum, for it is easy to adjust the positive and negative plates with the spectra exactly parallel to one another lengthwise so that the lines will also be parallel. With a properly designed slit the spectrograph may be accurately adjusted once for all to give spectra in which the lines are exactly normal to the spectrum.

In measuring with the photographically reversed positive so that the positive may be placed on the negative without reversing end for end, unsymmetrical lines may be measured with the same accuracy as symmetrical lines, which is far from being the case in bisecting with a thread; also with closely clustered lines such as occur in the violet and ultra violet part of the solar spectrum the measures can be made by groups instead of single lines, for all the lines of one spectrum disappear simultaneously when the positive and the negative are brought into coincidence. This group method eliminates accidental irregularities in the distribution of the silver grains which certainly affect the measures of individual lines to some extent by any method of measuring.

Finally the strain on the eyes seems to be less severe in estimating densities of line images of considerable width compared with the strain of concentrating attention on an exceedingly narrow thread and trying to place it central on a less well defined line image.

The following fairly obvious objections may be made to the method :—

(1) The extra time and trouble required in making suitable positives and in setting up the plates for measurement

(2) The possibility of new sources of error introduced in copying especially when copies are obtained through the glass.

(3) Errors due to a parallax effect caused by the distance separating the two films.

(4) Confusion resulting from the multiplication of images in the field of view of the microscope.

Objection (1) must be weighed against the increase of accuracy obtained. The extra trouble in setting up the plates for measurement may be largely mitigated by suitably designed apparatus.

With regard to (2) the experience of the writer is that no measurable distortion occurs in the lines of a spectrum in copying either by contact, or with a lens and through the glass. If such distortion does occasionally occur such errors may be treated as purely accidental.

(3) Errors due to a parallax effect become appreciable if the positive and negative plates are separated by intervals greater than ·5 mm.; with suitable apparatus however the plates can be brought to within 0·05 mm. if the upper plate is cut as small as possible.

(4) The confusion of images is sometimes rather baffling when the positive is reversed end for end on the negative. With experience in working the method this difficulty disappears.

Apparatus.

The accompanying drawing shows the essential features of the apparatus that has been used. A photograph of the micrometer with the apparatus attached is also given.

In the drawing P is a sliding brass plate 12 inches long × 2½ inches wide and having an opening or slot cut along the centre lengthwise about ½ inch wide and 6 inches long. Two strips of wood are screwed to the plate underneath, one on each side of the opening; these form the mounting to which the positive is gummed film downwards.

Above P is a flat piece of hard wood W, ¼ inch thick, 7 inches long, and the same width as P. This also has an opening cut in the centre. Brass angle pieces A_1 A_2 are screwed to the wood along the edges; these support and guide the sliding plate. The edges of P are ground straight and parallel, and the inner surfaces of A_1 are filed true. Between the angle piece A_2 and the edge of the sliding plate a long spring S, made of hard brass wire is inserted; this holds the plate against A_1 and makes the sliding movement smooth and easy. The outer edge of W, and consequently the inner surface of A_1, is made parallel to the ways of the micrometer. The positive being attached to the sliding parts can by this means be moved over the negative, which is fixed to the micrometer stage below, until the corresponding lines are near together; and this movement cannot disturb the adjustment for parallelism of the spectrum lines in the two photographs.

The wood W is attached to the moving carriage of the micrometer by two strong angle pieces made of ⅛ inch steel plate. One of these R is shown in the drawing. Each is connected to the wood by a screw passing through a hole in the steel made just large enough to allow the threads to pass freely through. A large nut with milled head N fits on each screw, and between the steel and the wood pieces of stout clock spring C are placed. By turning the nuts the springs are either compressed or released and the parts below are drawn up or forced down. The positive plate can in this way be raised or lowered and its inclination adjusted to parallelism lengthwise with the negative.

On each of the steel angle pieces there is also provided a screw with milled head T. This is screwed through the steel in the position shown, the end bearing on the clock spring; its function is to adjust the inclination of the positive laterally and bring it into parallelism with the negative.

By means of the two adjustments the surfaces of positive and negative are made parallel and brought as near together as the unevenness of the plates will allow, usually within $\frac{1}{20}$ mm. Two clamping screws, M, hold the entire apparatus to the sliding carriage of the micrometer. The holes in the vertical part of the steel connecting plates are slotted and by loosening M the whole may be raised or lowered through about 10 mm.

The microscope tube is shown in the upper part of the diagram its objective being at O, about 3 inches above the plates to be measured. The microscope has a magnifying power of 12 diameters and a large field of view so that a length of 12 mm. of spectrum may be seen.

Method of working.—The negative to be measured is securely fastened to the micrometer stage along its edges by two or more strong dog clips. The sliding plate P is withdrawn and the positive copy which is cut as narrow as possible is fastened to the wooden strips with photographic paste. A very suitable adhesive is Higgins vegetable glue as this is not too strong, and when completely dry the plate may be easily detached. Before the gum has set the spectrum is made central and parallel to the edges of the sliding plate. A few minutes are allowed for the gum to set, and before the plate with the positive attached is replaced in the slide the latter is raised to its highest point by loosening the clamps M The plate is then put in and the whole lowered until the positive rests on the negative, film to film; the clamps are then tightened and the nuts N are turned so as to raise the positive just clear of the negative, the screws T are also slightly turned to adjust the two surfaces parallel. In order to bring the positive and negative spectra into coincidence and parallel to one another lengthwise the negative is adjusted laterally. In the micrometer which has been used for this work the stage is provided with lateral movements which are a great convenience in making this last adjustment.

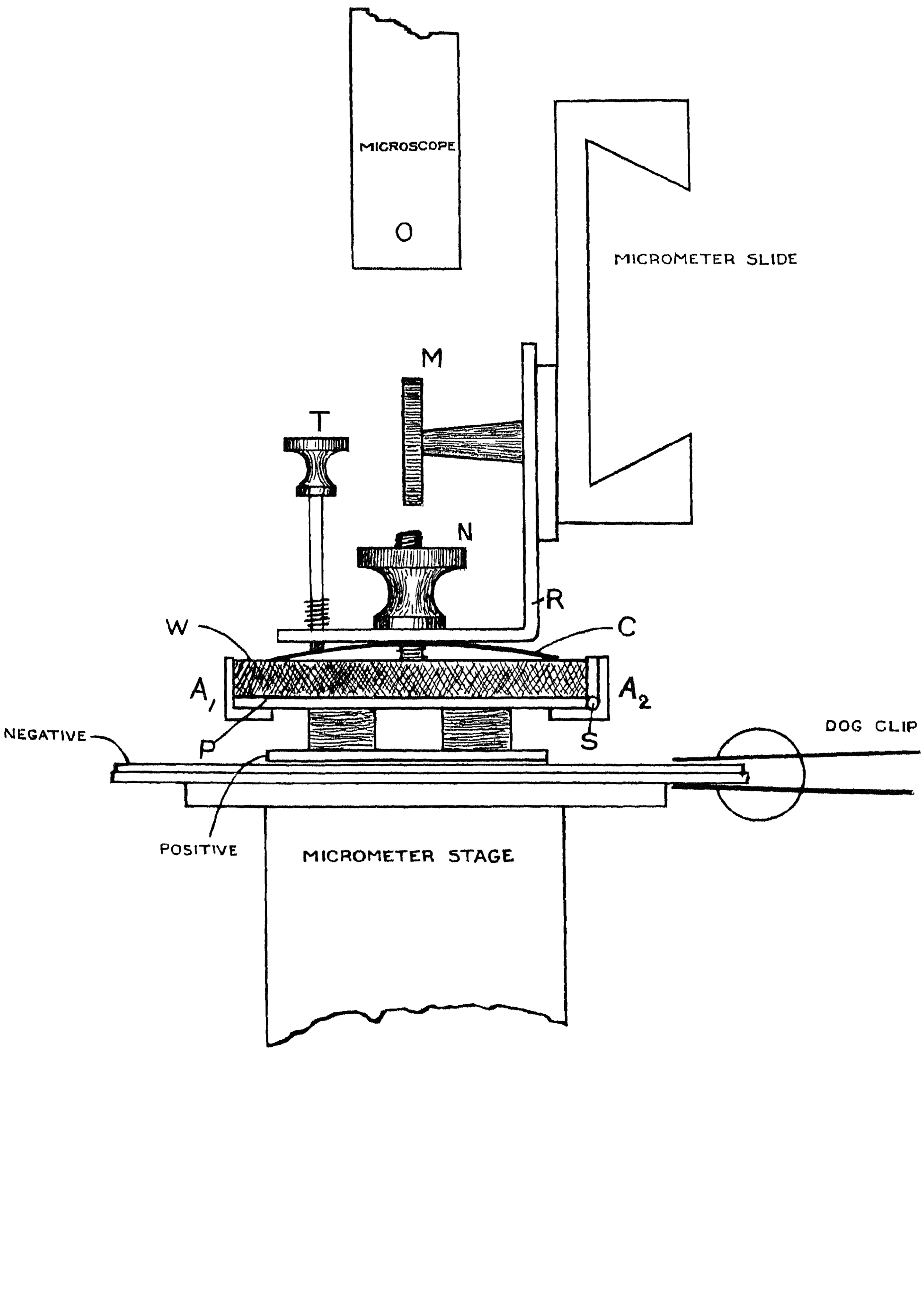
The positive may now be moved by hand over the negative until the corresponding lines in the two plates are near together in the field of view, it is then moved by the micrometer screw to get the successive coincidences of positive and negative images in the two spectra to be compared, the successive readings of the screw giving twice the interval separating the lines.

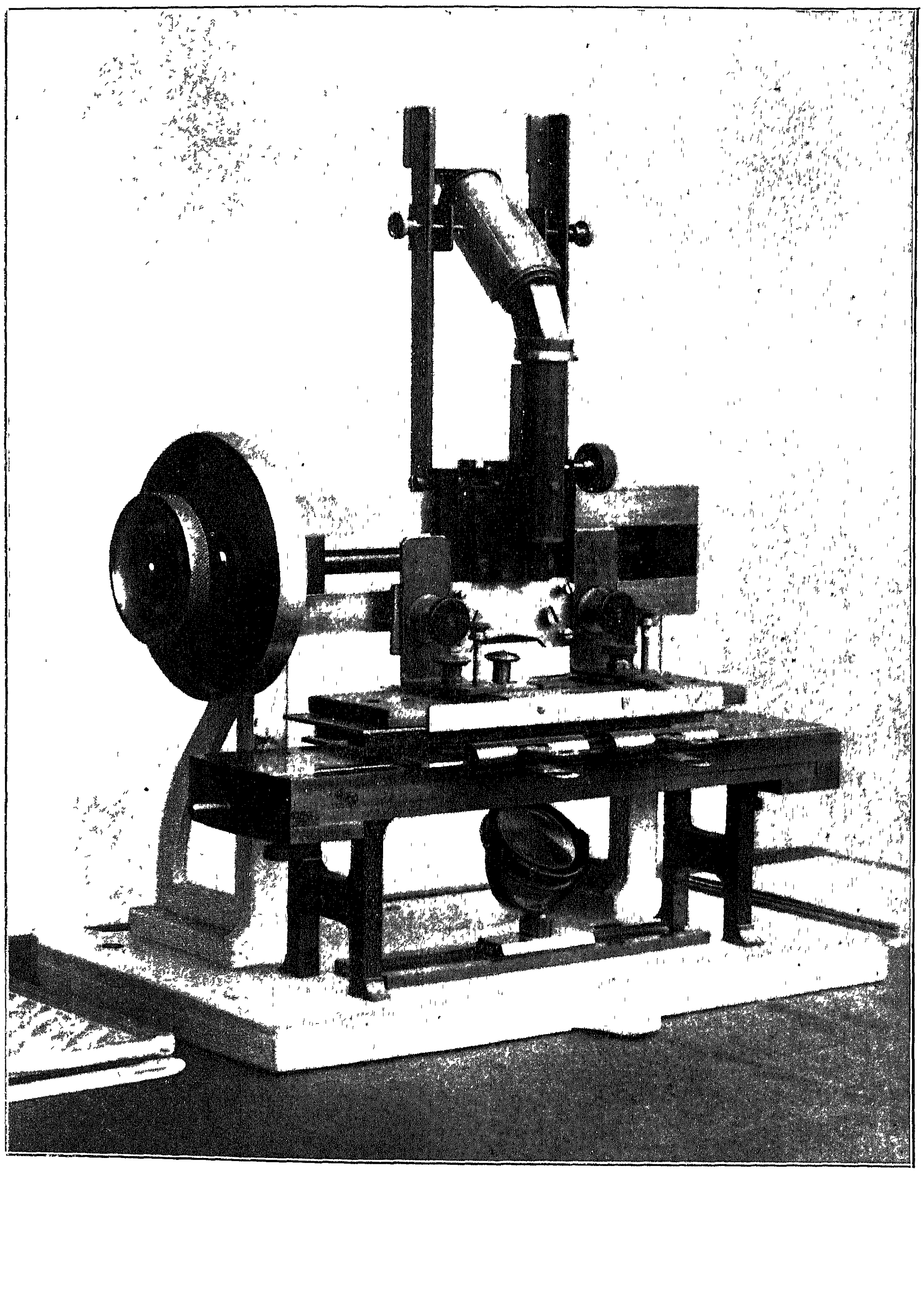
Results.

I give below two examples of measures made in the ordinary way and by the new method, to show the relative accuracy obtained. These represent two series of solar rotation plates. In the first series (example I) the exposures were made alternately on the sun's east and west limbs, the central strip of spectrum representing the west limb and the two side strips the east limb. An ordinary positive reversed end for end on the negative was used in the new method of measuring, the original negative being used for the ordinary measures. In the second series (example II) the exposures were made simultaneously on east and west limbs, these being represented by two contiguous strips of spectrum each 3 mm. in width. The original negative was used for the ordinary method of measuring, and copies enlarged 1·4 times for the positive on negative method.

I.—SOLAR ROTATION PLATE.

Date—February 28, 1911.		Alternate exposures—
Latitude (mean)	1°·4	centre strip west limb $\phi = 2°·1$.
Angle D	7°·2	side strips east limb $\phi = 0°·8$.
Correction to limb	$\frac{1}{30}$	


MICROSCOPE
O
MICROMETER SLIDE
M
T
N
R
W
C
A1
A2
P
S
NEGATIVE
DOG CLIP
POSITIVE
MICROMETER STAGE



Ordinary method.

λ	Direct.	Reversed.	Mean.	Factors	$\frac{\Delta\lambda}{2}$	Km/sec.	Residuals.
	mm.	mm.	mm.		Å		
6252 773 ..	·133	·128	·131	5553	·0363	1·74	− 1
6256·572 ..	·137	·138	·137	·5532	·0379	1 82	+ 7
6261·316 ..	·137	·123	·130	·5505	·0358	1·72	− 3
6265 348 ...	139	·137	·138	·5481	·0379	1 81	+ 6
6270·442 ..	·124	·135	130	·5454	·0354	1·69	− 6
6280·833 ...	·144	·135	·140	·5395	·0378	1·80	+ 5
6291·184 ...	·147	·137	·142	·5339	·0379	1·80	+ 5
6298 007	·137	·139	·138	·5301	·0367	1·75	0
6301·718 ...	·136	·136	·136	·5281	·0359	1·71	− 4
6302·709 .	32	131	·132	·5276	·0347	1·65	−10

Mean 1 749
Probable error . .. . ± ·012

Positive on negative method.

λ	Direct.	Reversed.	Half mean.	Factors.	$\frac{\Delta\lambda}{2}$	Km/sec.	Residuals.
	mm.	mm.	mm.		Å		
6252 773 ..	263	·251	·129	·5553	·0357	1·71	+ 1
6256 572 .	·261	251	·128	·5532	·0354	1 70	0
6261 316 ..	258	·253	·128	·5505	0352	1·69	− 1
6265 348	·253	·255	·127	·5481	·0348	1·66	− 4
6270 442 ..	·248	·260	·127	·5454	·0346	1·66	− 4
6280·833	·263	·265	·132	5395	0356	1·70	0
6291·184 .	·272	279	·138	·5339	0368	1·75	+ 5
6298 007	·276	270	·136	·5301	·0361	1·72	+ 2
6301 718 ..	·267	265	·133	·5281	0352	1 68	− 2
6302 709 ..	272	271	·136	·5276	·0358	1·71	+ 1

Mean ... ... 1·697
Probable error ... ... ± ·006

	Km/sec.
Mean result of plate giving equal weights	1·724
Correction to limb	+ ·057
Correction for secant of angle D	+ ·014
Correction to equator	+ ·001
Correction for earth's revolution	+ ·141
Sidereal velocity at equator .	1·937

II.—SOLAR ROTATION PLATE.

Date—May 22, 1913.	Simultaneous exposures. East and west strips contiguous.
Latitude . ... 8°·5	
Angle D . ... 1°·8	
Correction to limb . . ... $\frac{1}{38}$	

Ordinary method.

λ	Direct.	Reversed	Corrected mean *	Factors	$\frac{\Delta\lambda}{2}$	Km/sec.	Residuals.
	mm.	mm.	mm.		Å		
5560 434	115	·124	·117	·5840	·0340	1·84	+ 6
5562·933	·121	130	·123	5828	0358	1·93	+ 15
5565·931	·124	·126	·123	·5813	·0356	1·92	+ 14
5567·621	·110	·112	·108	·5805	·0314	1·69	− 9
5569 848	·118	118	115	·5793	0334	1 80	+ 2
5573 075	·120	116	·115	·5778	·0333	1 79	+ 1
5576 320	·116	·129	·120	5762	·0346	1·86	+ 8
5578 946	·115	·124	·117	5750	·0336	1 81	+ 3
5582·198	112	122	·114	·5733	·0328	1 76	− 2
5586 991	108	114	109	·5712	·0309	1 66	− 12
5588 985	·121	116	·116	5702	·0331	1 78	0
5590 343	116	·112	·111	·5695	·0317	1·70	− 8
5601 505	·120	113	·117	·5640	0330	1·76	− 2
5615·877	119	·118	116	·5571	·0308	1·64	− 14

Mean ... ... 1·782

Probable error ... ... ± ·016

* Correction for inclination of wire — ·0026 mm.

Positive on negative method (enlarged copies).

λ	Direct.	Reversed	Half mean.	Factors.	$\frac{\Delta\lambda}{2}$	Km/sec.	Residuals.
	mm.	mm.	mm		Å		
5560·434	·321	·315	·159	4172	0332	1·79	+ 1
5562·933	·326	·330	·164	4162	·0341	1·84	+ 6
5565·931	313	·330	161	4152	0334	1·80	+ 2
5567·621	322	315	·159	·4146	·0330	1·78	0
5569 848	·325	323	·162	·4138	·0335	1·80	+ 2
5573·075	·316	·327	·161	·4127	0332	1·79	+ 1
5576·320	·332	319	·163	·4116	·0335	1·80	+ 2
5578 946	332	299	158	4107	·0324	1·74	− 4
5582·198	·340	315	·164	·4095	·0335	1 80	+ 2
5586·991	·322	307	·157	·4078	·0320	1·72	− 6
5588·985	·324	·320	·162	·4072	0329	1·77	− 1
5590 343	315	314	157	·4067	0320	1·71	− 7
5601·505	335	330	·166	·4027	·0334	1 79	+ 1
5615·877	·331	·337	·167	·3977	0332	1·78	0

Mean ... . 1·779

Probable error .. .. ± ·006

	Km/sec.
Mean result of plate giving equal weights	1·780
Correction to limb	+ ·047
Correction for secant of angle D	+ ·0002
Correction to equator	+ ·034
Correction for earth's revolution	+ ·135
Sidereal equatorial velocity ...	1·996

The measures were made by myself and the same amount of care and attention was given to each method. The plates were first measured with the red end to the right hand and then reversed and the measures repeated. The results in fractions of a millimetre are given in the second and third column, and the means in the fourth column; halved in the case of the new method which measures the double interval. The column headed $\frac{\Delta\lambda}{2}$ gives the half interval in angstroms and this is converted into kilometres per second in the last column but one.

It is seen that the residuals are notably smaller in the case of the positive on negative measures, and the resulting probable error is half that derived from the ordinary measures in I, and less than half in II. Up to the present fourteen rotation plates have been measured by both methods and in all of these the residuals are smaller by the new method, the average probable error being ± ·015 km/sec. by the old method and ± ·009 km/sec by the new. This is a somewhat smaller difference between the methods than is shown above, but some of the earlier measures show larger probable errors which are doubtless due to inexperience in working the new method.

It will be noticed that in the first comparison there is a systematic difference amounting to nearly 3 per cent. in the mean results of the two methods. This is not easily explained, the inclination of the thread in the ordinary measures is in this case automatically allowed for in taking the mean readings of the two side spectra which are similar; and there appears to be no other source of systematic error. I can only suggest that personal bias affects one or other method, and I think it probable that the smaller values are the more correct. It is possible that in measuring in the ordinary way there is a tendency to exaggerate displacements even when, as in my own measures, a sliding mask is used to limit the field of view to one spectrum at a time. In all the rotation spectra I have measured in duplicate the old method gives larger values of the displacement than the new but there is often some uncertainty as to the correction for inclination of the thread. The average value of the sidereal velocity at the sun's equator from 14 plates is 1·946 km/sec. for the old method and 1·925 km/sec. for the new.

In example II the agreement of the mean results is very close but this is possibly accidental. The correction for inclination of the wire is determined by measuring the lines of the arc spectrum of iron impressed on the plates outside the solar spectra and in this plate only four arc lines are strong enough for measurement. The results given by these lines were not very consistent and the correction is therefore somewhat uncertain.

In measuring by either method the mean of five settings is taken as the reading for each line, and from the accordance of the individual settings the probable errors of the readings have been computed for all the lines in the two plates. The probable errors of the difference of readings, *i.e.*, the displacements were then derived for each line. The average probable error of a line derived in this way does not differ materially from that derived from the accordance of the different lines, as is shown below :—

Probable errors of a single line.

	By accordance of lines.	By accordance of settings.
No. 1 Ordinary method	± ·039 Km/sec.	± ·049 Km/sec.
„ Positive on negative	± ·019 „	± ·030 „
No. 2 Ordinary method	± ·050 „	± ·060 „
„ Positive on negative	± ·028 „	± ·023 „

The number of lines measured being 10 for No. 1 and 14 for No. 2 the probable errors of the mean results of the plates are—

Probable errors of mean results of plates.

	By accordance of lines	By accordance of settings.
No. 1 Ordinary method	± ·012 Km./sec.	± ·015 Km/sec.
„ „ Positive on negative	± ·006 „	± ·009 „
No. 2 Ordinary method	± ·016 „	± ·013 „
„ „ Positive on negative	± ·006 „	± ·007 „

For these plates therefore the probable error is about halved in the positive on negative measures as compared with the ordinary measures, and the gain in accuracy is about the same whichever way the probable errors are estimated.

The method has been found particularly useful in measuring the small displacements between the lines of the arc spectrum of iron and solar lines at the centre of the disc. In this case also enlargement of the original negative is advantageous. I give as an example a recently measured plate containing five iron lines. The positive and negative plates were enlarged from the original to a scale of 2·7 millimetres to the angstrom.

Date—March 26, 1912. Centre of sun's disc and Fe arc.

Hour angle of sun	24° 45′ east.	
Correction for orbital velocity of earth	+·485	Km/sec.
Correction for diurnal velocity of earth	−·191	„
Total correction = V = ...	+·294	„

λ	Direct	Reversed	Mean.	Factors	$\frac{\Delta\lambda}{2}$	Correction for V	⊙ — arc.
	mm.	mm	mm.		Å	Å	Å
4442 510	069	073	071	3720	·0132	− ·00436	+ 0088
4447·892	·103	·101	102	3711	·0189	− ·00136	+ 0145
4461 818	053	067	060	3687	·0111	− ·00437	+ ·0067
4466 727	·075	·079	·077	3678	0142	− ·00438	+ 0098
4494 738	·060	061	061	3639	·0110	− ·00441	+ ·0066

The different lines in this case show very different displacements, as is seen in the last column ⊙ — arc, it is not possible therefore to derive probable errors from the accordance of these as the differences are real. The average probable error for each displacement derived from the accordance of settings is ± ·0003 Å the greatest being ± 0005 Å and the least ± 0001 Å. The same mean result is got by a comparison of direct and reversed measures, taking account of the fact that the figures given in the 2nd, 3rd and 4th columns of the above table represent the double intervals.

The accuracy of settings for the arc lines is greater than for the solar lines, the mean probable error of an arc line from five settings being ± ·00018 Å and for a solar line ± 00024 Å. With the best arc lines the error does not exceed ± 0001 Å, which on the scale of the plate measured is equivalent to ·0003 mm. × 2 = ± ·0006 mm This extraordinary degree of precision may be easily attained by paying attention to certain details of manipulation both in taking the original photographs and in copying them. As the best results for unsymmetrical lines are got by photographically reversing the positive with reference to the negative and not reversing the spectrum end for end, it follows that the positive images on one side of the spectrum will be superposed on the negative images on the opposite side, and unless the images are of equal density on both sides the sensitiveness of the adjustment for coincidence will be greatly impaired. In taking the original photograph therefore care should be taken to ensure this equality of density. For direct current and a steady arc it is sufficient to reverse the poles during the exposure so that positive and negative poles change places with reference to the spectrograph slit, and an equal exposure is given in each position. This will also correct any very small change of wave-length which may be suspected in the radiation from positive or negative pole.

In making the positive and negative enlargements for measurement it is, as already mentioned, essential that both shall have the same gradation of tone; at any rate for the lines to be measured. In many cases the variation of density for the different lines is so great that it is difficult or not possible to obtain a positive which is the exact counterpart of the negative, but with ordinary care in development the positive may be made to exactly neutralise the negative for a large proportion of the lines. The "fit" of the plates may be tested immediately after fixing by sliding the positive on the negative film to film while wet, and holding up to the light. In measuring, good results cannot be obtained unless the movement of the micrometer is perfectly smooth and without appreciable "backlash". Ordinary spectrum micrometers leave very much to be desired in this respect, there is considerable friction in the gunmetal slide, and unless this is constantly attended to and cleaned the movement becomes irregular with much lost motion in parts of the slide where the oil has become thick, or dust has accumulated. The apparatus I have adapted for use with the micrometer is to be regarded as a preliminary makeshift, useful for ascertaining the possibilities of the method, I have little doubt that still greater accuracy could be attained if the micrometer were specially designed for the purpose It would be better for instance to have a fixed microscope and slide for the positive, and mount the negative on a carriage moving on wheels. With a practically frictionless movement the lost motion could be reduced to an infinitesimal amount and the wear on screw and nut would be greatly lessened.

KODAIKANAL,
29th July 1913.

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