

RESULTS OF MEASURES

MADE AT THE

ROYAL OBSERVATORY, GREENWICH,

UNDER THE DIRECTION OF

SIR W. H. M. CHRISTIE, K.C.B., M.A., D.Sc., F.R.S.,
ASTRONOMER ROYAL,

OF

PHOTOGRAPHS OF THE SUN

TAKEN AT

GREENWICH, IN INDIA, AND IN MAURITIUS,

IN THE YEAR

1904.

(EXTRACTED FROM THE GREENWICH OBSERVATIONS, 1904.)

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GREENWICH PHOTO-HELIOGRAPHIC RESULTS, 1904.

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ERRATA.

GREENWICH PHOTO-HELIOGRAPHIC RESULTS, 1904.

MEASURES OF POSITIONS AND AREAS OF SUN SPOTS AND FACULÆ, 1904.

Page.	Column.	Line.	
6	2	43	No. of Group, for 5164, read 5166.
9	2	6	Greenwich Civil Time, for 59°495, read 59°498.
12	2	15	Greenwich Civil Time, for 84°137, read 84°157.
14	1	29	Area of Faculæ, for 238, read 283.
		39	Total Area of Faculæ, for 953, read 998.
17	2	8	Greenwich Civil Time, for 118°531, read 118°538.
20	1	44	Area of Umbra, <i>dele</i> o. Area of Whole Spot, <i>dele</i> 11. Area of Faculæ, <i>dele</i> c. 46 Total Area of Whole Spots, for 205, read 194.
23	1	31	Greenwich Civil Time, for 155°078, read 155°478.
28	1	15	Distance from Centre, <i>dele</i> 0°554. Position Angle, <i>dele</i> 73°4. Longitude, <i>dele</i> 213°1. Latitude, <i>dele</i> +12°2. Area of Umbra, <i>dele</i> o. Area of Whole Spot, <i>dele</i> 5. 19 Total Area of Whole Spots, for 402, read 397.
39	Footnote.		Group 5315, for September 21-24, read September 20-24. Group 5318, for September 24-27, read September 24-October 2. Group 5318, <i>insert</i> The group is not seen on September 28, 29 or 30.
41	Footnote.		Group 5322, for October 6-16, read October 6-17. Group 5325, for October 9-20, read October 8-20.
46	Footnote.		Group 5351, for November 2-12, read November 1-12.
47	1	36	Area of Faculæ, for 191, read 125.
		37	Total Area of Faculæ, for 2760, read 2694.
48	Footnote.		Group 5362, for November 18-23, read November 18-26. Group 5362, <i>insert</i> The group is not seen on November 25. Group 5364, for November 20-December 1, read November 19-December 1.
49	2	18	No. of Group, for 5360, read 5362.
		19	No. of Group, for 5360, read 5362.
	Footnote.		Group 5365, for November 21-22, read November 21-24. Group 5365, <i>insert</i> The group is not seen on November 23. Group 5368, for November 25, read November 25-26.
51	Footnote.		Group 5383, for is broken up, read has broken up.
52	2	20	Area of Umbra, for 1, read 2.
		44	Total Area of Umbra, for 269, read 270.
55	Footnote.		Group 5400, for December 18-21, read December 17-21.

LEDGERS OF SUN SPOTS, 1904.

Page.	Group.	Date.	
61	5147	Jan. 10	Area of Umbra, for 2, read 0. Area of Whole Spot, for 8, read 0. Longitude, for 111°5, read ... Latitude, for +11°7, read ... Longitude from Central Meridian, for +22°8, read ...
			Means. Mean Area of Whole Spot, for 6, read 5. Mean Longitude of Group, for 110°80, read 110°63. Mean Latitude of Group, for +11°80, read 11°83.
71	5235	May 20	Area of Whole Spot, for 74, read 71. Means. Mean Area of Whole Spots, for 39, read 38.

GREENWICH PHOTO-HELIOGRAPHIC RESULTS, 1904.

INTRODUCTION.

§ 1. *Measures of Positions and Areas of Sun Spots and Faculae on Photographs taken at the Royal Observatory, Greenwich, at Dehra Dûn and at Kodaikânal Observatory in India, and at the Royal Alfred Observatory, Mauritius, in the year 1904; with the deduced Heliographic Longitudes and Latitudes.*

The photographs from which these measures were made were taken either at Greenwich; at Dehra Dûn, North-West Provinces, India; at Kodaikânal Observatory, Southern India; or at the Royal Alfred Observatory, Mauritius.

The photographs of the Greenwich series were taken either with the Thompson or with the Dallmeyer Photoheliograph. The Thompson Photoheliograph, which was in regular use for the greater part of the year, is a photographic refractor of 9 inches aperture, presented to the Royal Observatory by Sir Henry Thompson, which has been fitted with an enlarging doublet by Ross, and with a camera and shutter for rapid exposure so as to take photographs of the Sun on a scale of about 7.5 inches to the solar diameter. The Dallmeyer, which was used instead of the Thompson on 1904 February 22, 23 and 24, is an instrument used in the Transit of Venus expedition to New Zealand, which, as now adapted, gives a solar image of 8 inches diameter on the photographic plate.

The photographs have been taken throughout the year on gelatine dry plates, "Lantern" plates supplied by R. W. Thomas and Co. being used, with hydroquinone development.

The Indian photographs, which have been forwarded by the Solar Physics Committee to fill the gaps in the Greenwich series, were taken under the

superintendence of the Deputy Surveyor-General, Trigonometrical Survey of India, with a Dallmeyer Photoheliograph giving an image of the Sun nearly 8 inches in diameter. In the process adopted at Dehra Dûn, bromo-iodized collodion wet plates in connexion with iron development have been used, as well as "Lantern" dry plates.

The Mauritius photographs were taken under the superintendence of Mr. T. F. Claxton, Director of the Royal Alfred Observatory, Mauritius, with a Dallmeyer Photoheliograph, giving an image of the Sun about 8 inches in diameter. At the Mauritius Observatory bromo-iodized gelatine dry plates have been used with alkaline development.

Photographs of the Sun were taken at Greenwich on 211 days; Indian photographs on 139 days and Mauritius photographs on 11 days have been received from the Solar Physics Committee; and Professor C. Michie Smith has supplied two photographs taken at Kodaikânal Observatory with a Dallmeyer Photoheliograph to complete the total of 363 days for which there are either Greenwich, Indian, or Mauritius photographs of the Sun available for measurement in 1904.

The *first* column on each page contains the Greenwich civil time at which each photograph was taken, expressed by the day of the year and decimals of a day, reckoning from Greenwich mean midnight January 1d. 0h., and also by the day of the month (civil reckoning), which latter is placed opposite the total area of Spots and Faculæ for the day. The photographs taken at Dehra Dûn, in India, are distinguished by the letter I., those taken at Kodaikânal Observatory, India, by the letters KK., and those taken in Mauritius by the letter M.

The *second* column contains the initials of the two persons measuring the photograph; the initial on the left being that of the person who measured the photograph on the left of the centre of the measuring instrument, and that on the right being that of the person who measured on the right of the centre.

The following are the signatures of those persons who measured the photographs for the year 1904:—

E. W. Maunder	-	-	M	A. H. Smith	-	-	AS
R. Fowler	-	-	RF	C. F. Lait	-	-	CL

The *third* column gives the No. of the group, and the letter for the spot. The groups are numbered in order of their appearance.

The *next two* columns give the distance from the centre of the Sun in terms of the Sun's radius, and the position-angle from the Sun's axis, reckoned from the

Sun's north pole in the direction n , f , s , p , both results being corrected for the effects of astronomical refraction.

The measures of the photographs were made with a large position-micrometer specially constructed by Messrs. Troughton and Simms for the measurement of photographs of the Sun up to 12 inches in diameter. In this micrometer the photograph is held with its film-side uppermost on three pillars fixed on a circular plate, which can be turned through a small angle, about a pivot in its circumference, by means of a screw and antagonistic spring acting at the opposite extremity of the diameter. The pivot of this plate is mounted on the circumference of another circular plate, which can be turned by screw-action about a pivot in its circumference, 90° distant from that of the upper plate, this pivot being mounted on a circular plate with position-circle which rotates about its centre. By this means small movements in two directions at right angles to each other can be readily given, and the photograph can be accurately centred with respect to the position-circle. When this has been done, a positive eyepiece, having at its focus a glass diaphragm ruled with cross-lines into squares, with sides of one-hundredth of an inch (for measurement of areas), is moved along a slide diametrically across the photograph, the diaphragm being nearly in contact with the photographic film, so that parallax is avoided. The distance of a spot or facula from the centre of the Sun is read off by means of a scale and vernier to 1-250th of an inch (corresponding to 0.001 of the Sun's radius for photographs having a solar diameter of 8 inches). The position-angle is read off on a large position-circle which rotates with the photographic plate. The photograph is illuminated by diffused light reflected from white paper placed at an angle of 45° between the photograph and the plate below.

The following is the process of measurement of a photograph:—By means of the screws attached to the circular plates carrying the pillars which hold the photograph, the image of the Sun is centred as accurately as possible by rotation. The position-circle is then set to the readings 0° , 90° , 180° , and 270° in succession, and the scale readings taken for the two limbs. The scale being so adjusted that its zero coincides with the centre of rotation of the position-circle, the mean of the eight readings for the limb gives the mean radius of the Sun directly.

At the principal focus of the photoheliograph are two cross-spider-lines which serve to determine the zero of position-angles on the photograph.

The zero of position-angles for the Thompson and Dallmeyer Photoheliographs employed at Greenwich has been determined by the measurement of a plate which

has been exposed to the Sun's rays twice, with an interval of about 100 seconds between the two exposures, the instrument being firmly clamped. Two images of the Sun, overlapping each other by about a fifth part of the Sun's diameter, were therefore produced upon the plate, and the exposures having been so given that the line joining the cusps passed approximately through the centre of the plate, the inclination of the wires of the photoheliograph to this line was measured with the position-micrometer, and a small correction for the inclination of the Sun's path was then applied. The following tables give the correction for zero of position for the mean of the two wires as thus determined :—

Thompson Photoheliograph, to 1904 July 19.

Date, Greenwich Civil Time.			Correction for Zero.	Date, Greenwich Civil Time.			Correction for Zero.
d h			o /	d h			o /
1903	December	30. 11	+ 0. 10	1904	May	14. 13	+ 0. 27
1904	January	26. 12	+ 0. 19		June	4. 12	+ 0. 37
	February	10. 11	+ 0. 14			17. 11	+ 0. 23
	March	16. 11	+ 0. 23		July	1. 12	+ 0. 34
	April	2. 12	+ 0. 32			8. 11	+ 0. 30
		18. 15	+ 0. 20			19. 11	+ 0. 26

A correction of $+0^{\circ}.4$ for zero of position has been applied to all photographs taken with the Thompson Photoheliograph up to 1904 July 19.

New wires were inserted in the Thompson Photoheliograph on 1904 July 20.

Thompson Photoheliograph, from 1904 July 20.

Date, Greenwich Civil Time.			Correction for Zero.	Date, Greenwich Civil Time.			Correction for Zero.
d h			o /	d h			o /
1904	July	20. 11	+ 0. 38	1904	November	3. 12	+ 0. 22
		23. 10	+ 0. 37			21. 12	+ 0. 44
	August	3. 10	+ 0. 44			23. 12	+ 0. 29
		7. 14	+ 0. 45		December	2. 11	+ 0. 32
	September	15. 10	+ 0. 39			5. 13	+ 0. 37
		17. 10	+ 0. 39			12. 12	+ 0. 31
	October	4. 12	+ 0. 22	1905	January	26. 13	+ 0. 30

A correction of $+0^{\circ}.7$ for zero of position has been applied to all photographs taken with the Thompson Photoheliograph from 1904 July 20 to October 13, and a correction of $+0^{\circ}.6$ from October 14 to December 31.

The Thompson Photoheliograph was mounted on the tube of the 26-inch Thompson Photographic refractor throughout the year. The Thompson Photoheliograph is not fitted with a position-circle, and the position-angle of the wires, which are approximately parallel and perpendicular to the circle of declination, cannot be altered.

The Dallmeyer Photoheliograph was mounted on the equatorial stand belonging to it, which was erected on the terrace roof of the South Wing of the New Physical Observatory.

In the use at Greenwich of the Dallmeyer Photoheliograph the position-circle has usually been set to some convenient reading near that for zero, so that the wires are respectively very nearly parallel and perpendicular to the circle of declination, and a correction for zero of position of the photoheliograph for the mean of the two wires has been applied to the zero of the position-circle of the micrometer. The position-circle was set to the reading $354^{\circ}0$ throughout 1904.

The zero of the position-circle of the micrometer has been determined from the readings of the position-circle for the four extremities of the two wires. The resulting combined correction is applied to all position-circle readings for spots and faculæ, so as to give true position-angles.

In the use of the photoheliographs at Dehra Dûn and in Mauritius the position-circle has always been set to the zero as determined by allowing the diurnal motion to carry a spot or the Sun's limb along the horizontal wire, and the accuracy of the adjustment has been tested at short intervals. No correction for zero of position of the wires has therefore been applied for the reduction of the photographs taken in India or in Mauritius.

The uncorrected distance from the Sun's centre for spots and faculæ is read off directly to 1-250th of an inch by means of a scale and vernier, the zero of the scale of the new micrometer being adjusted to coincide with the centre of the instrument.

Two sets of measures of the Sun's limb and of spots and faculæ on each photograph have been taken, and the mean of the two sets adopted.

No correction has been applied to the photographs on account of distortion.

The correction for the effect of refraction has been thus found, the Sun's image

being assumed to be sensibly an ellipse. The refraction being sensibly $c \tan z$ where $c = \sin 57''.5 = \frac{1}{3600}$ nearly, and z is the apparent zenith-distance, we shall have—

$$\frac{\text{Vertical Diameter}}{\text{Horizontal Diameter}} = \frac{1 - c \sec^2 z}{1 - c} = 1 - c \tan^2 z;$$

and thus the effect of refraction will be to diminish any vertical ordinate y by the quantity $c \tan^2 z$. Resolving this along and perpendicular to the radius vector r , and putting v for the position-angle of the vertex, we have for δr and $\delta \theta$, the corrections to radius vector and position-angle for the effect of refraction—

$$\delta r = + c \cdot \tan^2 z \times r \cdot \cos^2 (\theta - v) = + c \cdot \tan^2 z \times r \times \frac{1 + \cos 2 (\theta - v)}{2},$$

$$\delta \theta = - c \cdot \tan^2 z \cdot \sin (\theta - v) \cdot \cos (\theta - v) = - c \cdot \tan^2 z \frac{\sin 2 (\theta - v)}{2}.$$

The quantity δr thus found is the correction, on the supposition that a horizontal diameter of the Sun is taken as the scale. But, as the mean of two diameters at right angles has been used, the scale itself requires the correction $\delta R = + c \cdot \tan^2 z \times R \times \frac{1}{2} \left\{ \frac{1 + \cos 2 (\theta_0 - v)}{2} + \frac{1 + \cos 2 (\theta_0 + 90^\circ - v)}{2} \right\} = + \frac{1}{2} c R \cdot \tan^2 z$, where R is the Sun's mean radius and $\theta_0, \theta_0 + 90^\circ$ the position-angles of the two diameters measured. Thus the final correction to r becomes—

$$\delta r = + c \cdot \tan^2 z \times r \times \frac{\cos 2 (\theta - v)}{2}.$$

The quantities $c \tan^2 z$, $-\frac{\sin 2 (\theta - v)}{2}$, and $\frac{\cos 2 (\theta - v)}{2}$ have been tabulated for use as follows, $c \tan^2 z$ being expressed in circular measure and in arc for application to distances and position-angles respectively:—

$c \tan^2 z$.

z .	In Circular Measure.	In Arc.	z .	In Circular Measure.	In Arc.	z .	In Circular Measure.	In Arc.
°		'	°		'	°		'
80	.0089	31	70	.0021	7	60	.0008	3
79	.0073	25	69	.0019	6½	58	.0007	2
78	.0061	21	68	.0017	6	56	.0006	2
77	.0052	18	67	.0015	5½	54	.0005	2
76	.0045	15	66	.0014	5	52	.0005	2
75	.0039	13	65	.0013	4½	50	.0004	1
74	.0034	11½	64	.0012	4	45	.0003	1
73	.0030	10	63	.0011	4	40	.0002	1
72	.0026	9	62	.0010	3	30	.0001	0
71	.0023	8	61	.0009	3			

Factors for Refraction.

$\theta - v$	$\theta - v$	$\frac{\sin 2(\theta - v)}{2}$	$\frac{\cos 2(\theta - v)}{2}$	$\theta - v$	$\theta - v$	$\frac{\sin 2(\theta - v)}{2}$	$\frac{\cos 2(\theta - v)}{2}$
0	0			0	0		
5	180	·00	+ ·50	90	270	·00	- ·50
10	185	- ·09	+ ·49	95	275	+ ·09	- ·49
15	190	- ·17	+ ·47	100	280	+ ·17	- ·47
20	195	- ·25	+ ·43	105	285	+ ·25	- ·43
25	200	- ·32	+ ·38	110	290	+ ·32	- ·38
30	205	- ·38	+ ·32	115	295	+ ·38	- ·32
35	210	- ·43	+ ·25	120	300	+ ·43	- ·25
40	215	- ·47	+ ·17	125	305	+ ·47	- ·17
45	220	- ·49	+ ·09	130	310	+ ·49	- ·09
50	225	- ·50	·00	135	315	+ ·50	·00
55	230	- ·49	- ·09	140	320	+ ·49	+ ·09
60	235	- ·47	- ·17	145	325	+ ·47	+ ·17
65	240	- ·43	- ·25	150	330	+ ·43	+ ·25
70	245	- ·38	- ·32	155	335	+ ·38	+ ·32
75	250	- ·32	- ·38	160	340	+ ·32	+ ·38
80	255	- ·25	- ·43	165	345	+ ·25	+ ·43
85	260	- ·17	- ·47	170	350	+ ·17	+ ·47
90	265	- ·09	- ·49	175	355	+ ·09	+ ·49
	270	·00	- ·50	180	360	·00	+ ·50

The position-angle of the vertex v is readily taken from a globe.

The distance from centre in terms of the Sun's radius given in the *fourth* column is then readily found by dividing the measured distance r_0 , as corrected for refraction, by the measured mean radius of the Sun, R ; and the position-angle from the Sun's axis given in the *fifth* column is obtained by applying to the position-angle (from the N. point) corrected for refraction the position-angle of the Sun's axis derived from the *Auxiliary Tables for determining the Angle of Position of the Sun's Axis, and the Latitude and Longitude of the Earth referred to the Sun's Equator*, by Warren De La Rue, F.R.S.

The *sixth* and *seventh* columns give the heliographic longitude and latitude of the spot, which are thus computed.* Let r be the measured distance of a spot from the centre of the Sun's apparent disk, R the measured radius of the Sun on the photograph, (R) the tabular semidiameter of the Sun in arc, and ρ, ρ' the angular distances of a

* "Researches on Solar Physics: Heliographical Positions and Areas of Sun Spots observed with the Kew Photoheliograph during the years 1862 and 1863," by W. De La Rue, B. Stewart, and B. Loewy. *Phil. Trans.*, 1869.

spot from the centre of the apparent disk as viewed from the Sun's centre and from the Earth respectively. Then we have—

$$\rho' = \frac{r}{R}(R); \text{ and } \sin(\rho + \rho') = \frac{r}{R},$$

$$\text{whence } \rho = \sin^{-1} \frac{r}{R} - \rho'.$$

Log. $\sin \rho$ and log. $\cos \rho$, as computed from this formula, are given in *Tables for the Reduction of Solar Observations No. 2*, by Warren De La Rue, F.R.S. Then, if D , λ are the heliographic latitudes of the Earth and the spot respectively, referred to the Sun's equator, and L , l the heliographic longitudes reckoned from the ascending node of the Sun's equator on the ecliptic, and χ the position-angle from the Sun's axis, we have by the ordinary equations of spherical trigonometry—

$$\sin \lambda = \cos \rho \sin D + \sin \rho \cos D \cos \chi$$

$$\sin(L - l) = \sin \chi \sin \rho \sec \lambda.$$

The quantities L and D are derived from Warren De La Rue's *Auxiliary Tables* before referred to, in the computation of which the following formulæ have been used—

$$\tan L = \cos I \tan(\odot - N)$$

$$\sin D = \sin I \sin(\odot - N)$$

where I is the inclination of the Sun's equator to the ecliptic, N the longitude of the ascending node, and \odot the longitude of the Sun.

The position-angle χ is given by the formula—

$$\chi = P + G + H$$

where P is the position-angle from the north point of the Sun, and G and H two auxiliary angles given by the formulæ—

$$\tan G = \tan \omega \cos \odot$$

$$\tan H = \tan I \cos(\odot - N)$$

where ω is the obliquity of the ecliptic.

It will be seen that G is the inclination of two planes through the line joining the centres of the Earth and Sun passing through the poles of the Earth and of the ecliptic respectively, and that H is the inclination of two planes through the same line and the poles of the Sun and of the ecliptic. The values assumed for I , N , ω in the computation of the tables are $7^{\circ}.15'$, $74^{\circ}.25'$, and $23^{\circ}.27'.5$ respectively.

The heliographic longitude of the spot is found from l , the heliographic longitude from node, by subtracting the reduction to the prime meridian, which is the longitude of the node at the epoch of the photograph, referred to the assumed prime meridian, the latter being the meridian which passed through the ascending node at mean noon, 1854 Jan. 1. The period of rotation assumed is 25.38 days.

The heliographic longitude and latitude of the centre of the Sun's disk at the time of the exposure of each photograph are also given (in brackets) in the *sixth* and *seventh* columns respectively. The longitude of the centre of the disk is found by subtracting the reduction to the prime meridian from L , the longitude of the centre from the node. The latitude of the centre is of course the same as D , the heliographic latitude of the Earth.

The measures of areas given in the *last three* columns were made with a glass diaphragm ruled into squares, with sides of one-hundredth of an inch, and placed as nearly as possible in contact with the photographic film. The integral number of squares and parts of a square contained in the area of a spot or facula was estimated by the observer, two independent sets of measures being made by two observers. The mean of the two sets of measures has been taken for each photograph. The factor for converting the areas, as measured in ten-thousandths of a square inch, into millionths of the Sun's visible hemisphere, allowing for the effect of foreshortening, has been inferred by means of a table of double entry, giving the equivalent of one square for different values of the Sun's radius, and for different distances of the spot or facula from the Sun's centre as measured by means of the position-micrometer.

The individual spots in a group have in some cases not been measured separately, but combined into a cluster of two or three small spots close together, the position of the centre of gravity and the aggregate area of the cluster being given. The actual number of individual spots is usually stated in the notes.

§ 2. *Ledgers of Areas and Heliographic Positions of Groups of Sun Spots deduced from the measurement of the Solar photographs for each day in the year 1904.*

In these ledgers the daily results for each group are collected together from the measures of the individual spots and given in a condensed form. The first column gives, for each day on which the group was observed, the Greenwich civil time at which each photograph was taken, expressed by the day of the month (civil reckoning) and the decimals of a day reckoning from Greenwich mean midnight. The second and third columns give the sums, for each day, of the projected areas of all the umbrae and whole spots comprised in the group, the projected area being the area as

it is measured upon the photograph, uncorrected for foreshortening, and expressed in millionths of the Sun's apparent disk. The fourth and fifth columns give the sums for each day of the areas of all the umbrae and whole spots comprised in the group, corrected for foreshortening, and expressed in millionths of the Sun's visible hemisphere. The sixth and seventh columns give the mean longitude and latitude of the group, found by multiplying the longitude and latitude of each separately measured component of the group by its area, and dividing the sum of the products by the sum of the areas. The last column gives the mean longitude of the group from the central meridian, and is found by subtracting the longitude of the centre of the disk from the mean longitude of the group. At the foot of these daily results for each group are given the mean areas of umbrae and whole spots and the mean longitude and latitude for the period of observation.

§ 3. *Total Projected Areas of Sun Spots and Faculae for each day, and Mean Areas and Mean Heliographic Latitude of Sun Spots and Faculae for each Rotation of the Sun, and for the year 1904.*

This section requires no further explanation.

W. H. M. CHRISTIE.

Royal Observatory, Greenwich.

1905 December 23.

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