GREENWICH

PHOTO-HELIOGRAPHIC

RESULTS.

1909. Dir

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.

AND EDITED BY

F. W. DYSON, M.A., F.R.S.,
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OF

PHOTOGRAPHS OF THE SUN

TAKEN

AT GREENWICH AND IN INDIA

IN THE YEAR

1909.

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ERRATA.

GREENWICH PHOTO-HELIOGRAPHIC RESULTS, 1909.

Measures of Positions and Areas of Sun Spots and Faculæ, 1909.

Page.	Column.	Line.	
5	1	14	No. of Group, *for* 6600, *read* 6600*.
	Footnote.		*Insert* Group 6600*, January 14. A small spot, *sf* the place of Group 6600.
	Footnote.		Group 6602, *for* January 15–26, *read* January 14–26.
7	Footnote.		*Insert* Probably a revival of Groups 6598.
21	Footnote.		*Insert p* Group 6645, and with it a return of Group 6625.
30	Footnote.		Group 6663. *Insert* Return of Group 6651.
63	1	40 and 4	No. of Group, *for* 6757, *read* 6757.*
70	2	13	Greenwich Civil Time, *for* 337·554, *read* 337·544.
74	Footnote.		Group 6796, *for* January 9, *read* January 8.

Ledgers of Sun Spots, 1909.

Page.	Group.		
89	6663	Headnote.	*Insert* Return of Group 6651.

GREENWICH PHOTO-HELIOGRAPHIC RESULTS, 1909.

INTRODUCTION.

§ 1. *Measures of Positions and Areas of Sun Spots and Faculæ on Photographs taken at the Royal Observatory, Greenwich, at Dehra Dûn and at the Kodaikánal Observatory in India, and at the Royal Alfred Observatory, Mauritius, in the year* 1909 ; *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; or at the Kodaikánal Observatory, Southern India.

The photographs of the Sun, taken at Greenwich, were taken either with the Thompson or with the Dallmeyer Photoheliograph. The Thompson Photoheliograph, which was in regular use throughout 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 has been occasionally used as well as the Thompson—is an instrument used in the Transit of Venus expedition to New Zealand, which, as now adapted, gives a solar image of nearly 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 & Co. being used, with hydroquinone development.

The photographs from Dehra Dûn, 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; and the Kodaikánal photographs were taken under the superintendence of Professor C. Michie Smith, Director of that Observatory. At each observatory the instrument employed was a Dallmeyer Photoheliograph giving an image of the Sun about 8 inches in diameter. The plates and development used have been much the same at each of the three collaborating observatories.

Photographs of the Sun were available for measurement upon each day in 1909, except August 1, the photographs finally selected for measurement being supplied by the different observatories as under :—

Greenwich	172
Dehra Dûn	176
Kodaikánal	16
Total	364
Days Unrepresented	1
Total	365

The following are the signatures of those persons who measured the photographs for the year 1909 :—

E. W. Maunder - -	M	C. F. Lait - - -	CL
A. H. Smith - - -	AS	F. A. Saville - - -	FS

At the principal focus of the photoheliographs 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 Kodaikánal Photoheliographs 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 table gives the correction for zero of position for the mean of the two wires as thus determined :—

Thompson Photoheliograph.

Date, Greenwich Civil Time.			Correction for Zero.	Date, Greenwich Civil Time.			Correction for Zero.
		d h	° ′			d h	° ′
1908	December	28. 11	+ 0. 8	1909	July	2. 12	− 0. 7
1909	January	7. 11	+ 0. 6			19. 10	− 0. 10
		20. 12	+ 0. 12		August	4. 16	− 0. 4
		30. 11	− 0. 7			21. 12	− 0. 4
	February	12. 12	− 0. 2			27. 10	− 0. 6
	March	5. 12	+ 0. 4		September	15. 15	+ 0. 11
	April	3. 11	− 0. 3		October	8. 15	+ 0. 17
		17. 12	+ 0. 1		November	2. 11	− 0. 6
	May	1. 10	+ 0. 2			18. 10	− 0. 9
		11. 12	− 0. 1		December	3. 10	− 0. 20
		28. 12	− 0. 4			20. 11	− 0. 1
	June	16. 12	− 0. 6	1910	January	10. 13	+ 0. 15

Kodaikánal Photoheliograph.

Date, Greenwich Civil Time.			Correction for Zero.	Date, Greenwich Civil Time.			Correction for Zero.
		d h	° ′			d h	° ′
1909	January	5. 4	+ 0. 6	1909	July	20. 3	+ 0. 4
		21. 4	+ 0. 7		August	5. 3	− 0. 10
	February	4. 3	− 0. 7			18. 3	+ 0. 13
	May	11. 4	− 0. 6		September	9. 3	− 0. 1
		26. 3	+ 0. 5		December	3. 4	− 0. 2
	June	10. 3	+ 0. 18			16. 3	+ 0. 5
		29. 3	− 0. 11	1910	January	7. 3	− 0. 8

The wires in the Dehra Dûn Photoheliograph have been approximately parallel and perpendicular to the circle of declination throughout the year; their adjustment being usually tested by stopping the driving clock immediately after a photograph has been taken, and making a second exposure some two minutes after the first, so that a portion of a second image of the Sun, just intersecting the first, is obtained upon the plate.

No correction for zero of position has been applied to any of the photographs taken throughout the year 1909.

The Thompson Photoheliograph was mounted on the tube of the 26-inch Thompson Photographic refractor throughout the year. It 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 *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 Greenwich are distinguished by the letter G, those taken at Dehra Dûn, in India, by the letter D, and those taken at Kodaikánal Observatory, India, by the letter K.

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 *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.

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.

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 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 $c = \sin 57''\cdot 5 = \frac{1}{3600}$ 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—

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

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

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

$$\delta \mathrm{R} = + c \,.\, \tan^2 z \times \mathrm{R} \times \tfrac{1}{2} \left\{ \frac{1 + \cos 2\,(\theta_0 - v)}{2} + \frac{1 + \cos 2\,(\theta_0 + 90^\circ - v)}{2} \right\} = + \tfrac{1}{2}\, c\, \mathrm{R} \,.\, \tan^2 z,$$

where R is the Sun's mean radius and θ_0, $\theta_0 + 90^\circ$ the position-angles of the two diameters measured. Thus the final correction to r becomes—

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

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	180	·00	+ ·50	90	270	·00	− ·50
5	185	− ·09	+ ·49	95	275	+ ·09	− ·49
10	190	− ·17	+ ·47	100	280	+ ·17	− ·47
15	195	− ·25	+ ·43	105	285	+ ·25	− ·43
20	200	− ·32	+ ·38	110	290	+ ·32	− ·38
25	205	− ·38	+ ·32	115	295	+ ·38	− ·32
30	210	− ·43	+ ·25	120	300	+ ·43	− ·25
35	215	− ·47	+ ·17	125	305	+ ·47	− ·17
40	220	− ·49	+ ·09	130	310	+ ·49	− ·09
45	225	− ·50	·00	135	315	+ ·50	·00
50	230	− ·49	− ·09	140	320	+ ·49	+ ·09
55	235	− ·47	− ·17	145	325	+ ·47	+ ·17
60	240	− ·43	− ·25	150	330	+ ·43	+ ·25
65	245	− ·38	− ·32	155	335	+ ·38	+ ·32
70	250	− ·32	− ·38	160	340	+ ·32	+ ·38
75	255	− ·25	− ·43	165	345	+ ·25	+ ·43
80	260	− ·17	− ·47	170	350	+ ·17	+ ·47
85	265	− ·09	− ·49	175	355	+ ·09	+ ·49
90	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. This position-angle of the Sun's axis from the North point is also given (in brackets) in the *fifth* column.

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 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 ρ and log. cos ρ, 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 the heliographic longitude of the spot from the solar meridian passing through the centre of the disk, longitudes west of the centre being reckoned as positive, and χ the position-angle from the Sun's axis, we have by the ordinary equations of spherical trigonometry—

$$\sin\lambda = \cos\rho \sin D + \sin\rho \cos D \cos\chi$$
$$\sin l = -\sin\chi \sin\rho \sec\lambda.$$

The position-angle χ is found from the position-angle from the North Point by subtracting from it algebraically, P, the position-angle of the N end of the Sun's axis, measured eastward from the North Point of the disk. The heliographic longitude of

* "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.

the spot is found from l, its heliographic longitude from the Central Meridian, by adding l algebraically to L, the heliographic longitude of the centre of the disk. The three quantities P, D, and L for the time of the exposure of each photograph are derived from the Ephemeris for Physical Observations of the Sun given on p. 20 of the *Appendix* to the *Nautical Almanac* for 1909, and are printed (in brackets) in the *fifth*, *sixth*, and *seventh* columns respectively. D, the heliographic latitude of the Earth, is of course the same as the latitude of the centre of the Sun's disk.

The inclination of the Sun's axis to the ecliptic is assumed to be 82° 45′, the longitude of the ascending node for 1909·0 to be 74° 29′·4, and the period of the Sun's sidereal rotation to be 25·38 days; the meridian which passed through the ascending node 1854 January 1, Greenwich Mean Noon, being taken as the zero meridian.

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 many cases not been measured separately, but combined into a cluster of several small spots close together, the position of the centre of gravity and the aggregate area of the cluster being given.

§ 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* 1909.

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 column indicates by the initial letter of the observatory, the place where the photograph was taken; the letters G, D, and K standing for Greenwich, Dehra Dûn, and Kodaikánal respectively. The third and fourth columns give the sums, for each day, of the projected areas of all the umbræ 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 fifth and sixth columns give the sums for each day of the areas of all the umbræ and whole spots comprised in the group, corrected for foreshortening, and expressed in millionths of the Sun's visible hemisphere. The seventh and eighth 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 umbræ and whole spots and the mean longitude and latitude for the period of observation.

§ 3. *Catalogue of Recurrent Groups of Sun Spots compiled from the Ledgers of Groups of Sun Spots for the year* 1909.

This catalogue is in continuation of the Catalogue of Recurrent Groups of Sun Spots for the Years 1874 to 1906, published as an *Appendix* to the *Greenwich Observations*, 1907, and of the similar Catalogues for the Years 1907 and 1908 contained in the *Greenwich Photo-Heliographic Results* for those years; and, therefore, the reference numbers contained in the first column run on from those given therein. The number of the spot group is given in the second column, and the third column gives the synodic Rotation of the Sun, when the spot group crossed the central meridian, the Rotations being numbered as in Section 4. The fourth and fifth columns give, for each group, the Date of the photograph upon which the group was first seen, and the Heliographic Longitude from the Central Meridian of the group as measured on that photograph; the sixth and seventh columns, in like manner, give the Date of the photograph on which the group was last seen, with its Longitude from the Central Meridian then; whilst the eighth column gives the number of days for which photographs are available on which the group was measured. The four columns next following give respectively the Mean Daily Area as corrected for fore-shortening for the Umbræ and for the Whole Spots of the group, together with its Mean Heliographic Longitude and Latitude, and are derived directly from the Ledger of Spot Groups; and the last column supplies a brief description of the group.

The method of forming the Catalogue has been this:—If any spot group when first seen was 60° or more to the east of the Central Meridian—the detail given in the fifth column—then the Spot Ledgers, and, if necessary, the Daily Heliographic Results also, were searched some fifteen or sixteen days earlier, to ascertain whether a spot group of similar heliographic longitude and latitude was then near the west limb of the Sun. Similarly, if any spot group when last seen was 60° or more to the west of the Central Meridian—the detail given in the seventh column—then the Spot Ledgers, and, if necessary, the Daily Heliographic Results also, were searched some fifteen or sixteen days later, to ascertain whether a spot group of similar heliographic longitude and latitude was then near the east limb of the Sun. Both the search forward and the search backward have been made in the case of every spot group that was observed close to both the east and west limbs, in order that no possible case of identity might be overlooked. When there appeared to be a case of probable identity between spot groups observed in two consecutive rotations of the Sun, the character of the second group has been carefully compared with that of the first in each of the three elements —area, longitude, and latitude. In cases where the weight of evidence appeared to render probable the continued existence of the spot, it has been numbered in the catalogue and where there has been some element of uncertainty, a note has been added. If, on the other hand, the weight of evidence appeared to go in the other direction, but was not quite decisive, the series has been printed in the catalogue but a separate number has not been given it. It has been distinguished by the number of the preceding series, placed in brackets and marked with an asterisk. In cases where a well-defined series has been recorded, there have sometimes been included in brackets spot groups undoubtedly belonging to the same general disturbance, but for which the evidence of continuity of action was not sufficient. All cases have been excluded from the catalogue wherein there has been a clear unmistakable breach of continuity of action.

§ 4. *Total Areas of Sun Spots and Faculæ for each day, and Mean Areas and Mean Heliographic Latitude of Sun Spots and Faculæ for each Rotation of the Sun, and for the year* 1909.

This section requires no further explanation.

F. W. DYSON.

Royal Observatory, Greenwich,
1910 *December.*