Some Phenomena of Sunspots and of Terrestrial Magnetism at Kew Observatory

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III. *Some Phenomena of Sunspots and of Terrestrial Magnetism at Kew Observatory.*

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CONTENTS.

§ 1. IT was discovered half a century ago by SABINE, LAMONT and WOLF that a relation exists between sunspots and the daily range of magnetic declination. If the regular diurnal inequality of declination be determined for the year as a whole, then it has been shown that corresponding to equal increments of sunspot frequency, as determined by WOLF and WOLFER, of Zurich, there are at least approximately equal increments in the range. In some instances the range taken has been not that of an inequality derived from all hours of the day, but one derived from daily measurements at two fixed hours, approaching more or less closely to the average times at which the needle has its extreme easterly and westerly positions. The range thus derived is unlikely to bear an absolutely invariable ratio to the range of the diurnal inequality, but for the present purpose the comparison may be regarded as made with the range of the diurnal inequality, but of minor accuracy.

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The relation refers, it should be noticed, to corresponding data from the year as a whole. It may be expressed by the equation

$$R = a(1+mS), \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where R denotes the range of the diurnal inequality of declination, S the sunspot frequency, while a and m are constants for the particular station concerned.

In several previous papers* I have dealt with this formula, showing that it applies equally to the other magnetic elements, though with different values of a and m, and that it may be applied—though with less close agreement between observation and calculation—to the individual months of the year, provided m as well as a be allotted different values in different months. The values obtained for m for different magnetic elements, and for the same element at different seasons of the year, varied largely. At all the European stations considered, m was larger for H (horizontal force) than for D (declination), and larger for winter than for summer.

§ 2. WOLF and WOLFER's frequency figures are not the only statistics published for sunspots. Measurements have been made at Greenwich for many years of the areas of the faculæ, whole sunspot areas and umbræ both as "projected," *i.e.*, as measured in photographs, and as "corrected" for foreshortening. In a paper† published in 1906 I took all the Greenwich measurements into account when discussing D and H data from Falmouth for the magnetically quiet days of the twelve years 1891 to 1902. It was found (*loc. cit.*, Table II., p. 168) that for the twelve years mentioned the variations from year to year in the four quantities—whole spots projected, whole spots corrected, umbræ projected and umbræ corrected—had followed so similar a course that it could make little difference which of the four one took to represent solar activity in any investigation relating to mean annual values. The corrected areas, for instance, for whole spots and umbræ stood very nearly in the ratio of 6 to 1.

The variation from year to year in WOLFER's sunspot frequencies differed distinctly but not largely from that of the Greenwich spot areas. A considerably greater divergence appeared in the case of the Greenwich measurements of faculæ.

Formulæ of the type (1) were assumed as existing between the range of the mean diurnal inequality for the year in D and H at Falmouth and each in turn of the five solar quantities—faculæ (corrected areas), umbræ (projected and corrected areas), whole spots (corrected areas), and WOLFER's sunspot frequencies. Values were found for the constants a and m in (1) by the method of least squares, and a comparison was made (*loc. cit.*, Tables XVIII. and XIX., pp. 190 and 191) between the observed and calculated values of the D and H ranges for the twelve years, in order to see in which of the five cases the agreement with observation was closest.

In both D and H the closest agreement was obtained for WOLFER's frequencies,

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* 'Phil. Trans.,' A, vol. 202, p. 415; vol. 203, p. 151; vol. 208, p. 245, &c.

† 'Cambridge Transactions,' vol. 20, p. 165.

but the difference between the agreement in their case and in that of whole sunspot areas was small. In the case of H, the umbræ corrected gave as good an agreement as the whole spots, and the umbræ projected were very little behind. In D, the umbræ gave a distinctly inferior agreement; and in both D and H the agreement in the case of the faculæ was very decidedly inferior to that from the other solar quantities.

The natural inference from these results—though in the absence of trial it can only claim to be a probability—is that in any attempt to investigate a numerical relationship between sunspots and terrestrial magnetism it is not likely to matter much whether we consider Wolfer's frequencies or the Greenwich areas of whole spots or of umbræ; and, if we take Greenwich data, it would appear unlikely to make much difference whether projected or corrected areas are employed.

§ 3. The first attempt* which I made to investigate a relationship between sunspots and terrestrial magnetism on individual days employed Wolfer's *provisional* frequencies, as published quarterly in the 'Meteorologische Zeitschrift.' When discussing the Kew "quiet" day diurnal inequalities of the eleven years 1890 to 1900, it occured to me that if any intimate relationship exists between sunspot activity and magnetic disturbance on the same day, we should expect sunspot frequency to be decidedly below its mean on the average magnetically "quiet" day. A comparison was accordingly made of the mean sunspot frequency derived from the "quiet" days selected by the Astronomer Royal, and that derived from all days of the year. The comparison was made for the eleven years 1890 to 1900 as a whole, and for two sub-groups of years, representative of sunspot maximum and minimum. It was also made, employing the whole eleven years, for three seasons of the year, winter (November to February), summer (May to August), and Equinox (remaining four months). In no single instance was there a difference between the mean sunspot frequencies from all days and from "quiet" days only, such as suggested any real relationship. The two mean frequencies derived from all months of the eleven years, viz., 41·22 for all days and 41·28 for "quiet" days, were practically identical.

§ 4. The next attempt† which calls for remark proceeded on different lines. It made use of the annual Greenwich tables, which give the daily values of projected sunspot areas—expressed in terms of the one millionth of the visible disc as unit—applying them to the 660 selected "quiet" days of the years 1890 to 1900, and to 209 days of the same eleven years selected for the large size of the magnetic disturbances shown. The days of each month were divided into three groups; the first and last of these groups in a month of 30 days contained respectively the 10 days of largest and the 10 days of smallest sunspot area. It was then investigated how the 660 "quiet" days and the 209 highly disturbed days distributed themselves between the

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[*] 'Phil. Trans.,' A, vol. 202, p. 433.

[†] 'Phil. Trans.,' A, vol. 208, p. 234.

three groups. The distribution expressed in percentages of the total number of days, whether 660 or 209, was as follows:—

	In group of days of—		
	Largest spot area.	Intermediate spot area.	Smallest spot area.
"Quiet" days	31·7	34·5	33·8
Highly disturbed days. . . .	35·6	34·0	30·4

Thus the group of days of largest spot area contained 2·1 per cent. fewer "quiet" days, and 5·2 per cent. more disturbed days than the group of days of smallest spot area.

§ 5. The fact that this second investigation gives at least a suggestion of the relationship sought for, while the first investigation gave a purely negative result, was at first very puzzling; but it began to dawn on me that the difference might have something to do with the fact that days of large spot area, and days of small spot area both tend to congregate in groups, and not to be isolated. Influenced partly by this idea, and partly by the desirability of testing a theory of ARRHENIUS, who suggested that the magnetic disturbance effects visible on the earth, are due to the discharge from the sun of electrified particles likely to take some 48 hours to travel to the earth, I next investigated (in the same paper) whether the association was not between magnetic phenomena on the earth and phenomena existing on the sun, 1, 2, 3, or 4 days previously. In one investigation the 10 days of each month were taken for which the *absolute* D range (*i.e.*, the excess of the daily maximum over the daily minimum declination) was greatest. Calling any one of these selected days n, the Greenwich projected sunspot area was put down in separate columns for the day n, and three previous days $n-1$, $n-2$, and $n-3$. This being done for each of the 10 days of largest D range in the month, we have 10 spot areas in each of the four columns headed n, $n-1$, $n-2$, and $n-3$. Summing up and taking means for each column, we get results representative of the spot area on a representative day, characterised by a large D range, and on each of the three previous days.

If ARRHENIUS's theory were true, then we should expect the mean spot area for day $n-2$ to be decidedly in excess of the means from the other three columns, and also in excess of the mean derived from all days of the month.

As a matter of fact, when all the months of the 11 years were treated in this way, and the results combined, the mean spot areas from the four columns were *all* in excess of the mean from all days, and the excess was largest for column $n-3$.

As complementary to this investigation, the 10 days of least D range in each month of the 11 years were got out, and the corresponding sunspot areas were put down for each of these and the three previous days. In this instance, there was a *deficiency* in the mean derived from each of the columns headed n, $n-1$, $n-2$, $n-3$ as compared to the average day of the 11 years, and the deficiency was greatest in column $n-3$.

The calculations were repeated, limiting the days of largest and of least D range each to 5 a month. The two groups of days thus represented more extreme conditions than in the previous investigation, and consistently with this the phenomena proved to be of the same general character as before, only more pronounced. In the investigation which employed 5-day groups there were in reality six columns headed $n+1$, n, $n-1$, $n-2$, $n-3$, and $n-4$, thus representing six successive days, extending from four days before to one day after the representative day of large (or small) D range.

§ 6. As another line of attack, the initial selection of days was based on the sunspot area,* the one group of days for any month consisting of the 10 days of largest area, the other of the 10 days of least area. The D ranges were put down for each day of either group, and for the three *subsequent* days in columns headed respectively n, $n+1$, $n+2$, and $n+3$. Taking again a mean from all months of the 11 years, the mean D ranges from the four columns for the group of days of large spot area were all above the mean derived from all days of the year, and the excess was greatest in column $n+3$.

In short, when the 11 years as a whole were combined, all the lines of investigation pointed to a relationship between the size of the absolute D range on individual days and sunspot areas on one or more preceding days. It appeared, however, that if ARRHENIUS's views were correct, the time requisite for the electrified particle to travel from the sun to the earth must vary from less than 1 to more than 3 days, and it seemed that 4 days must be a more common interval than 3, and 3 days a more common interval than 2. The phenomena were, however, at least as favourable to the view that magnetic conditions on any one day represent an integral to which a number of previous days contribute.

The similarity in the nature of the results derived by these different investigations from the 11 years as a whole, and the fact that the apparent sunspot influence indicated was far from infinitesimal, seemed to preclude the possibility of the phenomena being wholly accidental. There was, however, this remarkable fact, that when the years were treated individually, some of them, notably 1895, gave results which appeared to be of an opposite character to those derived from the whole 11 years, there being an apparent association of large D ranges with small, not large, spot areas. Further investigation thus appeared necessary, and it was clear that it ought to be of a much more comprehensive character, calling for a large expenditure of time. It is only within the last twelve months that a suitable opportunity has presented itself.

§ 7. The first question now to be considered is whether D is the best magnetic element on which to base the enquiry. The investigations which involved applications

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* National Physical Laboratory, 'Collected Researches,' vol. 5, 1908, p. 55.

of WOLF's formula (1) to diurnal inequality ranges showed that when Kew "quiet" days were considered—the information for other than "quiet" days at Kew is still lacking—inclination (I) was the element for which the constant m was largest, *i.e.*, for which the greatest percentage increase of range occurred for a given increase in sunspot frequency. Next to I came H.

Values of I are not recorded directly by the magnetographs, but have to be calculated from the recorded values of H and V (vertical force). Thus it would be a very difficult, if not practically impossible, task to find absolute daily ranges of I. Daily ranges of H, on the other hand, are as easily obtained as those of D, provided one neglects the corrections required to allow for the variation of temperature. At Kew such neglect seldom causes an error as large as 2γ ($1\gamma \equiv 1 \times 10^{-5}$ C.G.S.) in the absolute daily range, and often is without any effect, and for investigations such as the present the slight increase in the accuracy of individual daily ranges that might ensue from the application of temperature corrections would be immaterial.

In 1908 a grant was obtained from the Government Grant Committee for the measurement of all Kew H and V curves of the 11 years 1890 to 1900, and the work naturally included the determination of the absolute daily ranges, which thus became available for the present enquiry.

The increase of sensitiveness in the method expected from the substitution of H for D ranges was considerable, as will be seen by reference to Table I. Adopting the notation of (1), 100m represents the percentage increase in the range of the diurnal inequality answering to an increase in WOLFER's sunspot frequency from 0 to 100. The results to which the letter A is attached in Table I. were obtained by least squares, those to which the letter B is attached by what I have called the "method of groups."

TABLE I.—Values of 100m at Kew.

	Method.	D.	H.	H value ÷ D value.
From range of mean diurnal inequality for the year . .	A	0·71	1·07	1·51
	B	0·66	1·04	1·58
From inequality ranges of 12 months of the year individually considered	A	0·63	0·89	1·41
	B	0·68	1·00	1·47

If, then, the relation between absolute ranges on individual days and sunspots follows similar laws to those presented in the case of the range of the diurnal inequality, we should expect the differences disclosed by investigations such as those described in §§ 5 and 6 to be increased some 50 per cent. when D ranges are replaced by H ranges.

Absolute daily ranges, however, are affected by disturbance in a much greater degree than inequality ranges derived from all days of the year, so some direct confirmation was desirable. It was obtained as follows: The monthly groups of 10 days already employed in connection with the D ranges, were utilized for H ranges, for the 3 years 1892, 1893, and 1894, which were the years of largest sunspot frequency between 1890 and 1900. The investigation was limited to the representative day n of largest (or least) sunspot area, and the three immediately following days $n+1$, $n+2$, and $n+3$.

The results derived by meaning the several columns for the three years separately appear in Table II. Each entry, it will be understood, represents a mean derived from 10×12 or 120 days,

TABLE II.—Comparison of D and H results from 10-day Groups.

Element.	Year.	Days of large spot area.				Yearly mean from all days.	Days of small spot area.			
		n.	$n+1$.	$n+2$.	$n+3$.		n.	$n+1$.	$n+2$.	$n+3$.
D (unit 1′)	1892	16·96	17·96	18·75	19·74	17·70	16·23	15·96	16·01	15·96
	1893	15·37	15·91	16·32	16·35	15·62	15·39	15·28	15·17	15·33
	1894	17·73	18·05	18·11	18·19	16·50	15·06	14·58	14·88	15·14
Mean . .	—	16·69	17·31	17·73	18·09	16·61	15·56	15·27	15·35	15·48
H (unit 1γ)	1892	84·4	88·5	91·7	101·2	84·0	73·4	71·0	71·0	68·0
	1893	70·9	73·1	75·4	76·0	69·7	69·1	66·1	63·9	65·8
	1894	86·8	91·5	91·8	95·1	81·4	69·1	69·1	71·3	73·1
Mean . .	—	80·7	84·4	86·3	90·8	78·4	70·5	68·7	68·7	69·0

Expressing the algebraic excess of each of the 3-year means in the columns n, $n+1$, $n+2$, and $n+3$ over the corresponding means from all days of the year (viz., $16'{\cdot}61$ for D and $78{\cdot}4\gamma$ for H) as percentages of the latter mean values, we obtain the results given in Table III.

TABLE III.—D and H results from 10-day Groups, as Percentages.

Element.	Group of days of large spot area.				Group of days of small spot area.			
	n.	$n+1$.	$n+2$.	$n+3$.	n.	$n+1$.	$n+2$.	$n+3$.
D	+0·5	+4·2	+ 6·7	+ 9·0	− 6·3	− 8·0	− 7·5	− 6·8
H	+3·0	+7·7	+10·1	+15·8	−10·0	−12·3	−12·3	−12·0

Taking the numerical sums of the percentage figures from the large and small spot area groups separately, we find

$$(\text{H sums})/(\text{D sums}) = 1{\cdot}79 \text{ from days of large spot area,}$$
$$\text{,,} \qquad\quad \text{,,} \quad = 1{\cdot}63 \quad \text{,,} \quad \text{,,} \quad \text{,, small} \quad \text{,,} \quad \text{,,} \;.$$

This makes the phenomenon some 70 per cent. larger in H than in D, and so more than justifies our anticipations.

§ 8. In the majority of the earlier investigations use was made of 10-day groups selected by reference to the size of the absolute daily range. In the investigations now to be described it was decided to employ 5-day groups, and to make the Greenwich projected sunspot area the criterion for selection. It had become obvious that the number of days preceding and following the representative day must be largely increased, if one wished to ascertain the true nature of the phenomenon, and it was obvious that the arithmetical operations would thus become exceedingly heavy, even with 5-day groups. Experience had also shown that the 5 days of largest spot area in a month were not infrequently consecutive, while this was hardly ever the case for the 10 days of largest area. Thus 5 appeared a more natural number than 10, while the fact that the majority of the 5 days often occurred in a sequence led to a marked economy of time in entering the data in the several columns.

The main reason for preferring the spot area as the criterion for grouping the days was that it promised to facilitate the comparison of results from different stations, and the comparison of results from different elements at the same station. The numerical results for the sunspot areas for the groups of days of the present investigation will obviously serve for any similar investigation dealing with the same period of years.

One slight drawback to sunspot areas as the criterion of selection is the absence of spot areas for a few days in the Greenwich publications. In these cases the day for which information was lacking was disregarded when selecting the 5 days of large (or small) spot area; but when it occurred in any column (other, of course, than n) it had assigned to it the arithmetic mean of the areas for the two adjacent days.

There were a few days for which Kew H ranges were lacking. The gaps were filled up by reference to the Falmouth curves, with the exception of one occasion when the traces at both Kew and Falmouth got off the sheet. The range for that day was taken as if the curve stopped at the edge of the sheet. Judging by the appearance of the curves, the consequent underestimate of the range was not serious.

It was decided to take 15 days before and 15 after each selected day. Thus, calling the representative day n, there were 31 columns of figures extending from day $n-15$ to day $n+15$.

There was one month in 1890 and one in 1900 when the days showing measureable sunspot areas numbered less than 5. These two months were omitted, leaving in all 130. The investigation relating to the 5 days a month of largest spot area thus included the treatment of $130 \times 31 \times 5$, or 20150, H ranges and as many sunspot areas.

Sunspot Areas.

§ 9. In the subsequent comparisons of sunspot areas and magnetic phenomena use was made not merely of the whole 11 years 1890 to 1900, but also of the following groups of these years :—

1890, 1899, and 1900 representing sunspot minimum ;

1891, 1895, and 1896 representing the most rapid portion of the rise of sunspot areas to the maximum and their subsequent decline, and also representing an exceptionally high average state of magnetic disturbance ;

All the years (8) except those in the last-mentioned group ;

1892, 1893, and 1894 representing sunspot maximum.

In the case of the 11 years, the three seasons winter, equinox, and summer, as defined in § 3, were also considered separately.

In the case of the sunspot maximum years there were two investigations, one based as in the other cases on the 5 days a month of largest spot area, the other on the 5 days a month of least spot area. The sunspot area data derived from these investigations appear in Table IV. Column n gives the characteristics of the representative of the selected 5 days a month. The columns $n-15$ to $n-1$ give the characteristics of the 15 days immediately preceding the representative day, columns $n+1$ to $n+15$ the characteristics of the 15 days immediately following the representative day. The figures in these 31 columns represent percentages of the mean spot area derived from the whole 31 columns.

The method aims at securing a pulse of high (or low) spot area centering at day n, and our immediate object is to ascertain the form of that pulse.

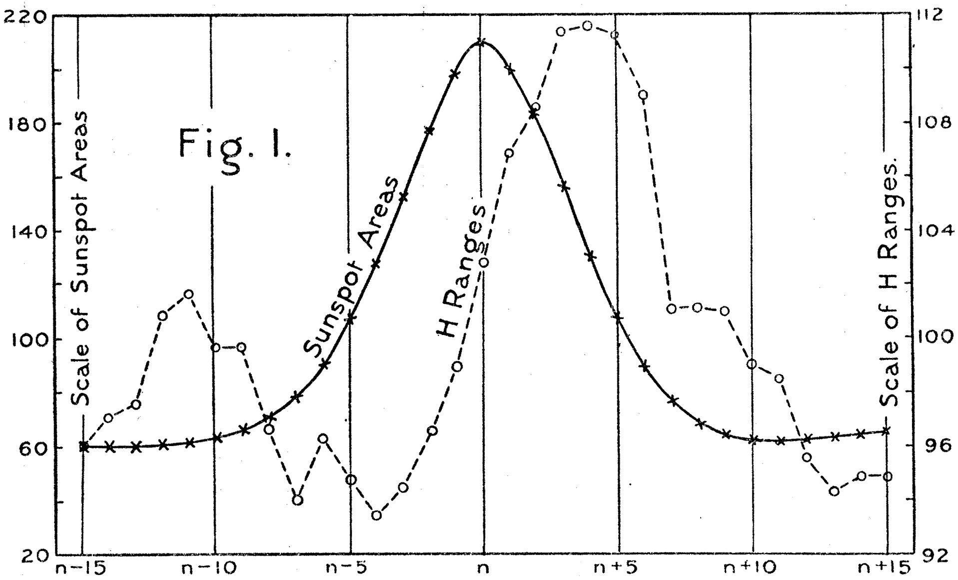
Fig. 1.

§ 10. The 11-year data in the first line of Table IV. are shown graphically in the full line curve of fig. 1. They represent an exceedingly smooth and nearly symmetrical

TABLE IV.—Sunspot Areas Expressed as Percentages of their Mean.

	$n-15$.	$n-14$.	$n-13$.	$n-12$.	$n-11$.	$n-10$.	$n-9$.	$n-8$.	$n-7$.	$n-6$.	$n-5$.	$n-4$.	$n-3$.	$n-2$.	$n-1$.	n.
Eleven years, all months	61	60	60	61	62	64	66	71	78	90	107	127	152	178	198	210
,, ,, Winter	60	60	60	63	65	69	74	80	87	98	112	128	150	169	186	198
,, ,, Equinox	59	60	61	61	63	63	64	68	75	87	105	130	158	186	207	219
,, ,, Summer	64	61	59	58	58	59	61	65	73	86	101	123	150	178	200	212
1890, 1899, 1900	48	49	49	50	48	47	45	48	58	77	103	139	182	227	267	292
1891, 1895, 1896	53	54	57	61	66	70	75	80	86	95	108	124	145	169	188	202
Other 8 years	64	64	61	61	60	61	63	67	75	88	105	128	155	182	202	213
1892, 1893, 1894	71	69	65	64	63	64	67	72	80	91	105	124	147	169	188	198
1892, 1893, 1894, representative days of *minimum* spot area	136	137	137	136	132	127	122	114	105	93	81	69	57	46	38	33

	$n+1$.	$n+2$.	$n+3$.	$n+4$.	$n+5$.	$n+6$.	$n+7$.	$n+8$.	$n+9$.	$n+10$.	$n+11$.	$n+12$.	$n+13$.	$n+14$.	$n+15$.	Mean spot area.
Eleven years, all months	200	184	156	130	107	89	77	69	65	63	62	63	63	64	65	939
,, ,, Winter	187	170	150	128	109	92	79	70	64	62	62	64	66	68	68	945
,, ,, Equinox	210	201	164	135	110	91	78	70	64	61	55	51	49	48	48	890
,, ,, Summer	202	181	155	127	103	86	74	67	65	65	68	71	74	76	78	983
1890, 1899, 1900	267	228	180	138	103	76	60	48	43	41	41	40	37	34	35	163
1891, 1895, 1896	195	176	151	125	103	86	74	68	65	65	66	70	72	75	76	1044
Other 8 years	202	187	158	132	109	91	78	69	64	62	60	59	59	60	61	900
1892, 1893, 1894	188	178	152	130	110	95	84	76	70	67	64	62	61	62	64	1786
1892, 1893, 1894, representative days of *minimum* spot area	39	49	63	77	92	104	115	122	127	130	130	127	123	120	119	1735

pulse, with its crest of course in column n. The differences between the figures in any corresponding pair of columns $n-s$ and $n+s$ are very small, but on the whole there is a tendency for the figure in column $n+s$ to be the larger of the two. From column $n-15$ to column $n-9$, and again from column $n+9$ to column $n+15$, the sunspot figure is nearly constant. The pulse is obviously of a favourable type for the investigation of the presence or absence of a corresponding pulse in any magnetic quantity.

The pulses in the case of all three seasons from the 11 years are fairly symmetrical with respect to column n for values of s up to 5 or more; but for values of s in excess of 9 or 10 there is considerable a-symmetry. The figures show a marked tendency to fall from column $n+11$ to column $n+15$ in the case of equinox, and a similar tendency to rise in the case of summer. These phenomena are presumably "accidents," and would disappear if a large number of 11-year periods were combined; but they merit attention, in view of their possible influence on the magnetic phenomena presently to be described.

Whether the more rounded character of the pulse in winter is wholly accidental is more open to doubt. If a natural phenomenon, characteristic of the season, it would seem to imply some direct action of the earth on sunspots, and so far as I am aware astronomers have not succeeded in establishing any such action.

The difference between the sunspot maximum and minimum years is marked, the pulse being much more rounded and less accentuated in the former. This may have been a peculiarity of the particular sunspot cycle, but it seems not unlikely to be fairly representative of sunspot maximum and minimum. Towards minimum there are usually a number of days without visible sunspots, and any finite number, however small, is infinite when compared to zero.

Omitting the last line of Table IV., which represents the exact antithesis of the conditions represented by the first eight lines, it will be seen that the sunspot area even on the fourth day after the representative day of largest area is still some 30 per cent. above the mean for the period. It would thus be quite in harmony with the hypothesis of a direct instantaneous action of sunspots upon the earth, if the range of the magnetic elements were decidedly above the mean for at least 4 days after the day of largest area. But, on this hypothesis, the excess above the average range on the fourth day after the day of largest area should be only some 30 per cent. or less of the excess on the actual day of largest area.

If the effect on the absolute magnetic range in individual days followed a similar law to that exhibited by the range of the mean diurnal inequality for the year, its absolute size would depend on the absolute difference in the sunspot area. For instance, if we compare the results in Table IV. for the groups of years of sunspot minimum and maximum, the total range of sunspot area in the former case—being the excess at day n over day $n+14$—would be in Greenwich units

$$(292-34)\times 163/100 = 420,$$

while in the latter case it would be

$$(198-61)\times 1786/100 = 2447.$$

Thus, on the above hypothesis, the difference between the greatest and least representative daily magnetic ranges—got out from the days included in Table IV.—should be about 5·8 times as large in the sunspot maximum as in the sunspot minimum group of years.

The rise to the crest of the pulse in Table IV. and the subsequent fall practically take place between days $n-7$ and $n+7$, *i.e.*, the pulse extends over about 15 days. There would obviously be advantages in making the pulse narrower. This could be done, to a certain extent, by reducing the monthly number of selected days. But even if we took only the one day of largest spot area of the month, the pulse would remain far from wall sided, because the days adjacent to that of largest spot area have almost always themselves areas much above the average of the month. On the other hand, if one took only 1 or 2 days a month, the number of years would probably have to be largely increased to get as smooth a progression as that shown in the first line of Table IV.

The last line of Table IV., dealing with the representative days of *least* spot area of the years of sunspot maximum, gives of course a trough instead of a crest at day n. The symmetry with respect to column n is not quite so good as in the case of the representative days of largest spot area from the same group of years, but still is very fair.

§ 11. Table V. gives the results for H ranges corresponding to the sunspot data in Table IV. The values of the ranges in columns $n-15$ to $n+15$ are expressed as percentages of the mean range derived from these 31 columns. These absolute mean ranges appear in the last column of the table.

If there were no relation between sunspots and magnetic phenomena on individual days, then we should expect the departures from 100 in the figures in the first 31 columns of Table V. to be small and irregular. There is certainly less smoothness in the progression of the figures than in Table IV., and the percentage variations shown are much smaller; but there are features which it is impossible to ascribe to accident.

Let us first consider the data from the 11 years in the first four lines of Table V. Accidental features are obviously not entirely eliminated, but there cannot be two opinions as to the existence of a marked pulse, the crest occurring some days after that of sunspot areas. In every case there is a marked depression or trough some days in advance of the day n which represents the maximum of sunspot areas. In the first line of Table V., representing all months of the year—represented graphically in the broken-line curve of fig. 1—the trough occurs about 4 days in advance, and the range is still below its mean on the day before sunspot maximum, *i.e.*, at a time when, as appears from Table IV., sunspot area is almost double its mean. The rise from the trough to the crest is regular, and the crest itself

TABLE V.—Horizontal Force Ranges Expressed as Percentages of their Mean.

	$n-15$.	$n-14$.	$n-13$.	$n-12$.	$n-11$.	$n-10$.	$n-9$.	$n-8$.	$n-7$.	$n-6$.	$n-5$.	$n-4$.	$n-3$.	$n-2$.	$n-1$.	n.
Eleven years, all months . .	96	97	98	101	102	100	100	97	94	96	95	94	95	97	99	103
,, ,, Winter . . .	96	94	93	97	99	96	94	91	90	95	96	98	97	97	103	103
,, ,, Equinox . .	99	102	100	103	102	97	97	96	94	93	95	94	96	100	102	109
,, ,, Summer . .	94	95	99	102	104	105	106	102	97	100	94	90	92	94	94	96
1890, 1899, 1900	97	100	100	102	102	99	97	93	92	94	93	95	95	96	101	103
1891, 1895, 1896	100	100	102	104	103	105	111	105	101	103	101	95	95	93	91	93
Other 8 years	95	96	96	100	101	97	95	93	91	94	92	93	94	98	103	107
1892, 1893, 1894	96	96	96	101	102	96	91	90	88	90	86	86	86	91	97	110
1892, 1893, 1894, representative days of *minimum* spot area	106	107	109	114	106	108	108	103	105	106	102	106	103	96	94	88

	$n+1$.	$n+2$.	$n+3$.	$n+4$.	$n+5$.	$n+6$.	$n+7$.	$n+8$.	$n+9$.	$n+10$.	$n+11$.	$n+12$.	$n+13$.	$n+14$.	$n+15$.	Mean H range.
																γ
Eleven years, all months . .	107	108	111	112	111	109	101	101	101	99	98	96	94	95	95	61·3
,, ,, Winter . . .	103	101	111	114	115	114	99	104	107	104	107	100	95	93	94	49·8
,, ,, Equinox . .	113	114	113	110	106	101	98	98	98	96	94	94	96	97	97	64·5
,, ,, Summer . .	105	109	110	111	113	113	106	103	100	98	96	94	93	94	94	69·5
1890, 1899, 1900	107	109	113	112	108	106	98	101	103	100	98	95	95	97	97	44·4
1891, 1895, 1896	92	94	99	104	101	100	97	97	97	100	104	105	103	103	101	65·1
Other 8 years	113	114	116	115	115	112	103	103	102	98	96	92	91	92	93	59·9
1892, 1893, 1894	114	119	124	122	126	123	109	107	105	101	97	89	87	87	88	79·3
1892, 1893, 1894, representative days of *minimum* spot area	86	89	90	92	91	94	96	96	99	102	103	100	98	103	100	77·4

rounded, the ranges in columns $n+3$ to $n+5$ being almost equal. The crest value is 12 per cent. above the mean range, and the preceding trough value 6 per cent. below. Thus the amplitude of the wave from trough to crest represents 18 per cent. of the average H range.

The figures for the three seasons in Table V. are less regular. The number of years would presumably have to be trebled to get results as smooth as in the first line of the table. All the seasons, however, show the same general features as the year as a whole. In winter and equinox an excess above the mean range appears at an earlier day than in the case of the year. In summer, on the other hand, the range does not attain its mean value until the sunspot maximum has passed. The differences, however, that exist between the seasonal data for sunspots in Table IV. may be responsible for some of the differences between the seasonal data in Table V.

The crest occurring after the day of sunspot maximum is not the only one visible in Table V. The results for the year and the three seasons all show a secondary pulse, whose crest occurs about 11 days before the day of largest spot area, *i.e.*, about 15 days before the crest of the principal pulse in the H ranges.

Coming to the separate groups of years, each, it will be seen, shows the above two pulses, the crest of the one about 4 days after, the crest of the other about 11 days before, the crest of sunspot areas. The group of years in which the phenomena are most prominent and regular is that including the three years of sunspot maximum. In this case the difference between the principal crest and the preceding trough represents 40 per cent. of the mean daily range, or about 32γ.

The sunspot minimum years give very similar results to the sunspot maximum years, but the difference between the principal crest and trough is only 20 per cent. of the mean daily range, or about 9γ. The group of years 1891, 1895, 1896 exhibits special features. This group includes the years in which the earlier investigation, referred to above, found large sunspot areas associated with small D ranges, and conversely. The same conclusion would have followed from the present investigation if it had been limited to the day of largest spot area and three following days. The fundamental phenomenon apparently was an exceptional development of what in the other years is a secondary pulse, with a postponement of the trough preceding the day of largest spot area until day $n-1$. As in other years, however, there is a marked rise from this trough; but the trough itself is unusually deep, and the crest of what in other years is the principal pulse does not much overtop the average value. Thus in some ways the depression in the H ranges some days in advance of the sunspot pulse appears a more persistent feature than the excess in the H ranges some days after the crest of that pulse.

§ 12. The last line in Table V., answering to the selected days of *least* spot area, dealt with in the last line of Table IV., shows a marked depression in the H ranges, extending from 2 days before to 8 or 9 days after the day n of least sunspot area. The actually lowest figure is on day $n+1$, but from day n to day $n+5$ the value is nearly constant. In this case the sunspot area was below its mean from 6 days before to 5 days after day n, so that here again there seems a lag of about 4 days. The incidence of the pulse which has its crest about day $n-12$ in the last line of Table V. is sufficiently accounted for by the high values of sunspot area in the last line of Table IV. for days prior to $n-11$. The difference between this crest and the subsequent trough represents 28 per cent. of the corresponding mean absolute daily range of H, or about 21·7γ. This is about two-thirds of the corresponding amplitude in the line above, answering to the days of largest spot area. The ranges of the sunspot values in the last and second last lines of Table IV. were respectively about 1804 and 2447 of the Greenwich units of area, so the H range and sunspot area ratios in the two cases are fairly similar.

§ 13. While Table V. seems to prove to demonstration that in the average year there is a clear association of H ranges with sunspot area some days previously, the relation is either of a somewhat complex character, or else is liable to be much overshadowed in individual years by other influences. It is obviously desirable that details enabling an independent judgment to be formed should be at the disposal of all interested in the subject. It is hoped that Table VI. will suffice for this purpose.

The figures in Table VI. are the mean absolute H ranges, in terms of 1γ as unit, from the representative 31 days $n-15$ to $n+15$ of the individual 11 years. Values which exceed the mean derived from the whole 31 days are in heavy type, so that one can see at a glance how far each year conforms to or departs from the general features of the 11 years combined, as exhibited in the first line of Table V. No single feature, it will be seen, is clearly exhibited by all the years. Three of them have the figure in column $n+4$ below the average, though the deficiencies are all trifling; and four of them have the figure in column $n-4$ above the average.

§ 14. One aspect of the case which suggests itself when individual H ranges are scrutinised calls for consideration. The number of days contributing to the mean value for a single year of one of the 31 columns of Table VI. is normally 60. Now there are a few days the H range of which is altogether outstanding. Thus in February, 1892, two successive days had ranges of 720γ and 650γ. The range of the average day of 1892, though larger than that of any other year, was only 84γ. This will explain how the presence of even one outstanding range in a column sensibly affects the mean value, and if any "accident" should bring two or three such days into the same column for a single year the result might be to simulate a marked influence which had no real existence.

It is obvious *à priori* that, so far as the present research is concerned, a range of 720γ must be regarded as largely an "accident." There are no outstanding daily values of sunspot area in the whole 11 years which overtop their neighbours in the way the larger magnetic ranges do. The recognition of this fact suggested the next mode of attack. It follows lines which were suggested by the procedure followed now

TABLE VI.—Horizontal Force Ranges (unit 1γ) for 31 Consecutive Days, including Representative Day n, of Large Sunspot Area.

Year.	$n-15$.	$n-14$.	$n-13$.	$n-12$.	$n-11$.	$n-10$.	$n-9$.	$n-8$.	$n-7$.	$n-6$.	$n-5$.	$n-4$.	$n-3$.	$n-2$.	$n-1$.	n.
1890	**46·7**	**47·7**	**47·6**	**45·9**	44·0	43·2	42·4	40·2	41·8	42·3	41·2	41·4	41·1	40·6	42·8	40·9
1891	57·7	58·0	57·4	61·1	59·1	**62·9**	**67·3**	**67·5**	**70·3**	**72·7**	**70·3**	**66·2**	**67·0**	**63·7**	60·6	58·6
1892	**86·2**	**87·6**	**92·6**	**94·3**	**90·1**	80·0	75·5	69·8	67·8	74·3	64·1	63·4	64·4	72·8	80·0	**90·5**
1893	64·4	61·3	61·2	66·4	68·6	**71·0**	68·0	67·3	63·8	62·5	59·2	57·2	59·4	61·9	**64·6**	**71·3**
1894	78·5	79·3	75·3	79·8	**84·8**	77·5	72·8	77·5	77·5	77·0	80·5	**83·7**	81·6	80·9	**85·9**	**90·8**
1895	**78·2**	**76·7**	**80·3**	**76·9**	**71·2**	69·4	**74·1**	67·1	64·2	64·7	61·4	59·4	60·1	58·8	59·0	62·1
1896	59·0	61·3	61·5	**64·9**	**71·5**	**73·2**	**75·3**	**70·0**	61·9	**63·0**	**65·7**	60·1	59·6	59·8	57·0	61·0
1897	46·5	48·1	47·8	48·8	50·4	51·4	**54·9**	**54·9**	52·0	**53·8**	**57·1**	**56·1**	**57·6**	**57·1**	**56·8**	53·1
1898	49·5	49·0	48·6	52·1	53·7	55·0	55·5	53·7	54·2	**56·3**	**56·8**	**57·1**	**60·5**	**69·1**	**69·3**	**68·4**
1899	42·6	47·0	**50·7**	**54·7**	**56·3**	**53·3**	**51·2**	48·0	46·8	48·4	46·8	49·2	49·0	47·7	50·1	**51·2**
1900	**39·9**	38·2	34·7	35·4	36·1	34·8	35·6	35·3	33·7	34·4	36·2	36·4	36·3	**39·0**	**41·6**	**44·7**
11 years mean . .	59·0	59·5	59·8	**61·8**	**62·3**	61·1	61·1	59·2	57·6	59·0	58·1	57·3	57·9	59·2	60·7	**63·0**

Year.	$n+1$.	$n+2$.	$n+3$.	$n+4$.	$n+5$.	$n+6$.	$n+7$.	$n+8$.	$n+9$.	$n+10$.	$n+11$.	$n+12$.	$n+13$.	$n+14$.	$n+15$.	Mean.
1890	42·1	41·4	43·2	44·1	**44·3**	42·5	43·4	**47·5**	**49·1**	**47·3**	**46·9**	**46·3**	**46·1**	**49·6**	**48·8**	44·2
1891	54·8	51·4	53·7	**62·2**	59·5	61·6	57·7	56·3	59·3	61·6	**66·4**	**67·7**	**62·7**	61·4	59·4	61·8
1892	**94·8**	**100·7**	**117·1**	**116·8**	**109·7**	**102·3**	**92·6**	**94·4**	**88·0**	83·6	79·5	70·1	68·1	70·9	73·2	84·4
1893	**75·1**	**74·0**	**81·1**	**78·5**	**78·5**	**80·1**	**79·9**	**82·5**	**78·8**	**76·4**	**74·8**	**72·5**	**70·2**	**70·2**	**71·7**	70·1
1894	**102·6**	**108·0**	**96·9**	**95·8**	**110·7**	**109·1**	**87·0**	78·1	82·1	79·6	77·6	70·4	68·4	66·7	64·2	83·2
1895	64·4	64·8	69·4	**69·8**	70·2	70·6	**73·0**	**75·7**	**75·3**	**75·3**	**77·3**	**79·2**	**80·7**	**81·9**	**78·3**	70·6
1896	60·5	**67·4**	**70·2**	**71·0**	**66·4**	**63·3**	58·4	57·6	55·7	58·8	60·0	57·6	57·5	57·4	59·8	62·8
1897	49·7	46·6	47·3	48·6	51·5	**54·9**	**56·6**	**56·3**	**54·3**	50·6	48·3	50·6	50·7	51·7	**52·4**	52·1
1898	**75·7**	**74·1**	**64·3**	**61·0**	**59·8**	51·8	46·1	46·8	49·5	48·4	50·2	50·4	51·0	51·6	52·0	56·2
1899	**54·3**	**57·4**	**59·7**	**54·6**	49·6	**51·4**	48·2	49·6	49·7	49·4	46·4	45·8	47·1	47·5	48·2	50·1
1900	**46·0**	**45·7**	**48·4**	**50·4**	**49·9**	**47·3**	**39·5**	37·6	**38·9**	36·7	37·2	34·3	33·3	31·6	32·4	38·8
11 years mean . .	**65·5**	**66·5**	**68·3**	**68·4**	**68·2**	**66·8**	**62·0**	**62·0**	**61·9**	60·7	60·4	58·6	57·8	58·2	58·2	61·3

for some years at de Bilt in presenting the results obtained by international co-operation for the "magnetic character" of individual days.

Each co-operating station assigns a "character" figure "0," "1," or "2" to each day, according as it is quiet, moderately disturbed, or highly disturbed. The character figures assigned by the co-operating stations are summed at de Bilt, as if they were ordinary numerical quantities, and the final order assigned to the days in the scale of disturbance is based on these sums (or their arithmetic means). If, for instance, 30 stations send in results, and all assign character "2" to one particular day, while half the stations assign "2," and half assign "1" to a second day, the total character sums obtained at de Bilt for the two days would be respectively 60 and 45, giving as the mean estimates 2 and 1·5.

The principles followed in assigning character figures at different stations vary, and the fact that the scale of values is so narrow necessitates grouping together at any one station days which differ widely in disturbance. It is also very difficult to maintain even a roughly uniform standard throughout a series of years. One naturally wishes to discriminate between the days of each year, and if one adopts a standard which gives fairly similar numbers of days of characters "0," "1," and "2" in a highly disturbed year, one has in a quiet year hardly any "2's," and a wholly extravagant number of "0's." The natural consequence is a tendency to lower the standard for a "1" or a "2" in a quiet year, and to raise it in a disturbed year. This renders character figures a somewhat uncertain basis for the comparison of one year or one group of years with another, but it militates only slightly against their use when comparing days of the same month, or even days of different months of the same year, unless the year is much more disturbed in some months than others.

The international scheme came into operation in 1906, and since that time character figures at Kew have always been assigned by myself, so that I have had considerable practice. The choice at Kew has been based not so much on the absolute size of the changes shown as on the more or less oscillatory nature of the curves.

§ 15. The second line of attack differs from the first only in substituting the character figures of individual days for their H ranges. As the period to be considered preceded the introduction of the international scheme, it was first necessary to assign character figures to the days of the 11 years. This was not so formidable a task as might appear at first sight. A single glance at the curves usually enables one to assign the character figure to about half the days of a month. My own practice is to consider the D and H curves of the month separately in the first instance, assigning to each character figures $\underline{0}$, 0, $\overline{0}$; $\underline{1}$, 1, $\overline{1}$; $\underline{2}$, 2, and $\overline{2}$. By "$\underline{0}$" is meant a very quiet curve, by "$\overline{0}$" a curve one inclines to assign "0" to but hesitates, regarding the assignment of "1" as at least a possibility, and so on. At Kew V (vertical force) curves need hardly be considered, as the element is so much less disturbed than D and H. If the D and H curves for the same day both get a "$\underline{0}$" or a "0," then usually character "0" is assigned without further enquiry. If both get "$\overline{0}$," or one a "$\overline{0}$" and the other a "1," they are considered side by side, before a decision is reached. This will explain the general method. There are, of course, not a few days when the giving a "0" or a "1," or a "1" or a "2" is very much a toss up. If the choice made one day were to be made independently even the next week, there would be no doubt an appreciable number of alterations in the figure ascribed, and the longer the interval between the two choices the more would this tend to be the case.

In view of this fact, in the present enquiry, the days of each year were dealt with, so far as practicable, in immediate succession. While the standard remained, I think, fairly uniform throughout the days of any one year, it not improbably varied sensibly as between different years, for the time that elapsed between the consideration of the first and last of the years was naturally considerable.

In assigning the character figures the appearance of the curves was alone considered, and the lists of the daily ranges were never consulted, so that the two lines of investigation are at least absolutely independent. A distinction to be borne in mind is that the character figure is a measure only of disturbance, whereas the daily range is usually dependent both on disturbance and on the regular diurnal variation.

The data resulting from the use of the character figures appear in Table VII., results being given for the 11 years combined and for the same groups of years as in Tables IV. and V. The results in the 31 columns $n-15$ to $n+15$ are expressed as percentages of their mean; and the absolute values of these means are given in the last column of the table. In the last line of Table VII., as in the corresponding lines of Tables IV. and V., the column n contains the representative days of *smallest* spot area.

§ 16. The progression of the figures in Table VII. is less smooth than in Table V., but the conclusions indicated are very similar. In each of the first five lines, where the selected days were those of largest spot area, there is a conspicuous trough a few days before the representative day n, followed by a considerable rise to a crest, which occurs usually on day $n+4$. This crest markedly overtops the average mean, except for the group of years 1891, 1895, and 1896, which exhibits the same peculiarity as in Table V. In addition to this pulse there is a second pulse, as in Table V., with its crest about 11 days before the day of largest sunspot area. The chief departure from the phenomena seen in Table V. is that this earlier pulse has become decidedly more prominent. This fact, and the further fact that the earlier, or secondary, pulse is in both tables especially conspicuous in the case of the highly disturbed years 1891, 1895, and 1896, suggests that the phenomenon is largely a pure disturbance effect. At the same time, the years of sunspot minimum 1890, 1899, and 1900, show a more prominent crest at day $n-12$ than do the years of sunspot maximum, which were much more disturbed.

An explanation of the secondary pulse which may suggest itself is that a reduction of sunspot area below the mean for the year is itself a cause of disturbance. If, however, this were the true explanation, the last line in Tables V. and VII. should exhibit a crest about day $n+4$ much more prominent than the crests in any of the other lines at day $n-11$. This it will be seen is far from the case.

TABLE VII.—Character Figures Expressed as Percentages of their Mean.

	$n-15$.	$n-14$.	$n-13$.	$n-12$.	$n-11$.	$n-10$.	$n-9$.	$n-8$.	$n-7$.	$n-6$.	$n-5$.	$n-4$.	$n-3$.	$n-2$.	$n-1$.	n.
Eleven years	95	96	99	106	105	107	102	100	92	92	93	90	91	91	95	98
1890, 1899, 1900 . . .	92	98	101	111	111	104	94	92	87	91	83	88	94	90	102	103
1891, 1895, 1896 . . .	97	103	107	117	115	119	119	111	98	99	99	95	91	87	82	81
Other 8 years	94	93	94	101	100	100	94	94	88	89	89	88	92	93	101	106
1892, 1893, 1894 . . .	97	97	100	103	102	100	92	93	87	82	79	73	70	75	87	99
1892, 1893, 1894, representative days of *minimum* spot area .	93	99	104	109	111	108	108	108	108	110	106	112	108	111	108	94

	$n+1$.	$n+2$.	$n+3$.	$n+4$.	$n+5$.	$n+6$.	$n+7$.	$n+8$.	$n+9$.	$n+10$.	$n+11$.	$n+12$.	$n+13$.	$n+14$.	$n+15$.	Mean character figure.
Eleven years	101	102	106	109	108	108	103	104	104	103	103	100	98	100	99	0·70
1890, 1899, 1900 . . .	111	112	117	118	113	115	105	102	104	106	92	89	85	94	96	0·47
1891, 1895, 1896 . . .	79	85	91	101	100	95	93	96	97	98	108	111	108	110	108	0·86
Other 8 years	111	111	114	113	112	114	109	109	107	106	101	94	93	96	95	0·64
1892, 1893, 1894 . . .	112	117	120	118	120	120	115	114	113	111	112	100	100	99	95	0·78
1892, 1893, 1894, representative days of *minimum* spot area .	88	91	97	92	94	95	97	91	93	99	95	91	94	93	90	0·80

TABLE VIII.—Character Figures for 31 Consecutive Days, including Representative Day n, of Large Sunspot Area.

Year.	$n-15$.	$n-14$.	$n-13$.	$n-12$.	$n-11$.	$n-10$.	$n-9$.	$n-8$.	$n-7$.	$n-6$.	$n-5$.	$n-4$.	$n-3$.	$n-2$.	$n-1$.	n.
1890	**0·55**	**0·64**	**0·64**	**0·62**	**0·58**	**0·55**	**0·47**	0·47	0·51	**0·58**	0·51	0·45	0·42	0·42	0·47	0·42
1891	0·70	0·73	0·67	0·77	**0·82**	**0·88**	**0·87**	**0·92**	**0·90**	**0·95**	**0·92**	**0·88**	**0·92**	**0·82**	0·72	0·63
1892	**0·85**	**0·87**	**0·92**	**0·83**	0·77	0·72	0·72	0·72	0·70	0·63	0·58	0·50	0·45	0·55	0·68	0·77
1893	0·58	0·58	0·58	**0·70**	**0·73**	**0·78**	0·68	0·67	0·57	0·43	0·37	0·33	0·38	0·45	0·57	**0·70**
1894	0·83	0·82	0·85	0·87	**0·88**	0·85	0·75	0·78	0·78	0·85	**0·90**	**0·88**	0·82	0·75	0·78	0·85
1895	**1·10**	**1·15**	**1·25**	**1·27**	**1·13**	**1·12**	**1·12**	**1·03**	0·85	0·80	0·77	0·77	0·70	0·75	0·77	0·78
1896	0·70	0·78	**0·83**	**0·97**	**1·02**	**1·07**	**1·07**	**0·92**	0·78	0·80	**0·87**	0·78	0·73	0·66	0·62	0·67
1897	0·65	0·62	0·58	0·58	0·60	0·65	0·70	0·67	0·62	0·68	**0·78**	**0·85**	**0·88**	**0·85**	**0·85**	**0·75**
1898	0·60	0·48	0·50	0·62	0·60	0·68	0·67	**0·70**	0·63	0·67	**0·78**	**0·73**	**0·85**	**0·92**	**0·88**	**0·93**
1899	0·40	0·45	**0·62**	**0·70**	**0·77**	**0·68**	0·60	0·60	0·58	0·58	0·48	0·57	**0·67**	**0·62**	**0·65**	**0·70**
1900	**0·36**	**0·31**	0·18	0·27	0·24	0·25	0·27	0·25	0·13	0·13	0·18	0·24	0·25	0·25	**0·33**	**0·35**
11 years' mean . .	0·67	0·68	0·69	**0·75**	**0·74**	**0·75**	**0·72**	0·70	0·64	0·65	0·65	0·63	0·64	0·64	0 67	0·69

Year.	$n+1$.	$n+2$.	$n+3$.	$n+4$.	$n+5$.	$n+6$.	$n+7$.	$n+8$.	$n+9$.	$n+10$.	$n+11$.	$n+12$.	$n+13$.	$n+14$.	$n+15$.
1890	0·51	0·45	0·51	**0·53**	0·47	0·49	0·47	0·49	**0·55**	**0·58**	**0·53**	0·51	0·51	**0·56**	**0·55**
1891	0·57	0·52	0·53	**0·78**	0·77	0·73	0·70	0·68	0·68	0·73	**0·82**	**0·90**	**0·85**	**0·82**	0·77
1892	**0·88**	**0·90**	**0·90**	**0·93**	**1·03**	**1·00**	**0·88**	**0·87**	**0·82**	0·73	0·77	0·70	0·73	**0·78**	0·73
1893	**0·83**	**0·85**	**0·95**	**0·85**	**0·87**	**0·87**	**0·87**	**0·85**	**0·87**	**0·83**	**0·83**	0·70	0·73	0·70	0·75
1894	**0·90**	**0·98**	**0·95**	**0·97**	**0·92**	**0·93**	**0·93**	**0·95**	**0·97**	**1·03**	**1·02**	**0·93**	0·87	0·83	0·73
1895	0·80	0·87	0·92	0·92	0·93	0·90	**1·00**	**1·07**	**1·08**	**1·08**	**1·20**	**1·20**	**1·22**	**1·25**	**1·18**
1896	0·67	0·80	**0·88**	**0·90**	**0·87**	0·82	0·68	0·72	0·73	0·72	0·75	0·77	0·72	0·77	**0·83**
1897	0·65	0·57	0·58	0·58	0·67	**0·77**	**0·85**	**0·87**	**0·78**	**0·75**	0·63	0·65	0·63	**0·72**	**0·73**
1898	**0·88**	**0·80**	**0·80**	**0·78**	**0·70**	0·65	0·57	0·62	0·58	0·58	0·65	0·62	0·62	0·57	0·58
1899	**0·72**	**0·78**	**0·78**	**0·75**	**0·70**	**0·70**	**0·63**	**0·62**	0·58	0·57	0·48	0·47	0·52	0·55	0·57
1900	**0·35**	**0·36**	**0·36**	**0·40**	**0·44**	**0·45**	**0·40**	**0·35**	**0·35**	**0·36**	**0·31**	0·29	0·18	0·22	0·25
11 years' mean . .	**0·71**	**0·72**	**0·74**	**0·76**	**0·76**	**0·76**	**0·73**	**0·74**	**0·73**	**0·72**	**0·73**	0·70	0·69	**0·71**	0·70

§ 17. Table VIII. gives for comparison with Table VI. the character data for individual years from which Table VII. was derived. The entries are the arithmetic means of the character figures, heavy type being used when the mean value for the year derived from the whole 31 columns is exceeded.

If entries in Tables VI. and VIII., which exceed the yearly mean, be regarded as affected by a positive sign, and those which fall short of the mean as affected by a negative sign, the parallelism between the two tables can be roughly gauged by comparing the number of agreements and differences in the signs of the corresponding entries. There are in all 11 × 31, or 341 entries in each table. One of these—the entry in column $n+6$ of Table VI. for year 1895—exactly equals the mean value. Omitting this, there are no fewer than 286 agreements in sign as against 54 differences. Many of the differences of sign occur in cases where the departure from the mean value is trifling. The natural inference is that disturbance plays a large part in the phenomena exhibited even by the H ranges.

Of the 99 entries in the columns headed $n-9$ to $n-1$ only 32 are above the mean in Table VI., and only 31 in Table VIII.; whereas of the 99 entries in the columns headed $n+1$ to $n+9$, those above the mean number 59 in Table VI. and 62 in Table VIII.

§ 18. The difference between the days which follow and which precede the representative day n of large sunspot area is brought out, perhaps even more clearly, by considering the algebraical excess of the percentage value for day $n+s$ over that for day $n-s$, for the values 1 to 15 of s included in Tables IV., V., and VII. Table IX. gives the results thus obtained for the 11 years combined. It was derived from data going one decimal place beyond the data given in Tables IV., V., and VII.

TABLE IX.—Excess of Percentage Figure for Day $n+s$ over that for Day $n-s$ in Tables IV., V., and VII.

s.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.
Spot area . . .	+2	+ 6	+ 4	+ 3	+ 1	− 1	− 1	−2	−2	−1	0	+2	+3	+4	+4
H ranges . . .	+8	+12	+17	+18	+16	+13	+ 7	+4	+1	−1	−3	−5	−3	−2	−1
Character figures .	+6	+11	+14	+18	+15	+15	+12	+4	+1	−3	−2	−5	0	+4	+4

The first line shows how trifling the a-symmetry was in the sunspot areas, considering how greatly the area on day n exceeded the mean.

The differences appearing in the last two lines of Table IX. for values of s exceeding 9 are presumably dependent in part on sunspot phenomena prior to day $n-15$. The fact that the data from H ranges and character figures accord so closely, not merely in sign but in absolute size, must be regarded as largely fortuitous, because the scale of the character figures is a wholly arbitrary one.

§ 19. The application of the method of Table IX. to the data for the group of years

1892, 1893, and 1894, led to some very striking results, which are given in Table X. Use was made in the calculations of figures going one decimal place beyond the figures in Tables V. and VII.

Data in Table X., in the lines to which the letter A is attached, answer to the case where n is the representative day of largest sunspot area; those in the lines to which B is attached answer to the case where n is the representative day of smallest spot area. By A−B is meant the algebraic excess of the A figures over the corresponding B figures.

TABLE X.—Excess of Percentage Figure for Day $n+s$ over that for Day $n-s$ for Years 1892 to 1894 in Tables V. and VII.

s.		1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.
H ranges	A. .	+18	+28	+38	+36	+40	+33	+21	+17	+14	+ 5	− 5	−12	−10	−9	−8
	B. .	− 8	− 8	−12	−14	−11	−12	− 9	− 8	− 9	− 6	− 3	−14	−11	−5	−6
	A−B. .	+26	+36	+50	+50	+51	+45	+30	+25	+23	+11	− 2	+ 2	+ 1	−4	−2
Character figures	A. .	+25	+42	+49	+44	+41	+38	+27	+21	+21	+11	+10	− 3	− 1	+2	−2
	B. .	−20	−20	−11	−19	−13	−15	−11	−17	−15	−10	−16	−18	−11	−6	−3
	A−B. .	+45	+62	+60	+63	+54	+53	+38	+38	+36	+21	+26	+15	+10	+8	+1

Every B figure in Table X. is negative. For values of s up to 9 this may reasonably be ascribed to the passage of the pulse of low sunspot area centering at day $s = 0$. But for higher values of s it seems to arise from a pulse of high values in both range and character figures having its crest about day $n-12$ or $n-11$. This presumably is a more or less distinct phenomenon.

The spot area at the crest of the pulse of large spot area for the years 1892 to 1894, now under consideration, was 98 per cent. in excess of the mean for the 31 days, while the spot area at the trough of the pulse of small spot area showed a deficiency of only 67 per cent. from the 31-day mean. One would thus have expected the A figures in Table X. to exceed the B figures numerically, but the excess shown is larger than would have been anticipated. Thus, in this instance, a deficiency of sunspots below the mean seems to have exerted a smaller influence than a corresponding excess.

The large size of the percentage excesses in Table X., and the regularity in the figures for values of s up to 10, are phenomena of so striking a character that a warning seems desirable against attaching undue significance to them. From 1892 to 1894 there must have been a very close parallelism between the variations of sunspot areas and H ranges, pulses in the latter quantity tending to follow those of the former after an interval averaging about 4 days; but in view of the differences between the phenomena of different years shown in Tables VI. and VIII., it is clear that other important influences have to be considered.

These other influences would appear to have sometimes opposed the influence in virtue of which a sunspot pulse is followed by a magnetic pulse, and so long as the nature of the other influences and the various inter-relationships are unknown, it would be unsafe to assume that years of sunspot maximum always behave in the same way as 1892 to 1894.

§ 20. One of the possibilities suggested by Tables V. and VII. was that there might be a periodic fluctuation in magnetic properties, which was in phase with sunspot variations to a much greater extent in some years than in others. Various such periods have in fact been advanced by earlier investigators. A 26-day period has been suggested by several magneticians, including HORNSTEIN and BROUN. Dr. AD. SCHMIDT, of Potsdam, claims to have discovered that a large proportion of magnetic storms of the very largest kind are separated by intervals which are multiples of 29·97 days. In 1904–5, Mr. E. W. MAUNDER,[*] in two important papers, discussing the magnetic storms recorded at Greenwich from 1848 to 1903, claimed to have discovered a period of 27·275 days, corresponding to the time of rotation of the sunspot zones on the sun. The validity of Mr. MAUNDER'S claim to have established a period was supported by the present Astronomer Royal[†] amongst others, on arguments based on the mathematical theory of probability.

I had myself[‡] occasion, at the instance of the Editor of 'Terrestrial Magnetism,' to read carefully and criticise the first of Mr. MAUNDER'S papers, dealing with magnetic storms from 1888 to 1903. The result left me undecided whether Mr. MAUNDER had established his case. One important point in favour of his contention was that practically the same periodic time had been deduced from a study of magnetic storms at Toronto by Mr. ARTHUR HARVEY,[§] he and Mr. MAUNDER being ignorant of each other's work. A second fact in its favour was that a list of 125 magnetic storms at Kew between 1890 and 1900, got out by myself in an absolutely unprejudiced way, gave 21 intervals of from 25 to 28 days, while intervals of from 21 to 24 days and 29 to 32 days numbered respectively only 7 and 9. I experienced, however, a difficulty as to the proper mathematical basis for applying a probability calculation. As it so happened, the standard of disturbance accepted as defining a magnetic storm was such that the *average* interval between successive Greenwich storms from 1888 to 1903 was 29 days, and that between successive Kew storms from 1890 to 1900 was 28 days, both being intervals undesirably close to the supposed period. Another difficulty was that the times of commencement of the storms, from which Mr. MAUNDER derived his intervals, had an extraordinarily marked diurnal period, showing that they were

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[*] Royal Astronomical Society's 'Notices,' vol. 65, pp. 2 and 538.

[†] 'The Observatory,' vol. 28, 1905, p. 176.

[‡] 'Terrestrial Magnetism,' vol. 10, 1905, p. 9.

[§] 'Trans. Can. Inst.,' 1898–99, p. 345, &c.

largely influenced by something essentially local. The conclusion which I ultimately expressed* was that "whilst in the opinion of the writer further investigation is required to justify the final acceptance of any of Mr. MAUNDER'S views, his paper is a most important one."

Several other criticisms of Mr. MAUNDER'S work were published at the time. One which influenced me to some extent in undertaking the investigation now to be described, was made by Prof. H. H. TURNER† on behalf of Prof. SCHUSTER, in the discussion of Mr. MAUNDER'S paper before the Royal Astronomical Society. Prof. SCHUSTER apparently considered the data to raise a presumption, rather than afford a demonstration, of the existence of *a* period, and after applying his periodogram methods he seemed to think there was more to be said for a 13·64 than a 27·28-day period. As a final summary of his views it is stated (*loc. cit.*, p. 84):—

"We have in fact a choice between two interpretations—

"1. Magnetic storms are apt to occur at times which, starting from a certain point, are multiples of 13·64 days. During some years the odd multiples and during other years the even intervals are principally concerned.

"2. Magnetic storms often recur after several successive intervals which are equal to some lapse of time sufficiently near 27·28 days to fall within the limits of rotation of sunspot zones."

§ 21. If we look at Tables V. and VII. we see that the interval between the crests of the principal and secondary pulses is somewhere about 15 days, but the crests are so rounded that the interval might well be a day or more short of this. The fact reminded me of Prof. SCHUSTER'S remark about a 13·64-day period; it also suggested that we might have to do with the half of Dr. SCHMIDT'S period. It thus appeared desirable to ascertain definitely whether the magnetic data employed in the previous investigations did or did not show a period. This was investigated in the following way:—

The 5 days of largest H range in each month were selected, and the magnetic character figures put down in successive columns for each of these and the 35 subsequent days. The columns were numbered n to $n+35$, the column n including the representative days of largest H range. A year or two's data sufficed to show that something was to emerge, so the enquiry was applied to the whole 11 years, and the investigation was extended so as to include 5 days (columns $n-5$ to $n-1$) preceding the selected days in column n.

The method may appear of somewhat a hybrid character. Naturally one would have preferred to base the enquiry entirely on the H ranges, or else entirely on the character figures. The objection to the former course was that a range is a 3 or 4 figure result. The research entailed dealing with 60 × 41 × 11, or over 27,000 entries, and having for these character figures instead of ranges meant a great economy of

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* *Loc. cit.*, p. 14.

† 'Observatory,' Jan. 13, 1905, p. 80.

effort. The selection of the original 5 days a month from consideration of the H ranges was due to its greater simplicity. If there had been in each month 5 and only 5 days of magnetic character "2," one would naturally have preferred to take them. But some months had no days of character "2" at all, while others had considerably over 5, and there was no obvious simple way of selecting 5 days from each month as the most disturbed. One might, of course, have selected every day of character "2," but this would have given enormously more weight to the highly disturbed than to the quiet years.

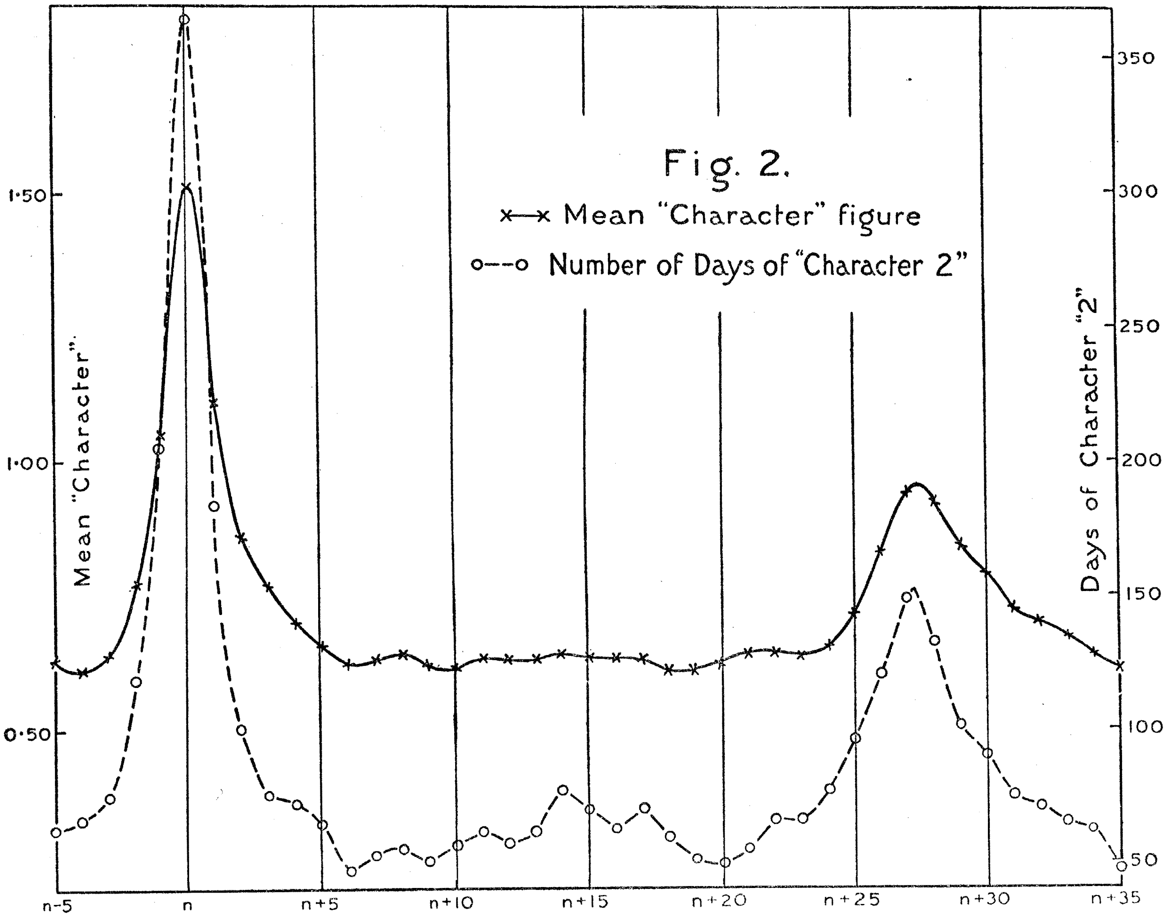
Before discussing the results of the enquiry it is desirable to consider the nature of the data. In a large disturbance, or what is usually called a "magnetic storm," all the elements are as a rule so disturbed that one unhesitatingly assigns a "2" on inspection of the trace of any one of the elements, whether D, H, or even V. But there are many days to which I have assigned a "2" which would get only a "1" if the record of the most disturbed element—whether D or H—were left out of account. In the present investigation, as explained above, the selection of days depended entirely on the H range. It was thus certain *à priori* that in some months one or more of the selected days would only have a character figure "1," while days not selected would have character "2." Still it was abundantly clear that the character figure of the representative day n would be much above the average in every month, and that when a large number of months were included, the mean character figure from column n would be much larger than any other. The method was thus certain to give a well-marked pulse with its crest in column n.

Again, there is a tendency for disturbed days (or days of large H range) to occur in groups of 2 or more rather than singly. Suppose we have 3 consecutive days of character "2" amongst the 5 selected for one month, all the other days in their neighbourhood being of character "1" or "0." Obviously the character figures from these 3 days will occur in each of the 5 columns headed $n-2$ to $n+2$. Thus the pulse will not be a wall-sided one confined to day n, but will extend to adjacent days. The tendency to occur in groups is however less marked in the case of high character figures than in that of large spot areas. Thus we know in advance that we are certain to have a pulse, with crest at day n, somewhat resembling that of sunspot areas in Table IV., but probably less wide. Five or six days after the crest we may expect the pulse to die out, and thereafter, if no period exists shorter than 35 days, we may expect the mean character figures derived from the successive columns to show only irregular accidental departures from a dead-level value. If a period of m days exists, then we may expect a second pulse with its crest in column $n+m$, the height of the crest above the surrounding level being small unless the period is a well-marked one.

§ 22. The results of the investigation appear in Table XI. It includes data from the whole eleven years, and from three specified sub-groups of years. The figures in the columns headed $n-5$ to $n+35$ represent the corresponding mean values of the character figure, the days contributing to each mean being 660 for the 11-year and

180 for the 3-year groups. To assist the eye, vertical lines divide the columns into blocks of five. The last column gives the mean value of the character figure from all days of the year dealt with. These annual means are nearly, but not quite, the same as the means that would be derived by combining the figures from the 41 previous columns. Entries in the table which exceed the annual means are in heavy type.

Considering first the 11-year data, we have the primary pulse anticipated, with its crest at day n, the value for this day being more than double the mean from all days of the period. The 11-year mean is exceeded in the six columns $n-2$ to $n+3$, and columns $n-3$, $n+4$, and $n+5$ are also obviously affected by the pulse. From columns $n+6$ to $n+23$ inclusive we have a practically dead-level value, with only such fluctuations as would naturally arise accidentally. In column $n+24$ there begins a well-marked pulse, covering columns $n+24$ to $n+33$. The seven columns $n+25$ to $n+31$ give values above the 11-year mean, and the crest comes between columns $n+27$ and $n+28$. The values in these two columns are respectively 34 and 21 per cent. above the 11-year mean.



A consideration of the numerical results in the first line of Table XI, or their graphical representation in fig. 2, will probably remove the doubt which has I think

TABLE XI.—Mean Character Figures on 41 Consecutive Days, including the Representative Day n, of Large H Range.

	$n-5$.	$n-4$.	$n-3$.	$n-2$.	$n-1$.	n.	$n+1$.	$n+2$.	$n+3$.	$n+4$.	$n+5$.
Eleven years	0·63	0·61	0·64	**0·77**	**1·05**	**1·51**	**1·11**	**0·86**	**0·77**	0·70	0·66
1890, 1899, 1900 . .	0·43	0·41	0·41	**0·57**	**0·77**	**1·17**	**0·82**	**0·59**	**0·51**	0·43	0·48
1891, 1895, 1896 . .	0·70	0·68	0·77	**0·94**	**1·22**	**1·73**	**1·32**	**1·06**	**0·96**	**0·87**	0·76
1892, 1893, 1894 . .	0·82	0·73	0·72	**0·81**	**1·13**	**1·59**	**1·21**	**0·93**	**0·86**	0·77	0·74

	$n+6$.	$n+7$.	$n+8$.	$n+9$.	$n+10$.	$n+11$.	$n+12$.	$n+13$.	$n+14$.	$n+15$.	$n+16$.	$n+17$.	$n+18$.	$n+19$.	$n+20$.
Eleven years	0·62	0·63	0·64	0·62	0·61	0·63	0·63	0·63	0·64	0·63	0·63	0·63	0·61	0·61	0·62
1890, 1899, 1900 . .	0·43	0·44	0·43	0·43	0·43	0·38	0·39	0·44	0·42	0·43	0·41	0·38	0·37	0·40	0·42
1891, 1895, 1896 . .	0·68	0·73	0·74	0·73	0·70	0·75	0·75	0·81	0·84	0·80	0·82	0·78	0·70	0·74	0·77
1892, 1893, 1894 . .	0·74	0·74	0·74	0·69	0·64	0·72	0·76	0·71	0·73	0·71	0·71	0·77	0·71	0·69	0·66

	$n+21$.	$n+22$.	$n+23$.	$n+24$.	$n+25$.	$n+26$.	$n+27$.	$n+28$.	$n+29$.	$n+30$.	$n+31$.	$n+32$.	$n+33$.	$n+34$.	$n+35$.	Mean from all days.
Eleven years	0·64	0·64	0·63	0·65	**0·71**	**0·83**	**0·94**	**0·92**	**0·84**	**0·79**	**0·72**	0·70	0·67	0·64	0·61	0·70
1890, 1899, 1900 . .	0·39	0·37	0·37	0·34	0·47	**0·63**	**0·71**	**0·68**	**0·57**	**0·52**	**0·56**	**0·53**	**0·51**	0·44	0·41	0·47
1891, 1895, 1896 . .	0·74	0·78	0·76	0·84	**0·87**	**0·98**	**1·13**	**1·15**	**1·02**	**0·94**	0·82	0·79	0·73	0·72	0·66	0·84
1892, 1893, 1894 . .	0·78	**0·81**	0·75	0·76	**0·79**	**0·81**	**0·94**	**0·91**	**0·93**	**0·88**	**0·79**	**0·82**	0·78	0·74	0·72	0·78

hitherto prevailed amongst magneticians as to the reality of a 27–28-day period of a kind. There is undoubtedly a period, in the sense that a day which follows 27 or 28 days after a disturbed day is more likely to be itself distubed than is the average day. But whether there is a period in the sense in which the term is applied to solar and lunar phenomena, which go through a regular cycle in a fixed period of time, and continually persist in doing so, is of course an entirely different matter. The present investigation does not throw, and was not intended to throw, light on this further question.

§ 23. Data which relate to so long a period as 24-hours are not naturally very well adapted for determining the length of a period with any high precision. For such a purpose one wants data relating to a much shorter interval of time. Such data could be obtained in the present case by following the recent example of Prof. BIDLINGMAIER,[*] of Wilhelmshaven Observatory, in assigning character figures to individual hours of the day. It might prove possible in this way to estimate the period to a fraction of an hour, and investigate whether it is the same in all years, or depends in any way on the solar latitude of the greatest sunspot distribution, which is known to vary throughout the sunspot cycle. In this way light might be thrown on the cause of the phenomenon, whether of solar, lunar, or terrestrial origin.

Though we can hardly expect to make a very exact estimate of the length of the period shown by the 11-year figures in Table XI., it may be worth recording the results of several rough estimates which are fairly accordant. It will be best to employ not the actual data in Table XI., but the sums of the character figures for the 660 days from which these data were derived. These sums contain each three significant figures. They had the following values for the columns specified :—

Column . . .	$n+24$.	$n+25$.	$n+26$.	$n+27$.	$n+28$.	$n+29$.	$n+30$.	$n+31$.	$n+32$.	$n+33$.
Sum	430	467	545	620	607	556	523	476	464	440

Calculations were made on the following lines :—

$$\text{Basis (i)}\left\{\begin{array}{l}\text{From day } n+26 \text{ to day } n+27 \text{ rise of } 75 \text{ per diem,}\\ \quad ,, \quad n+28 \quad ,, \quad n+29 \text{ fall } ,, \; 51 \quad ,, \;.\end{array}\right.$$

$$\text{Basis (ii)}\left\{\begin{array}{l}\text{From day } n+25 \text{ to day } n+27 \text{ mean rise of } 76{\cdot}5 \text{ per diem,}\\ \quad ,, \quad n+28 \quad ,, \quad n+31 \quad ,, \text{ fall } ,, \; 43{\cdot}6 \quad ,, \;.\end{array}\right.$$

If we assume the rates of change between day $n+27$ and the summit, and between the summit and day $n+28$, to be first as in (i), second as in (ii), we find for the period—

On basis (i) 27·30 days,
,, (ii) 27·25 ,, .

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[*] 'Veröffentlichungen des k. Observatoriums in Wilhelmshaven,' Blatt 1–4, 1910, 1911.

The rise to the crest was clearly more rapid than the subsequent fall, the secondary pulse resembling closely in this respect the primary, for which successive character totals ran as follows :—

Column . .	$n-3$.	$n-2$.	$n-1$.	n.	$n+1$.	$n+2$.	$n+3$.	$n+4$.	$n+5$.
Sum . . .	423	510	690	996	731	570	511	463	438

Assuming a uniform progression between days $n-3$ and $n-4$, and again between days $n+4$ and $n+5$, we find

Value 430 occurring at $n-2{\cdot}92$ as well as at $n+24$,
,, 440 ,, $n+4{\cdot}92$,, ,, $n+33$.

These two values come near the beginning and end of both pulses, and we may thus regard 7·84 days in the primary pulse as represented by the somewhat increased width of 9 days in the secondary pulse. If now we assume the widening exhibited by the secondary pulse to be contributed to in like proportion from the parts which precede and follow the crest, and take $27+x$ as the time of the crest, we have

$$(3+x)\div\{5+(1-x)\} = 2{\cdot}92/4{\cdot}92,$$

whence $x = 0{\cdot}35$, and so period $= 27{\cdot}35$ days.

From these and other similarly rough calculations I should assign to the period as indicated by the 11-year data the duration $27{\cdot}3 \pm 0{\cdot}1$ days. Of any period shorter than this there seems not even a suggestion in the 11-year figures.

§ 24. Let us now return to a consideration of the results from the three shorter groups of years in Table XI. The figures are naturally less smooth than those in the first line, but all the groups show the 27–28-day period. Analogous figures were really got out for each half-year separately, and of these 22 sets of data there was not one that did not show enlarged values in the immediate neighbourhood of days $n+27$ and $n+28$. In every instance the mean from columns $n+26$ to $n+30$ exceeded the mean from columns $n+20$ to $n+25$, and in 14 of the half-years the largest value in any column subsequent to $n+5$—*i.e.*, subsequent to columns clearly affected by the preliminary pulse—occurred in one or other of the columns $n+27$ and $n+28$. There was only one whole year, 1894, in which the figures in columns $n+27$ and $n+28$ were both exceeded by the figure in any other column subsequent to $n+5$.

If we take the ratio borne by the larger of the two figures in columns $n+27$ and $n+28$ to the figure in column n as a measure of the prominence of the 27–28-day period, we find 0·62 for the whole 11 years, 0·59 for the sunspot maximum period, and 0·67 for the group composed of 1891, 1895, and 1896. The 27–28-day period was thus considerably most in evidence in the group of years which gave the faintest indication of the magnetic pulse following 4 days after the sunspot area pulse, and it was least in evidence in the sunspot maximum group of years, which gave the most prominent indication of the above pulse. The prominence of the 27–28-day period in the sunspot minimum groups of years, which contained comparatively few magnetic storms, would alone suffice to show that the phenomenon, whatever its nature, is not confined to outstanding disturbances such as those chronicled by Mr. MAUNDER.

A special feature in the results for 1891, 1895, and 1896 is a faint indication of a shorter period of about 14 days. The figures for this group of years in columns $n+13$ to $n+16$ all exceed the figure in any other column between $n+5$ and $n+23$. This seems hardly likely to be pure accident, and it may represent Prof. SCHUSTER's 13·64 days' period.

§ 25. In view of the interest attaching to the reality of a 27–28-day period, a similar investigation to the preceding was carried out for the two years 1894 and 1895, employing the H ranges instead of the character figures.

These two years were selected because, when character figures were employed, the one, 1895, showed the 27–28-day period specially clearly, while the other, 1894, showed it less clearly than perhaps any other year. The investigation based on H ranges took account only of the 5 representive days a month and the 35 following days. The results are given in Table XII., accompanied by the corresponding results previously obtained from the character figures. To facilitate comparison, both sets of figures are expressed as percentages of the arithmetic mean value derived from the 36 columns.

In the case of 1894 two sets of H range figures are given. The former and the character figures given depend on all the 60 selected days of the year. In obtaining the second set of H range figures, all ranges were omitted which exceeded 200γ, and a mean was taken from the remaining figures in each column. The object was to see the effect of omitting a few of the larger magnetic storms—all, in fact, which gave H ranges in excess of the largest range of 1895.

The data from 1895, though naturally not as smooth as the 3-year and 11-year data in Table XI., show the 27–28-day period quite as clearly. It is as unmistakable in the range as in the character figures. Again both range and character figures afford distinct indications of a 13–14-day period, which it will be remembered appeared in Table XI. only in the group of years containing 1895.

In 1894 the character figures and the range figures (i) both show not a peak at day $n+27$ or $n+28$, but a high plateau extending from about day $n+25$ to day $n+34$. The range figures, in fact, would seem to favour a Schmidt, or 30-day period, rather than a 27–28-day period. The reason of this is clear on examining the range (ii) figures. The high values in the range (i) figures in column $n+29$ and subsequent columns were mainly due to the fact that two outstanding ranges, respectively 637γ and 660γ, "happened" to fall one or both in these columns.

§ 26. The investigation embodied in Tables XI. and XII., though leading to somewhat unexpected results possessed of intrinsic interest, does not afford an immediate explanation of the phenomenon for which an explanation was being sought, viz., the

TABLE XII.—Percentage Values from Character Figures and H Ranges on 36 Consecutive Days, including the Representative Day n, of Large H range.

Year.	Data.	n.	$n+1$.	$n+2$.	$n+3$.	$n+4$.	$n+5$.	$n+6$.	$n+7$.	$n+8$.	$n+9$.	$n+10$.	$n+11$.	$n+12$.	$n+13$.	$n+14$.	$n+15$.
1895	Character figures . .	179	141	121	121	107	97	86	91	81	76	72	93	95	103	114	103
	H ranges	169	123	108	97	92	90	90	88	86	87	92	92	104	107	105	101
1894	Character figures . .	183	146	118	106	103	93	95	99	101	91	77	84	78	78	86	80
	H ranges (i)	215	144	119	97	100	102	82	91	99	87	81	84	80	83	80	77
	,, (ii)	174	121	106	98	102	96	92	93	100	92	91	94	89	94	90	86

Year.	Data.	$n+16$.	$n+17$.	$n+18$.	$n+19$.	$n+20$.	$n+21$.	$n+22$.	$n+23$.	$n+24$.	$n+25$.
1895	Character figures . .	98	97	76	86	81	81	76	81	98	93
	H ranges	102	91	83	87	88	88	82	89	100	108
1894	Character figures . .	73	88	84	90	78	101	101	78	90	112
	H ranges (i)	77	87	98	86	82	92	100	87	89	108
	,, (ii)	86	98	96	89	92	98	108	93	90	102

Year.	Data.	$n+26$.	$n+27$.	$n+28$.	$n+29$.	$n+30$.	$n+31$.	$n+32$.	$n+33$.	$n+34$.	$n+35$.
1895	Character figures . .	114	133	131	110	110	98	98	84	86	86
	H ranges	114	128	119	114	104	97	98	93	91	93
1894	Character figures . .	119	108	106	114	112	105	106	101	106	108
	H ranges (i)	107	103	105	111	125	121	104	105	101	91
	,, (ii)	114	112	105	103	103	100	101	96	103	93

TABLE XIII.—Incidence of Different Magnetic Characters in 31 Consecutive Days, including the Representative Day n of Large Sunspot Area.

	$n-15$.	$n-14$.	$n-13$.	$n-12$.	$n-11$.	$n-10$.	$n-9$.	$n-8$.	$n-7$.	$n-6$.	$n-5$.	$n-4$.	$n-3$.	$n-2$.	$n-1$.	n.
Character "2" days . .	76	**82**	**89**	**94**	**96**	**94**	**87**	81	67	73	78	72	67	71	73	78
" "1" " . .	288	282	279	**303**	296	**306**	**300**	**301**	290	281	273	275	290	280	293	297
Disturbed days	364	364	368	**397**	**392**	**400**	**387**	**382**	357	354	351	347	357	351	366	375
Quiet "	**296**	**296**	**292**	263	268	260	273	278	**303**	**306**	**309**	**313**	**303**	**309**	**294**	**285**

	$n+1$.	$n+2$.	$n+3$.	$n+4$.	$n+5$.	$n+6$.	$n+7$.	$n+8$.	$n+9$.	$n+10$.	$n+11$.	$n+12$.	$n+13$.	$n+14$.	$n+15$.	Mean from 31 columns.
Character "2" days . .	**82**	**89**	**85**	**86**	**88**	**89**	80	**86**	**83**	**82**	**89**	**87**	80	81	75	81·9
" "1" " . .	**302**	295	**321**	**332**	**325**	**320**	**319**	**312**	**314**	**315**	**301**	290	295	**304**	**311**	299·7
Disturbed days	**384**	**384**	**406**	**418**	**413**	**409**	**399**	**398**	**397**	**397**	**390**	377	375	**385**	**386**	381·6
Quiet "	276	276	254	242	247	251	261	262	263	263	270	**283**	**285**	275	274	278·4

inconspicuousness of the crest in column $n+4$ of Tables V. and VII. in the case of the group of years 1891, 1895, 1896, and the great development of the crest occurring 14 or 15 days earlier. There is, it is true, in Table XI. and XII. some indication of a period of about 14 days for the years 1891, 1895, and 1896, which is not apparent in the other groups of years, and this would help to explain an increased prominence in the crest about column $n-11$ in Tables V. and VII., if the crest in column $n+4$ had its usual prominence. But it cannot by itself account for the earlier and presumably secondary pulse being more prominent than the later.

Table XIII. aims at throwing further light on the phenomena of Tables V. and VII. A given mean H range, or a given mean character figure, may arise in many different ways. Of two collections of equal numbers of days which have the same mean range or character figure, one will contain a larger number of days of character "2" than the other. It appeared desirable to ascertain whether increase in a mean character figure in Table VII. arose from similar increases in the number of days of character "1" and "2," or whether it denoted a special development of highly disturbed days.

Each mean value in Table VII. for the 11-year period was derived from 660 days. Table XIII. shows how many of these were of character "2," and how many were of character "1." The days of character "2" and "1" combined give the total of disturbed days, and the difference between this total and 660 gives the number of days of character "0," *i.e.*, quiet days. The last column in Table XIII. gives the mean of the corresponding entries in columns $n-15$ to $n+15$, showing that on the average out of the 660 days in each column 82 were of character "2," 300 of character "1," and 278 of character "0." Figures which exceed the means in the last column are in heavy type.

Table XIII. makes it clear that the secondary pulse in Table VII., with crest about column $n-11$, is due almost entirely to an excess of days of character "2," while the primary pulse, with crest about column $n+4$, is mainly due to an excess of days of character "1." The number of days of character "2" in columns $n-12$, $n-11$, and $n-10$ notably exceeds that in any other column.

Quiet days are markedly in excess of the mean from 7 to 1 day previous to the day of largest spot area, and they are even in slight excess on the representative day itself. They are also decidedly in excess in columns $n-15$ to $n-13$, though their excess in column $n-13$ is neutralised by the co-existing excess in the number of days of character "2."

On the whole, it may be said that the primary pulse is due rather to the absence of quiet conditions than to the presence of large disturbance.

§ 27. Table XIV. serves the same purpose relative to Table XI. that Table XIII. served relative to Table VII. It proceeds, however, on a slightly different plan, and gives some data for the 3-year periods in addition to those for the whole 11 years. The first four lines give the total number of days of character "2." Consider, for example,

TABLE XIV.—Incidence of Magnetic Character in 41 Consecutive Days, including the Representative Day n of Large H Range.

	$n-5$.	$n-4$.	$n-3$.	$n-2$.	$n-1$.	n.	$n+1$.	$n+2$.	$n+3$.	$n+4$.	$n+5$.	$n+6$.	$n+7$.	$n+8$.	$n+9$.	$n+10$.
1890, 1899, 1900, number of "2's" .	10	11	12	19	29	54	26	12	9	12	11	5	3	5	9	9
1891, 1895, 1896, ,, "2's" .	22	19	30	55	79	132	73	49	35	25	22	15	22	23	24	24
1892, 1893, 1894, ,, "2's" .	23	20	17	25	57	108	54	23	19	19	19	17	16	14	10	13
Eleven years, ,, "2's" .	63	66	75	**118**	**205**	**365**	**184**	**101**	76	73	65	47	53	55	51	57
,, ,, ,, "1's" .	293	271	273	274	280	266	**363**	**368**	**359**	**317**	**308**	**316**	**309**	**314**	**310**	288
,, ,, disturbed days . . .	356	337	348	**392**	**485**	**631**	**547**	**469**	**435**	**390**	373	363	362	369	361	345
,, ,, quiet days	**304**	**323**	**312**	268	175	29	113	191	225	270	**287**	**297**	**298**	**291**	**299**	**315**

	$n+11$.	$n+12$.	$n+13$.	$n+14$.	$n+15$.	$n+16$.	$n+17$.	$n+18$.	$n+19$.	$n+20$.	$n+21$.	$n+22$.	$n+23$.	$n+24$.	$n+25$.
1890, 1899, 1900, number of "2's" .	10	7	6	11	11	9	6	3	3	7	5	5	8	11	16
1891, 1895, 1896, ,, "2's" .	27	30	33	39	36	32	26	21	24	22	18	24	25	33	42
1892, 1893, 1894, ,, "2's" .	14	14	14	15	16	16	24	18	15	9	20	26	19	16	21
Eleven years, ,, "2's" .	62	58	62	77	70	63	70	60	52	50	55	66	66	77	**96**
,, ,, ,, "1's" .	292	298	294	269	275	289	277	282	301	**310**	**311**	292	284	276	275
,, ,, disturbed days . . .	354	356	356	346	345	352	347	342	353	360	366	358	350	353	371
,, ,, quiet days	**306**	**304**	**304**	**314**	**315**	**308**	**313**	**318**	**307**	**300**	**294**	**302**	**310**	**307**	**289**

	$n+26$.	$n+27$.	$n+28$.	$n+29$.	$n+30$.	$n+31$.	$n+32$.	$n+33$.	$n+34$.	$n+35$.	Mean values.
1890, 1899, 1900, number of "2's" .	21	22	19	13	13	12	12	11	7	5	10
1891, 1895, 1896, ,, "2's" .	48	65	65	45	34	23	21	19	24	17	33
1892, 1893, 1894, ,, "2's" .	24	32	26	28	22	25	28	24	17	12	21
Eleven years, ,, "2's" .	**120**	**148**	**132**	**101**	**90**	75	71	65	62	47	79
,, ,, ,, "1's" .	**305**	**324**	**343**	**354**	**343**	**326**	**322**	**310**	300	**312**	302
,, ,, disturbed days . . .	**425**	**472**	**475**	**455**	**433**	**401**	**393**	375	362	359	381
,, ,, quiet days	235	188	185	205	227	259	267	**285**	**298**	**301**	279

the column headed n. This relates to the 5 days of largest H range in each month. These days total 180 in each of the 3-year periods, and 660 in the eleven years. Of the 180 selected days in the first 3-year group only 54 attained character "2." The corresponding numbers in the second and third 3-year groups were respectively 132 and 108, and of the 660 days selected from the 11 years 365 reached character "2."

The three last lines in Table XIV. all relate to the whole 11 years. Still considering column n, we learn that 266 of the 660 days had character "1." Combining these with the 365 days of character "2," we have in all 631 disturbed days, leaving 29 days of character "0." Nearly all these 29 quiet days came from the last months of 1900, when days of character "2" were non-existent, and days of character "1" were rare.

The data in columns $n-5$ to $n-1$, to $n+1$ to $n+35$, have an exactly similar significance. They refer, as in Table XI., to the 5 days before and the 35 days after the selected days of largest H range. The last column in the table shows what numbers we should have got from average days of the years concerned. Eleven-year data in columns $n-5$ to $n+35$ which exceed the corresponding figures in the last column are in heavy type.

The results relating to the character "2" figures from the 11 years are shown graphically in the broken line curve of fig. 2, p. 100.

The number of days of character "1" in the 11 years is very notably in excess of the mean in columns $n+27$ to $n+32$, but it is the great development of character "2" figures that is mainly responsible for the prominence of the 27–28-day period in Table XI. Taking the 11-year data, the number of days of character "2" is above the mean only in columns $n-2$ to $n+2$ and $n+25$ to $n+30$. The rise to the crest and the subsequent subsidence in the primary pulse of character "2" figures are exceedingly rapid, and the same is true to only a slightly less extent of the secondary pulse. The numbers of days "2" in columns $n+27$ and $n+28$ exceed those in columns $n-2$ and $n+2$, and simply tower over the numbers in columns $n+3$ to $n+24$. The relative prominence of the character "2" figures in columns $n+27$ and $n+28$ is even greater for the two first 3-year periods in Table XIV. than for the 11-year period. In the third or sunspot maximum group of years this prominence is less.

The number of days of character "1" is much less variable in Table XIV. than the number of days of character "2." When, however, there are a large number of the latter days there are so many the fewer available for other character figures. Thus the number of days of character "1" is perhaps less instructive than the number of disturbed days as a whole. This latter number subsides much less rapidly than it rises in both the primary and secondary pulses. This presumably is a direct consequence of the known fact that while a highly disturbed day often immediately follows a quiet day, the converse is rare.

The fewness of quiet days in columns $n+26$ to $n+30$ presents the 27–28-day period in perhaps as striking a light as any.

The standard of disturbance qualifying for "2" in the present investigation is low compared to that adopted by Mr. MAUNDER as denoting a "magnetic storm." During the 11 years as a whole nearly 1 day in 8 was allotted "2," while Mr. MAUNDER on the average had only about one storm—lasting some 30 hours—in 28 days.

With the standard adopted here, the chance of the magnetic disturbance attaining character "2" is about twice as great for a day which follows either 27 or 28 days after a day of character "2" as it is for the average day of the year.

§ 28. Table XV. gives for each year of the eleven WOLFER'S mean sunspot frequency, the number of days of character "0," "1," and "2," and the corresponding character figure for the average day, and finally the mean values of the absolute daily H and D ranges. The D ranges are expressed in terms of force, on the basis that a 1′ change of declination corresponded to a force of $5{\cdot}32\gamma$ acting perpendicular to the magnetic meridian.

TABLE XV.—Results for Individual Years.

Year.	WOLFER'S sunspot frequency.	Number of days of character.			Mean character figure.	Absolute daily range (unit 1γ).	
		0.	1.	2.		H.	D.
1890	7·1	193	155	17	0·51	44·8	56·8
1891	35·6	147	159	59	0·76	60·8	73·2
1892	73·0	129	189	48	0·78	84·0	94·2
1893	84·9	140	191	34	0·71	69·7	83·1
1894	78·0	98	220	47	0·86	81·4	87·8
1895	64·0	97	194	74	0·94	67·9	82·9
1896	41·8	132	168	66	0·82	64·5	77·2
1897	26·2	152	167	46	0·71	51·8	64·6
1898	26·7	161	158	46	0·68	56·0	65·4
1899	12·1	176	152	37	0·62	49·6	60·3
1900	9·5	274	82	9	0·27	37·3	48·8
Means . . .	41·7	154	167	44	0·70	60·7	72·2

As already remarked, it is difficult to avoid sensible fluctuations in the standard of character figures, but the range figures support the character figures in representing 1893—the year of largest sunspot frequency—as very decidedly less disturbed than the two adjacent years. Again, all the criteria agree in representing 1900 as decidedly the quietest year, though 1890 had fewer sunspots.

The range of the regular diurnal inequality was largest in the year of sunspot maximum. Other things being the same, the absolute range would naturally increase with that of the diurnal inequality. There is thus nothing surprising in the fact that the D and H absolute ranges in 1891, 1895, and 1896 are exceeded by those of 1893, though the character figure obtained for the latter year is less. Whether the character figure for 1892 ought really to be less than that for 1896, and whether the character figure of 1895 should be the largest of all, are results more open to doubt. The mean of the absolute daily ranges in 1892 and 1894, whether in H or D, decidedly exceeded that of any other year; but this was at least partly due to the incidence in these two years of an altogether outstanding proportion of the largest magnetic storms of the 11 years.

The H and D figures in Table XV. place the 11 years in exactly the same order as regards amplitude of range. In 1891, 1893, 1895, 1896, and 1897, the ratio borne by the mean D range to the mean H range lies between 1·19 and 1·22. The extreme values of the ratio are 1·08 in 1894 and 1·31 in 1900.

§ 29. Table XVI. distributes the total number of days of character "0," "1," and "2" under the twelve months to which they belong, and gives the corresponding mean value of the character figure. It also gives for comparison the corresponding mean absolute daily ranges in H and D, the latter expressed in terms of force as in the previous table.

TABLE XVI.—Results for the 12 Months. Totals and Means (11 Years 1890 to 1900).

Month.	Number of days of character.			Mean character figure.	Absolute daily range (unit 1γ).	
	0.	1.	2.		H.	D.
January	151	150	40	0·67	46·5	59·4
February	109	145	56	0·83	60·1	72·8
March	113	163	65	0·86	66·7	84·7
April	133	157	40	0·72	67·6	79·8
May	150	155	36	0·67	68·8	79·3
June	154	148	28	0·62	66·9	72·6
July	159	144	38	0·64	70·6	75·2
August	151	166	24	0·63	68·0	75·7
September	129	161	40	0·73	66·4	77·5
October	124	165	52	0·79	59·7	74·9
November	155	141	34	0·63	47·6	62·3
December	171	140	30	0·59	39·8	52·1

The more or less disturbed character of a month may be regarded as indicated either by the mean value of the character figure, or by the fewness of the days of character "0" as compared to the total. On either criterion, March was the most disturbed month, followed at no great interval by February and October. March was also the month of largest D range, but the H range in March was slightly exceeded in each of the five months April to August.

December had the fewest days of disturbance, the smallest mean magnetic character,

TABLE XVII.—Percentage Values of H Ranges (ordinary type) and Character Figures (heavy type).

	January.		February.		March.		April.		May.		June.		July.		August.		September.		October.		November.		December.		Year.	
1890	76	**81**	72	**73**	59	**53**	68	**51**	59	**68**	71	**59**	72	**70**	77	**87**	84	**96**	91	**110**	88	**95**	79	**44**	75	**74**
1891	75	**57**	79	**94**	100	**131**	110	**148**	110	**136**	90	**86**	87	**75**	102	**118**	112	**137**	120	**119**	106	**89**	108	**99**	100	**107**
1892	121	**91**	188	**137**	171	**131**	124	**93**	133	**102**	124	**86**	166	**140**	141	**93**	106	**114**	125	**110**	115	**95**	134	**143**	137	**111**
1893	119	**115**	98	**90**	101	**90**	115	**65**	95	**73**	128	**108**	118	**100**	130	**113**	120	**128**	120	**114**	127	**142**	108	**88**	115	**102**
1894	132	**101**	164	**115**	117	**83**	117	**102**	120	**121**	142	**162**	151	**155**	140	**113**	133	**132**	120	**119**	156	**174**	116	**126**	134	**125**
1895	102	**120**	110	**128**	113	**128**	120	**139**	111	**121**	123	**156**	114	**145**	85	**98**	94	**110**	123	**164**	135	**163**	117	**143**	112	**135**
1896	137	**172**	113	**150**	103	**128**	110	**121**	114	**116**	90	**97**	96	**125**	111	**144**	116	**91**	97	**90**	91	**79**	98	**94**	106	**117**
1897	86	**76**	70	**94**	78	**105**	115	**158**	100	**111**	83	**108**	76	**70**	75	**98**	73	**78**	85	**102**	79	**105**	111	**116**	86	**102**
1898	85	**101**	81	**73**	110	**94**	77	**84**	94	**97**	93	**108**	85	**110**	91	**113**	116	**105**	92	**90**	84	**89**	95	**126**	92	**99**
1899	84	**96**	70	**107**	76	**83**	83	**97**	94	**111**	90	**97**	78	**85**	84	**93**	90	**91**	70	**57**	71	**53**	88	**99**	82	**89**
1900	84	**91**	56	**39**	72	**75**	61	**42**	71	**44**	65	**32**	57	**25**	63	**31**	54	**18**	58	**25**	48	**16**	46	**22**	61	**39**

and decidedly the smallest daily range in both H and D. August and June, however, had a smaller number of days of character "2."

On the average of the 12 months, the D range is about 20 per cent. greater than the H range; but the proportional excess is notably less in June, July, and August than in the midwinter months.

§ 30. Table XVII. represents an attempt to reach comparative results for the 132 months of the 11 years. The figures in ordinary type were obtained from the mean values of the absolute daily H ranges in individual months. The value for each of the 11 Januarys was expressed as a percentage of the mean of the 11 January values, and the same was done for the other months of the year. This was intended to eliminate the annual variation in the amplitude of the daily range. The figures in heavy type were derived from the character figures, the value for each month being again expressed as a percentage of the arithmetic mean character figure for the 11 months of the same name. The data in the two columns headed "year" represent arithmetic means of the corresponding 12 percentage values in the monthly columns.

The difficulty of maintaining a uniform standard of magnetic character in different years should be remembered, as it introduces greater uncertainty in the character data of Table XVII. than in those of any previous table. Consider, for example, what would happen if the standard for characters "1" and "2" were lower for 1896 than other years. In January 1896 the character figure was remarkably large, as compared to that of the other months of the year. The consequence of the hypothetical low standard would be not merely to unduly exalt the character figure for January 1896 in Table XVII., but also to depress the character figures in all the other Januarys.

The data in the second last column of Table XVII. put the years in the same order as the corresponding data in Table XV.

The daily range remains very considerable in the quietest times when character figures are nearly all "0." Thus the range figures in Table XVII. naturally fluctuate within narrower limits than the character figures. The extreme smallness of the latter towards the end of 1900 is particularly striking.

While there are many marked differences in the order in which the two sets of figures place the months, a conspicuously high value in the one set of figures is nearly always associated with a high value in the other. January, 1896, March, 1892, June, 1894, November, 1894, and December, 1892, stand first in both lists for months of the same name; while February, 1892, July, 1894, September, 1894, October, 1895, November, 1895, and December, 1895, stand either first or second in both lists.

If we take a mean between the two sets of figures, November, 1894, was relatively the most disturbed, and November, 1900, was relatively the quietest month of all. February, 1892, from the same standpoint, only just fell short of November, 1894, and was followed after a slight interval by January, 1896, July, 1892, July, 1894, and June, 1894.

§ 31. An attempt was made to utilise the figures of Table XVII. in a similar way to that adopted earlier in the paper with daily magnetic values. Use was made of WOLFER's frequencies instead of the Greenwich sunspot areas, because mean values of the former were available for all months of the 11 years.

The three months of highest sunspot frequency in each year were entered in column n, the three months immediately preceding in column $n-1$, and the three months immediately subsequent in column $n+1$. The months having been thus arranged in three columns, corresponding lists were made of WOLFER's frequencies, and of the two sets of percentage figures in Table XVII. Exactly the same operations were then gone through, taking as basis the three months of least sunspot frequency in each year.

The mean results thus found from the eleven years are given in Table XVIII.

TABLE XVIII.—Data from Three Months of Largest and Three Months of Least Sunspot Frequency in each Year, 1890 to 1900.

	Sunspot frequencies.			H ranges, percentages.			Character figures, percentages.		
	$n-1$.	n.	$n+1$.	$n-1$.	n.	$n+1$.	$n-1$.	n.	$n+1$.
Months of largest frequency	43·4	54·7	43·6	103·0	104·5	102·4	110·9	104·1	102·6
Months of least frequency .	40·8	28·8	40·0	100·1	96·3	94·1	97·7	98·9	94·8
Excess of first group . . .	2·6	25·9	3·6	2·9	8·2	8·3	13·2	5·2	7·8

The number of months was too small to eliminate accidental features. This is especially true of the character figures for reasons already stated.

The greater uncertainty of the character figures is borne out by the fact that while the mean percentage value from the 3 months of largest sunspot frequency exceeded the corresponding mean from the 3 months of least frequency in every single year in the case of H ranges, the same phenomenon occurred in only 7 of the 11 years in the case of character figures.

The 4 days retardation, shown in Tables V. and VII., would lead to some association of sunspot frequency with magnetic phenomena in the following month, but even the H range figures in Table XVIII. suggest more connection than this would account for.

§ 32. In the case of the range, R, of mean diurnal inequality for the year in H at Kew, the formula found by applying the method of least squares to the observations of the 11 years, 1890–1900, may be written

$$R = R_0 (1 + 1{\cdot}07 \times 10^{-2} S), \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where R_0 denotes the range in an ideal year of no sunspots and S is WOLFER's sunspot frequency.

A rise of 100 in S would increase R by 107 per cent. of R_0. Hitherto, in the present paper, we have been employing as unit not R_0 but what is practically the mean value of R for the period concerned. Taking, for instance, the whole 11 years, for which the mean value of S was 41·7, and representing by $\overline{R}$ the mean value of R for the period, we may replace (1) by

$$R = \overline{R}\,(1+1{\cdot}07\times10^{-2}S)\div(1+1{\cdot}07\times0{\cdot}417)$$

$$= \overline{R}\,(1+1{\cdot}07\times10^{-2}S)/1{\cdot}446 \qquad (2)$$

In the case of the 11 years in Table IV. the difference between the extreme values of the Greenwich spot areas during the 31 days was 150 per cent. of the mean value. No serious error will arise in regarding Greenwich areas and WOLFER's frequencies as standing to one another in a constant ratio, or in assuming the mean value of the frequency for the representative 31 days to be exactly 41·7. If, then, the variation in absolute ranges on individual days followed, except for a lag, the same law as that of inequality ranges in individual years, the anticipated variation of H ranges in Table V. would have been

$$\overline{R}\,(1{\cdot}07\times0{\cdot}626)/1{\cdot}446,$$

and the change expressed as a percentage of the mean value would thus have been 46·3.

The percentage change actually seen in the H ranges was

$$111{\cdot}6-93{\cdot}5 = 18{\cdot}1,$$

or only 0·39 of that just deduced from the formula.

Again, taking the data of Table XVIII., in columns n, we have a percentage change of 8·2 in the absolute range, corresponding to a difference of 25·9 per cent. in sunspot frequency.

If the change in the absolute range had, in this case, followed the law embodied in (2), its amplitude as a percentage of its mean value would have been

$$1{\cdot}07\times25{\cdot}9/1{\cdot}446 = 19{\cdot}2.$$

The ratio of the observed to the calculated value in this case is

$$8{\cdot}2/19{\cdot}2 = 0{\cdot}43.$$

A still larger value for this ratio is obtainable from the H range data in Table V. for the years 1892 to 1894. The range of sunspot areas in the representative 31 days was 135 per cent. of the mean value, and the mean value of WOLFER's frequency for the 3 years was 78·6.

Thus the percentage change of H range calculated as in (2) would have been

$$(1{\cdot}07 \times 78{\cdot}6 \times 1{\cdot}35) \div (1 + 1{\cdot}07 \times 0{\cdot}786) = 62,$$

while the percentage change given in Table V. is 40. Thus the ratio of the observed to the calculated change is 0·65.

§ 33. Even mean annual values of the absolute H ranges do not vary with sunspot frequency at all as closely as do the diurnal inequality ranges. Still, if we compare any one of the 3 years of sunspot maximum, 1892, 1893, 1894 with any one of the 3 years of minimum, we find a greater difference between the absolute ranges than between the inequality ranges. Thus everything points to the conclusion that the magnetic wave, with crest 4 days after that of sunspots, represents only a part—in general, probably the smaller part—of the sunspot influence.

In addition, there seems to be an influence which maintains a high average range of diurnal variation in years of many sunspots, so that even when sunspot area for several days in succession falls to a comparatively low level, the daily range continues to exceed that normal to the same month of a year having the same mean sunspot area as the specified days.

Also there is a more distinctively disturbance element whose amplitude does not appear to be directly proportional to sunspot area, and which seems largely responsible for the 27–28-day period shown in Tables XI. and XIV.

It must be remembered that Tables V. and VII. cover only a sufficient number of days to show a sunspot influence which acts on the earth within 15 days of the sunspot phenomenon on the sun. A period longer than this, but shorter than 2 months, is not contradicted by Table XVIII.

Again, sunspots may not themselves be the actual sources of the solar influence, but only symptoms that something is happening, has already happened, or may only be about to happen, which exerts an influence on the earth.