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# Magnetic Declination at Kew Observatory, 1890 to 1900

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# V. *Magnetic Declination at Kew Observatory*, 1890 *to* 1900.

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(*From the National Physical Laboratory.*)

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Contents.

§ 1. In 1903 I carried out an analysis*—referred to here for brevity as A—of the results given by the Kew magnetographs on "quiet" days during the 11 years 1890 to 1900. This investigation brought to light various novel phenomena. It was subsequently shown—in a paper † to be referred to as B—that these phenomena are equally true of "quiet" days at Falmouth. Some of the phenomena suggested the

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* 'Phil. Trans. Roy. Soc.,' A, vol. 202, p. 335, 1903.

† 'Phil. Trans. Roy. Soc.,' A, vol. 204, p. 373, 1905.

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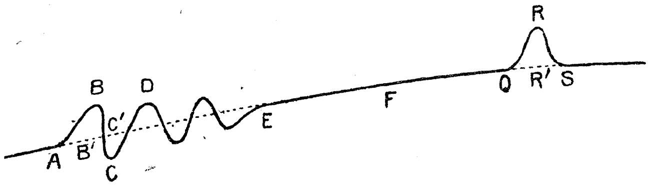
possibility of differences of a certain kind between quiet days and other undisturbed days, and between ordinary days and disturbed days. To prosecute this enquiry, it was necessary to make an analysis of the data from all days at Kew from 1890 to 1900. Declination being the element of most practical interest, and least open to instrumental uncertainties, it was decided to treat it thoroughly in the first instance.

§ 2. In measuring the quiet day curves at Kew—a practice instituted in 1890—it has been usual to smooth them when any little irregularities occur, by drawing a free-hand pencil trace following the general trend. It was decided, with some hesitation, to continue the practice, so that the results from all days should be as strictly comparable as possible with those from quiet days. The nature of the difficulties will be understood from the accompanying diagram. The continuous line curve ABCDEFQRS represents a hypothetical photographic record. The dotted line AB′C′R′ represents the smoothed curve. When the object aimed at is the regular diurnal inequality, it will probably be generally conceded that the method of smoothing adopted is satisfactory so far as the wave-like portion ABCDE is concerned, at least so long as the interval of time corresponding to this portion is under an hour. If, however, the times from A to B and from B to C were each an hour, the procedure would be disapproved by some authorities, who would argue that the free-hand curve should always be drawn so that its ordinate at any particular hour should represent the arithmetic mean of an infinite number of ordinates, uniformly distributed in time throughout the preceding and succeeding 30 minutes. It should, however, be remembered that the exact instant when an hour falls is really arbitrary. One observer may use Greenwich time, another local, and if the smoothing were carried out in accordance with the view last mentioned, it might make all the difference which choice happened to have been made. A disturbance such as QRS presents difficulties of another kind. If the time interval from Q to S is only a few minutes, and the general trend of the curve is very clearly shown, and closely similar to that of the average day, there can, I think, be little doubt that the best plan—at least when diurnal inequalities are concerned—is simply to disregard the disturbance altogether. If, however, the time from Q to S is considerable, and the general trend of the curve not clearly shown, the appropriate treatment is difficult to determine.



§ 3. The smoothing process was done partly by Mr. Baker, the Chief Assistant, and partly by myself. In some cases even considerable disturbances presented little difficulty, the oscillations being on the whole regular and the general trend of the curve clearly shown; but it was soon apparent that in other cases smoothing would be altogether too arbitrary a process. It was decided to omit such *disturbed* days entirely when calculating the regular diurnal inequality. The days thus omitted numbered 209, or an average of 19 a year.

§ 4. It should be clearly understood that in classifying a day as "disturbed," regard was paid exclusively to the nature and not to the mere magnitude of the disturbance. If the irregular movements were mainly of the type seen at QRS in the diagram on p. 206, or if the declination showed an abnormally high or low value for several successive hours, the curve was classified as disturbed, though the range might be less than in a neighbouring "ordinary" curve where the disturbances approached the type illustrated by ABE of the diagram. That the method of choice is open to criticism, I freely acknowledge. It introduces a personal element, and something unquestionably depends on the individual's freshness and nerve at the moment. If in his best form, he may at once make up his mind how to smooth a disturbed curve, even when heroic rectifications are necessary, whilst if he is tired and hesitates he probably in the end relegates the curve to the disturbed class. The selection of the disturbed days was in every case made by myself, and the curves for a single year were always considered together. Thus I regard the number of disturbed days as more appropriate for determining the relative amount of disturbance at different seasons of the year than for comparing one year with another. I have discussed this question at some length because other criterions for disturbance have been applied. Thus Mr. ELLIS has classified days as disturbed, and as of greater or less disturbance, mainly according to the amplitude of the range, and his classification has been followed by Mr. MAUNDER in his interesting researches into the relationship between sunspots and magnetic storms at Greenwich. At first sight, a reference to amplitude seems a simpler and more satisfactory method than the one that I have adopted, but it is in reality, as I have explained elsewhere, highly arbitrary. This will, I think, be recognised on referring to Table XIV., showing the mean of the *absolute daily ranges* (maximum less minimum) for each month from 1890 to 1900. The mean, it will be seen, varied in individual months from 4′·73 in December, 1900, to 24′·02 in March, 1892, and taking the mean of the twelve months it varied from 9′·17 in 1900 to 17′·70 in 1892. Even restricting ourselves to the Astronomer Royal's quiet days, the mean ranges for August, 1892, and December, 1899, were respectively 15′·20 and 3′·12. A range of 15′ at mid-winter at sunspot minimum *may* imply much more real disturbance than a range of 30′ at the equinox near sunspot maximum.

§ 5. Mr. MAUNDER'S list for the years 1890 to 1900 included 150 disturbances. His figures, however, denote not the number of disturbed days, but what he believed to be the number of separate magnetic storms. Disturbed conditions usually last for a good many hours, and not infrequently for two or more days. Thus the number of disturbed days naturally exceeds the number of separate storms. When disturbed conditions last for several days it is sometimes doubtful whether one is dealing with one or with several storms separated by comparatively quiet interludes. If we classify as one storm all groups of successive disturbed days we have 125 storms, two of them extending from one month to the next. The distribution of these and Mr. MAUNDER's storms in the different years is shown in Table I. The difference between the totals for Kew and Greenwich arises of course simply from the method of selection. A considerable number of days treated as "ordinary" at Kew would fairly rank as days of disturbance when regarded from the standpoint either of the amplitude or the number of the oscillatory movements, and would most naturally be classified as disturbed for purposes such as those of Mr. MAUNDER. The chief difference in the totals is for 1892 and 1893, especially the latter year. In 1893, sunspots were at their maximum, and the regular diurnal range was very large. A comparatively trifling disturbance might suffice to bring the range over 20′, which Mr. ELLIS treats, at least roughly, as a minimum value for a disturbance; thus, when main importance was assigned to the amplitude of the range, it was only natural to reach a larger number for the disturbed days in 1893 than when attention was directed to the greater or less abnormality of the curve. As compared to the two adjacent years, 1893 was, in fact, remarkable for the extraordinary absence of irregular movements.

TABLE I.—Disturbances.

| Year. | Disturbances at Kew. | | Storms at Greenwich, after MAUNDER. |
|---|---|---|---|
| | Number of days. | Number of storms. | |
| 1890 | 6 | 3 | 7 |
| 1891 | 22 | 12 | 14 |
| 1892 | 30 | 18 | 26 |
| 1893 | 11 | 7 | 20 |
| 1894 | 21 | 14 | 16 |
| 1895 | 19 | 14 | 11 |
| 1896 | 39 | 18 | 18 |
| 1897 | 14 | 11 | 11 |
| 1898 | 19 | 12 | 12 |
| 1899 | 20 | 11 | 12 |
| 1900 | 8 | 5 | 3 |
| Total . . . . | 209 | 125 | 150 |

§ 6. Table II. gives the distribution of the disturbances and disturbed days throughout the year, with corresponding data from Mr. MAUNDER's list; it also gives some particulars as to the amplitudes of the movements. In two cases, March–April, 1891, and January–February, 1896, where successive disturbed days belonged to two different months, the disturbance has been counted as two. In the second of these cases *six* successive days were treated as disturbed; no other sequence of disturbed days exceeded four. The Kew data in Table II. give a smoother annual distribution than the Greenwich data, and place the equinoctial maxima—which are prominent in both cases—somewhat later in the year. Both sets of figures make the spring maximum the more important. I have shown elsewhere that Mr. MAUNDER'S figures give a less accentuated annual inequality in years of many than in years of few sunspots. The same is true of the Kew data summarised in Table II. If we group the 34 disturbed days of 1890, 1899, and 1900, the years of fewest sunspots, and the 81 disturbed days of 1892 to 1895, the years of most sunspots, we find for the percentage number of occurrences in the three seasons, viz. :—

TABLE II.—Distribution of Disturbances.

| Month. | MAUNDER'S storms at Greenwich. | Kew. Number of separate storms. | Number of days disturbed. | Mean range. | Largest range. | Number of disturbed days when range— | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Over 60′. | Between 60′ and 40′. | Between 40′ and 20′. | Under 20′. |
| | | | | ′ | ′ | | | | |
| January . | 12 | 10 | 22 | 26·5 | 49·2 | 0 | 1 | 17 | 4 |
| February . | 22 | 15 | 24 | 36·5 | >79·0 | 2 | 6 | 16 | 0 |
| March . . | 21 | 19 | 30 | 34·0 | 85·6 | 3 | 4 | 19 | 4 |
| April . . | 12 | 11 | 17 | 29·5 | 58·0 | 0 | 1 | 13 | 3 |
| May . . | 14 | 9 | 16 | 36·5 | 77·4 | 1 | 6 | 9 | 0 |
| June . . | 7 | 5 | 6 | 35·3 | 40·5 | 0 | 2 | 4 | 0 |
| July . . | 8 | 7 | 10 | 38·3 | 77·0 | 2 | 2 | 4 | 2 |
| August . | 12 | 8 | 10 | 34·2 | 83·2 | 2 | 0 | 7 | 1 |
| September. | 16 | 10 | 15 | 33·8 | 57·7 | 0 | 3 | 11 | 1 |
| October . | 9 | 14 | 25 | 25·9 | 35·9 | 0 | 0 | 21 | 4 |
| November. | 10 | 10 | 20 | 33·3 | 53·9 | 0 | 3 | 17 | 0 |
| December . | 7 | 9 | 14 | 29·1 | 50·3 | 0 | 3 | 8 | 3 |

| | Winter. (November to February.) | Equinox. | Summer. (May to August.) |
|---|---|---|---|
| Years of sunspot minimum . . | 41 | 44 | 15 |
| ,, ,, maximum . . | 41 | 34 | 25 |

§ 7. The Kew disturbed days were got out without any reference whatsoever to Mr. MAUNDER'S list. It seems thus worth while considering whether they afford support or otherwise to his conclusion that magnetic storms tend to follow one another at an interval of about $27\frac{1}{4}$ days. Defining an "interval" as the time between the noons of the first days of two successive storms, the 110 intervals shorter than 60 days which were presented by the 125 storms at Kew were as follows :—

| Interval . . . . . . . | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Occurrences . . . . . | 5 | 6 | 4 | 4 | 4 | 0 | 1 | 3 | 0 | 5 | 2 | 2 | 3 | 6 | 1 |
| Interval . . . . . . . | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
| Occurrences . . . . . | 5 | 3 | 0 | 2 | 3 | 1 | 0 | 3 | 6 | 4 | 6 | 5 | 3 | 2 | 1 |
| Interval . . . . . . . | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 |
| Occurrences . . . . . | 3 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 0 | 1 | 0 | 2 | 2 | 1 | 0 |
| Interval . . . . . . . | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | | |
| Occurrences . . . . . | 0 | 2 | 0 | 0 | 1 | 0 | 1 | 2 | 0 | 1 | 1 | 0 | 0 | | |

The number of days in the remaining 14 intervals were respectively 62, 62, 64, 65, 76, 83, 87, 89, 93, 96, 100, 107, 112 and 272.

In the case of the two-day or even the three-day intervals, it might occasionally be questioned whether the successive storms should not have been counted as one, and conversely what was really one storm may occasionally have been counted as two.

Dividing the period between the first and last of the 125 storms by 124 we deduce 30·0 days as the average interval. If, however, we omit 1890 and 1900, years in which storms were very scarce, the average interval is reduced to 27·8. This should be borne in mind when considering the significance of the considerable number of times when the interval lay between 25 and 28 days.

§ 8. The disturbed days were not absolutely the only ones excluded from the computation of the regular diurnal variation. A very small number of days had to be excluded through stoppage of the clock or other misadventure. When only a few hours' trace had been lost during a quiet time, data were interpolated with the assistance of the Falmouth curves, kindly lent by Mr. KITTO.

With a view to the study of sunspot influence on the magnetic state of individual days, it was important to have a complete set of values of the absolute daily range (maximum less minimum). Stoppage of the clock—a rare occurrence—may conceal the exact time of the maximum or minimum, but it does not hide the extent of the range. In most cases of a short failure of trace one could be absolutely certain, having regard to the corresponding Falmouth curve, that neither maximum nor minimum was involved. But in a certain number of cases, especially in January during the determination of the scale values, there was some slight uncertainty, and in these cases the range was taken from the Falmouth curves. This raises no appreciable uncertainty, for, as I have shown elsewhere, declination amplitudes at Kew and Falmouth are practically identical. Only once during the whole 11 years —viz., on February 14, 1892—was there loss of trace owing to the light going beyond the edge of the sheet during a magnetic storm. In this case the maximum was taken as at the edge of the paper, so that the range deduced, 79′, is almost certainly an underestimate. This is, I think, the sole occasion during the whole 11 years in which there was any appreciable uncertainty as to the range.

### *Mean Annual Values.*

§ 9. A question of interest is whether any sensible difference, systematic or otherwise, exists between mean yearly values derived from all *ordinary* ("undisturbed") days and from *quiet* days. In the case of Pawlowsk (St. Petersburg) MÜLLER[*] found that the mean annual values of the declination derived from WILD'S "normal" days (which are very few in number and exceptionally quiet) were throughout the period 1873–85 invariably higher (more westerly) than those derived from all ordinary days, the average excess being 0′·24. Again, W. ELLIS[†] found for the seven years 1889–96 at Greenwich that the yearly means from the Astronomer Royal's quiet days were on the average 0′·08 higher than those from ordinary days. Only one year, 1891, showed the opposite phenomenon. Recently, however, ELLIS[‡] has found that while the quiet day mean was the larger in 1903 by 0′·1, it was smaller by the same amount in 1904.

To make the comparison absolutely fair, the mean quiet day in each month ought to come exactly in the middle of the month. This is only approximately true of the Astronomer Royal's quiet days. This being so, it seemed hardly worth while attempting an accuracy of the order 0′·01 in individual years, as this would have entailed the recalculation of the quiet day mean values, which are given in A only to the nearest 0′·1. Only the last seven years of the period were considered individually. The results obtained were as follows:—

ALGEBRAIC Excess of Quiet Day Mean.

| 1894. | 1895. | 1896. | 1897. | 1898. | 1899. | 1900. | Whole 11 years. |
|---|---|---|---|---|---|---|---|
| −0′·1 | 0′·0 | +0′·1 | +0′·1 | +0′·1 | 0′·0 | −0′·1 | +0′·02 |

For Greenwich Mr. ELLIS, using the same quiet days, got +0′·1 in all three years 1894 to 1896.

Taking everything into account, all we seem entitled to infer is that the Astronomer Royal's quiet days give a yearly mean in very close agreement with that obtained when only days of marked disturbance are omitted.

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[*] 'Repertorium für Meteorologie,' vol. 12, No. 8, 1889.

[†] 'Brit. Assoc. Report for 1898,' p. 80 (see especially p. 108).

[‡] 'Roy. Soc. Proc.,' vol. 79, p. 15.

## *Diurnal Inequality.*

§ 10. Tables III. and IV. give the mean diurnal inequalities for the several months of the year derived from the "ordinary" days (including the "quiet" days) and the "disturbed" days respectively. Non-cyclic changes have been eliminated in the usual way. The data in Table III. represent arithmetic means from the 11 months of the same name in the 11 years. All the ordinary day curves were smoothed, when necessary, as already described. In the case of the disturbed days the different

TABLE III.—Diurnal Inequality. Ordinary Days (+ to West).

| Hour . . . . . | Forenoon. 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ |
| January . . . . . . . . | −1·24 | −1·01 | −0·80 | −0·76 | −0·72 | **−0·70** | −0·74 | **−0·85** | −0·63 | +0·36 | +1·61 | +2·78 |
| February . . . . . . . | −1·74 | −1·46 | −1·34 | −1·25 | −1·24 | −1·22 | **−1·16** | **−1·26** | −1·17 | −0·05 | +1·78 | +3·32 |
| March . . . . . . . . | −1·75 | **−1·68** | −1·70 | −1·72 | −1·75 | −1·79 | −2·27 | **−3·02** | −2·76 | −0·94 | +2·02 | **+4·77** |
| April . . . . . . . . | −1·42 | −1·47 | −1·63 | −1·93 | −2·19 | −2·74 | −3·64 | **−4·22** | −3·53 | −1·22 | +2·04 | +5·19 |
| May . . . . . . . . | −1·38 | −1·58 | −1·86 | −2·37 | −3·26 | −3·98 | **−4·46** | −4·17 | −2·85 | −0·27 | +2·76 | +5·24 |
| June . . . . . . . . | −1·24 | −1·48 | −1·88 | −2·61 | −3·71 | −4·61 | **−4·91** | −4·61 | −3·39 | −0·99 | +2·00 | +4·61 |
| July . . . . . . . . | −1·28 | −1·63 | −1·93 | **−2·53** | −3·68 | −4·43 | **−4·54** | −4·19 | −3·07 | −0·91 | +1·90 | +4·56 |
| August . . . . . . . | −1·66 | −1·86 | −2·13 | −2·49 | −3·19 | −3·88 | **−4·21** | −3·82 | −2·30 | +0·34 | +3·29 | +5·87 |
| September . . . . . . | −1·88 | −1·93 | −2·10 | −2·24 | −2·35 | −2·65 | **−3·07** | −3·06 | −1·85 | +0·60 | +3·46 | +5·75 |
| October . . . . . . . | −1·62 | −1·49 | −1·41 | **−1·31** | **−1·31** | −1·37 | −1·72 | **−2·40** | −2·27 | −0·47 | +2·45 | +4·58 |
| November . . . . . . | −1·31 | −0·99 | −0·81 | **−0·78** | −0·79 | −0·85 | −0·85 | **−1·12** | −1·11 | +0·01 | +1·76 | +3·18 |
| December . . . . . . | −1·18 | −0·84 | −0·66 | −0·48 | −0·47 | **−0·46** | −0·49 | −0·53 | **−0·54** | +0·19 | +1·32 | +2·41 |

| Hour . . . | Afternoon. 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | Midt. | Range. | Sum of 24 differences from mean. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ |
| January. . . . | **+3·26** | +2·66 | +1·75 | +1·23 | +0·80 | +0·30 | −0·28 | −0·88 | −1·37 | **−1·66** | −1·64 | −1·49 | 4·92 | 29·52 |
| February . . . | **+4·08** | +3·99 | +3·01 | +1·82 | +1·12 | +0·55 | −0·04 | −0·66 | −1·33 | −1·74 | −1·96 | **−1·98** | 6·06 | 39·27 |
| March . . . . | **+6·06** | +5·85 | +4·41 | +2·52 | +0·99 | +0·24 | −0·34 | −0·76 | −1·24 | −1·55 | −1·68 | **−1·80** | 9·08 | 53·61 |
| April. . . . . | **+6·73** | +6·40 | +4·79 | +3·05 | +1·50 | +0·31 | −0·34 | −0·71 | −0·96 | −1·26 | −1·36 | −1·40 | 10·95 | 60·03 |
| May . . . . . | **+6·20** | +5·86 | +4·55 | +3·07 | +1·74 | +0·62 | −0·06 | −0·38 | −0·58 | −0·77 | −0·96 | −1·16 | 10·66 | 60·13 |
| June. . . . . | +5·82 | **+6·01** | +5·14 | +3·81 | +2·30 | +1·17 | +0·41 | +0·10 | −0·16 | −0·32 | −0·61 | −0·93 | 10·92 | 62·82 |
| July . . . . . | +5·92 | **+6·05** | +5·04 | +3·52 | +2·03 | +0·93 | +0·36 | +0·10 | −0·14 | −0·38 | −0·70 | −0·98 | 10·59 | 60·80 |
| August . . . . | **+6·80** | +6·19 | +4·57 | +2·54 | +0·91 | +0·02 | −0·22 | −0·44 | −0·67 | −0·98 | −1·21 | −1·45 | 11·01 | 61·04 |
| September. . . | **+6·42** | +5·53 | +3·81 | +2·02 | +0·73 | +0·08 | −0·36 | −0·82 | −1·16 | −1·43 | −1·69 | −1·85 | 9·49 | 56·84 |
| October. . . . | **+5·33** | +4·74 | +3·48 | +1·94 | +0·94 | +0·28 | −0·37 | −1·01 | −1·52 | −1·81 | **−1·90** | −1·77 | 7·73 | 47·47 |
| November . . . | **+3·61** | +3·06 | +2·13 | +1·47 | +0·84 | +0·27 | −0·29 | −0·89 | −1·47 | −1·73 | **−1·76** | −1·63 | 5·37 | 32·71 |
| December . . . | **+2·86** | +2·43 | +1·77 | +1·22 | +0·67 | +0·13 | −0·42 | −0·91 | −1·37 | **−1·60** | −1·58 | −1·50 | 4·46 | 26·03 |

years were not treated independently, thus the results in Table IV. depend more on the years having many disturbed days than on those having few. No smoothing was applied to the disturbed curves, readings being simply taken exactly at the hours. Until the means were calculated, one could not but feel doubtful whether a diurnal inequality would be recognisable, thus the comparative smoothness of the results is not a little remarkable.

TABLE IV.—Diurnal Inequality Disturbed Days (+ to West).

| | Forenoon. | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hour . . . . . | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. |
| | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ |
| January . . . . . . . . | − **6·02** | −2·77 | −2·82 | +0·27 | +0·66 | +0·73 | +1·37 | +0·97 | +1·22 | +2·19 | +3·25 | +4·31 |
| February . . . . . . . | − 3·51 | −**5·03** | −3·89 | −1·65 | −0·56 | +1·77 | +0·38 | +0·91 | +1·18 | +1·51 | +3·54 | +4·15 |
| March . . . . . . . . | − 4·50 | −3·89 | −6·15 | −3·23 | −0·40 | −1·01 | −0·50 | −0·38 | −0·22 | +2·15 | +4·76 | +6·97 |
| April . . . . . . . . | − 5·28 | −5·36 | −4·42 | −3·92 | −4·25 | −2·77 | −2·57 | −2·74 | −0·28 | +2·27 | +5·27 | +8·51 |
| May . . . . . . . . | − 6·35 | −6·23 | −5·95 | −2·92 | −1·86 | −2·69 | −2·14 | −2·77 | −1·54 | +1·15 | +5·36 | +6·37 |
| June . . . . . . . . | −**10·12** | −6·91 | −6·15 | −3·79 | −1·90 | +0·49 | −1·58 | −3·15 | −0·66 | +1·90 | +4·64 | +6·80 |
| July . . . . . . . . | − **5·51** | −3·13 | −4·98 | −3·04 | +1·76 | −2·86 | −4·53 | −2·71 | −2·28 | −0·71 | +1·77 | +6·28 |
| August . . . . . . . | − 4·19 | −3·87 | −0·64 | −0·99 | +0·96 | −1·04 | +1·23 | −1·71 | −1·64 | −0·29 | +1·41 | +5·91 |
| September . . . . . . | − 3·59 | −4·33 | −2·74 | −1·07 | −1·44 | −0·98 | −1·21 | −0·43 | +0·81 | +2·72 | +5·86 | +7·90 |
| October . . . . . . . | − 2·01 | −1·47 | −1·56 | −0·68 | +0·17 | +0·61 | +0·25 | −0·17 | +0·78 | +2·79 | +4·57 | +6·36 |
| November . . . . . . | − 3·08 | −1·78 | −0·66 | 0·00 | +1·94 | +1·59 | +4·05 | +1·50 | +1·47 | +2·67 | +3·92 | +**5·82** |
| December . . . . . . | − 4·00 | −3·53 | −2·67 | −2·63 | −0·40 | +0·44 | +0·47 | +1·01 | +0·52 | +2·07 | +1·60 | +3·98 |

| | Afternoon. | | | | | | | | | | | | Range. | Sum of 24 differences from mean. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hour . . . | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | Midt. | | |
| | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ |
| January . . . | + 4·35 | + **4·88** | +3·80 | +3·00 | +0·97 | +0·59 | +0·03 | −2·41 | −5·26 | −4·77 | −5·11 | −3·41 | 10·90 | 65·16 |
| February . . . | + **6·02** | + 5·83 | +5·78 | +3·89 | +0·97 | −2·34 | −1·99 | −1·36 | −4·40 | −3·37 | −4·12 | −3·60 | 11·05 | 71·75 |
| March . . . . | + 8·64 | + **8·74** | +8·08 | +5·23 | +3·03 | +1·32 | −2·78 | −4·85 | −5·21 | −**6·21** | −4·60 | −4·90 | 14·95 | 97·75 |
| April . . . . . | +10·68 | +**10·75** | +8·49 | +5·83 | +4·04 | +1·62 | −1·93 | −**5·85** | −4·40 | −4·13 | −4·58 | −4·95 | 16·60 | 114·89 |
| May . . . . . | + **8·98** | + 7·92 | +7·83 | +6·97 | +5·50 | +2·21 | +0·68 | −1·65 | −4·54 | −1·38 | −**6·72** | −6·26 | 15·70 | 105·97 |
| June . . . . . | + 6·95 | + **7·22** | +5·85 | +3·49 | +3·60 | +1·63 | +0·61 | −0·08 | −0·86 | +2·94 | −6·10 | −4·82 | 17·34 | 92·24 |
| July . . . . . | + 6·86 | + **7·73** | +7·20 | +4·55 | +3·45 | +2·52 | +2·21 | −2·31 | −3·09 | −2·69 | −2·46 | −4·08 | 13·24 | 88·71 |
| August . . . . | + 7·24 | + **7·58** | +6·71 | +5·10 | +2·75 | +0·25 | −2·47 | −**7·04** | −2·86 | −4·89 | −4·80 | −2·73 | 14·62 | 78·30 |
| September. . . | + **8·50** | + 7·86 | +4·86 | +2·93 | +2·50 | −1·92 | −3·27 | −**5·92** | −5·12 | −5·56 | −4·52 | −1·72 | 14·42 | 87·76 |
| October . . . . | + **6·81** | + 6·52 | +4·25 | +1·34 | +0·48 | −1·03 | −4·62 | −5·48 | −4·90 | −**6·11** | −4·26 | −2·67 | 12·92 | 69·89 |
| November . . . | + 4·98 | + 4·98 | +2·82 | +2·71 | +0·19 | −1·39 | −4·21 | −4·04 | −**6·56** | −5·57 | −6·52 | −4·74 | 12·38 | 77·19 |
| December . . . | + 4·45 | + **5·33** | +3·65 | +3·30 | +4·09 | +0·92 | +0·74 | −0·44 | −**6·55** | −4·76 | −4·88 | −2·80 | 11·88 | 65·23 |

Tables similar to III. were also formed for the years of sunspot maximum (1892 to 1895) and of sunspot minimum (1890, 1899, and 1900) independently but these are omitted here. Table V. contains, however, diurnal inequalities calculated from the whole year and the three seasons, viz., winter (November to February), summer (May to August), and equinox.

### TABLE V.—Diurnal Inequality. Ordinary Days.

| Season. | Hour . . . . | Forenoon. 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ |
| Year . . | Sunspot minimum . . . | −1·08 | **−1·01** | −1·08 | −1·29 | −1·62 | −1·92 | −2·21 | **−2·31** | −1·75 | −0·16 | +1·96 | +3·78 |
| | 11 years . . . . . . . | −1·48 | **−1·45** | −1·52 | −1·71 | −2·06 | −2·39 | −2·67 | **−2·77** | −2·12 | −0·28 | +2·20 | +4·35 |
| | Sunspot maximum . . | −1·84 | −1·90 | −1·98 | −2·17 | −2·54 | −2·93 | −3·23 | **−3·31** | −2·57 | −0·44 | +2·42 | +4·97 |
| Winter . | Sunspot minimum . . . | −0·90 | −0·64 | −0·52 | **−0·51** | −0·52 | −0·55 | −0·59 | **−0·69** | −0·58 | +0·30 | +1·57 | +2·54 |
| | 11 years . . . . . . . | −1·37 | −1·07 | −0·90 | −0·82 | −0·81 | **−0·81** | −0·81 | **−0·94** | −0·86 | +0·13 | +1·62 | +2·92 |
| | Sunspot maximum . . | −1·79 | −1·50 | −1·29 | −1·16 | −1·10 | **−1·09** | −1·09 | **−1·28** | −1·27 | −0·09 | +1·72 | +3·36 |
| Equinox . | Sunspot minimum . . . | −1·24 | **−1·13** | −1·27 | −1·37 | −1·47 | −1·66 | −2·17 | **−2·75** | −2·30 | −0·50 | +2·08 | +4·34 |
| | 11 years . . . . . . . | −1·67 | **−1·64** | −1·71 | −1·80 | −1·90 | −2·14 | −2·67 | **−3·18** | −2·60 | −0·51 | +2·49 | +5·07 |
| | Sunspot maximum . . | −2·05 | −2·13 | −2·20 | −2·28 | −2·39 | −2·70 | −3·26 | **−3·73** | −3·05 | −0·65 | +2·76 | +5·72 |
| Summer . | Sunspot minimum . . . | −1·09 | −1·25 | −1·46 | −1·99 | −2·87 | −3·54 | **−3·87** | −3·48 | −2·37 | −0·27 | +2·24 | +4·45 |
| | 11 years . . . . . . . | −1·39 | −1·64 | −1·95 | −2·50 | −3·46 | −4·22 | **−4·53** | −4·20 | −2·90 | −0·46 | +2·49 | +5·07 |
| | Sunspot maximum . . | −1·68 | −2·05 | −2·45 | −3·06 | −4·12 | −5·01 | **−5·33** | −4·91 | −3·40 | −0·59 | +2·75 | +5·82 |

| Season. | Hour . . . | Afternoon. 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | Midt. | Range. | Sum of 24 differences from mean. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ |
| Year . | Sunspot minimum | **+4·44** | +3·93 | +2·75 | +1·58 | +0·71 | +0·17 | −0·20 | −0·53 | −0·84 | −1·05 | **−1·15** | −1·14 | 6·75 | 38·66 |
| | 11 years . . . . | **+5·26** | +4·90 | +3·70 | +2·35 | +1·21 | +0·41 | −0·16 | −0·60 | −1·00 | −1·27 | −1·42 | **−1·50** | 8·03 | 48·78 |
| | Sunspot maximum | **+6·13** | +5·91 | +4·62 | +3·05 | +1·64 | +0·65 | −0·06 | −0·62 | −1·06 | −1·37 | −1·61 | −1·77 | 9·44 | 58·79 |
| Winter | Sunspot minimum | **+2·83** | +2·19 | +1·27 | +0·70 | +0·39 | +0·02 | −0·38 | −0·77 | −1·21 | **−1·38** | −1·36 | −1·20 | 4·21 | 23·61 |
| | 11 years . . . . | **+3·45** | +3·03 | +2·17 | +1·43 | +0·86 | +0·31 | −0·26 | −0·84 | −1·38 | −1·68 | **−1·73** | −1·65 | 5·18 | 31·85 |
| | Sunspot maximum | **+4·10** | +3·89 | +2·98 | +2·04 | +1·23 | +0·61 | −0·10 | −0·84 | −1·47 | −1·85 | **−2·01** | −2·00 | 6·11 | 39·86 |
| Equinox | Sunspot minimum | **+5·19** | +4·54 | +3·10 | +1·57 | +0·55 | +0·08 | −0·26 | −0·62 | −0·94 | −1·18 | −1·31 | **−1·32** | 7·94 | 42·94 |
| | 11 years . . . . | **+6·14** | +5·63 | +4·12 | +2·38 | +1·04 | +0·23 | −0·35 | −0·82 | −1·22 | −1·51 | −1·66 | **−1·71** | 9·32 | 54·19 |
| | Sunspot maximum | **+7·10** | +6·71 | +5·10 | +3·17 | +1·51 | +0·46 | −0·31 | −0·88 | −1·34 | −1·65 | −1·87 | −2·00 | 10·83 | 65·02 |
| Summer | Sunspot minimum | **+5·29** | +5·06 | +3·89 | +2·46 | +1·20 | +0·42 | +0·04 | −0·20 | −0·36 | −0·59 | −0·77 | −0·90 | 9·16 | 50·06 |
| | 11 years . . . . | **+6·18** | +6·03 | +4·82 | +3·23 | +1·74 | +0·68 | +0·12 | −0·15 | −0·39 | −0·61 | −0·87 | −1·13 | 10·71 | 60·76 |
| | Sunspot maximum | **+7·19** | +7·13 | +5·78 | +3·95 | +2·19 | +0·88 | +0·22 | −0·13 | −0·36 | −0·60 | −0·95 | −1·31 | 12·52 | 71·89 |

All maximum and minimum values which are distinctly shown appear in heavy type in Tables III. and V.; but in Table IV. only the absolutely largest and least values are thus indicated.

In the case of the ordinary days a double daily period is always clearly apparent in winter; but this tends to disappear in the equinoctial months, especially in years of sunspot maximum, and it is not recognisable in summer, even in the years of sunspot minimum.

§ 11. Table VI. gives the range of the diurnal inequality on ordinary days—still from hourly readings—for each individual month of the eleven years. It is instructive to compare the monthly means in Table VI. with the corresponding ranges in Tables III. and V. The observational data are exactly the same, and at first sight it may appear strange that the mean ranges in Table VI. are as a rule not equal to but greater than the ranges in Table III. This is due simply to the fact that the hours of maxima and minima vary slightly from year to year. The greater this variation the more does the mean in Table VI. exceed that in Table III. On the average of the 12 months the mean range in Table VI. is almost exactly 1 per cent. greater than that in Table III., but the ratio of the two ranges is notably largest in winter, varying from 1·03 in January to 1·00 in April, June and August.

TABLE VI.—Diurnal Inequality Ranges from Ordinary Days.

| | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. | Yearly means. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ |
| 1890 | 4·40 | 5·11 | 7·94 | 9·66 | 8·56 | 9·10 | 8·82 | 9·44 | 8·61 | 6·93 | 5·28 | 3·94 | 7·32 |
| 1891 | 4·27 | 5·07 | 8·36 | 10·35 | 11·37 | 9·99 | 11·23 | 10·85 | 9·69 | 9·13 | 6·83 | 4·64 | 8·48 |
| 1892 | 6·02 | 8·09 | 10·79 | 11·88 | 11·96 | 12·15 | 11·92 | 12·67 | 10·60 | 9·99 | 6·01 | 6·10 | 9·85 |
| 1893 | 5·90 | 7·99 | 11·84 | 14·40 | 13·31 | 13·87 | 13·05 | 14·36 | 12·09 | 9·97 | 6·66 | 5·39 | 10·74 |
| 1894 | 5·70 | 7·67 | 10·47 | 12·97 | 12·43 | 11·92 | 12·11 | 12·90 | 11·22 | 8·87 | 6·26 | 5·06 | 9·80 |
| 1895 | 5·60 | 7·40 | 9·56 | 12·57 | 12·73 | 14·11 | 12·66 | 10·71 | 9·85 | 7·78 | 6·16 | 5·38 | 9·54 |
| 1896 | 6·24 | 7·55 | 10·11 | 11·30 | 9·79 | 10·06 | 10·52 | 10·90 | 9·89 | 6·76 | 4·68 | 4·21 | 8·50 |
| 1897 | 4·54 | 5·39 | 8·88 | 10·23 | 9·88 | 9·68 | 9·62 | 10·27 | 8·52 | 6·48 | 5·36 | 4·22 | 7·76 |
| 1898 | 4·58 | 5·49 | 7·83 | 9·02 | 9·90 | 10·15 | 9·64 | 9·84 | 8·33 | 7·08 | 4·99 | 4·22 | 7·59 |
| 1899 | 4·16 | 4·73 | 7·54 | 9·46 | 9·40 | 9·88 | 8·53 | 9·72 | 9·16 | 6·71 | 4·49 | 3·80 | 7·30 |
| 1900 | 4·14 | 4·61 | 7·15 | 8·64 | 8·44 | 9·40 | 9·15 | 9·52 | 7·66 | 6·52 | 3·53 | 3·25 | 6·83 |
| Monthly means | 5·05 | 6·28 | 9·13 | 10·95 | 10·71 | 10·94 | 10·66 | 11·02 | 9·60 | 7·84 | 5·48 | 4·56 | 8·52 |

If we compare the arithmetic mean of the 132 ranges of Table VI. with the range in the mean diurnal inequality for the year in Table V. from the 11-year period, we find that the former is 6 per cent. the larger. This shows that the variability with the season of the year in the hours of maximum and minimum is greater than is the variability for the same month of the year in different years.

§ 12. Fig. 1 shows the mean diurnal inequalities for the year from the 11-year period for the ordinary and the disturbed days, with, for comparison, the corresponding inequality derived in A from quiet days. The difference between the ordinary and quiet day curves, though not large, is systematic.

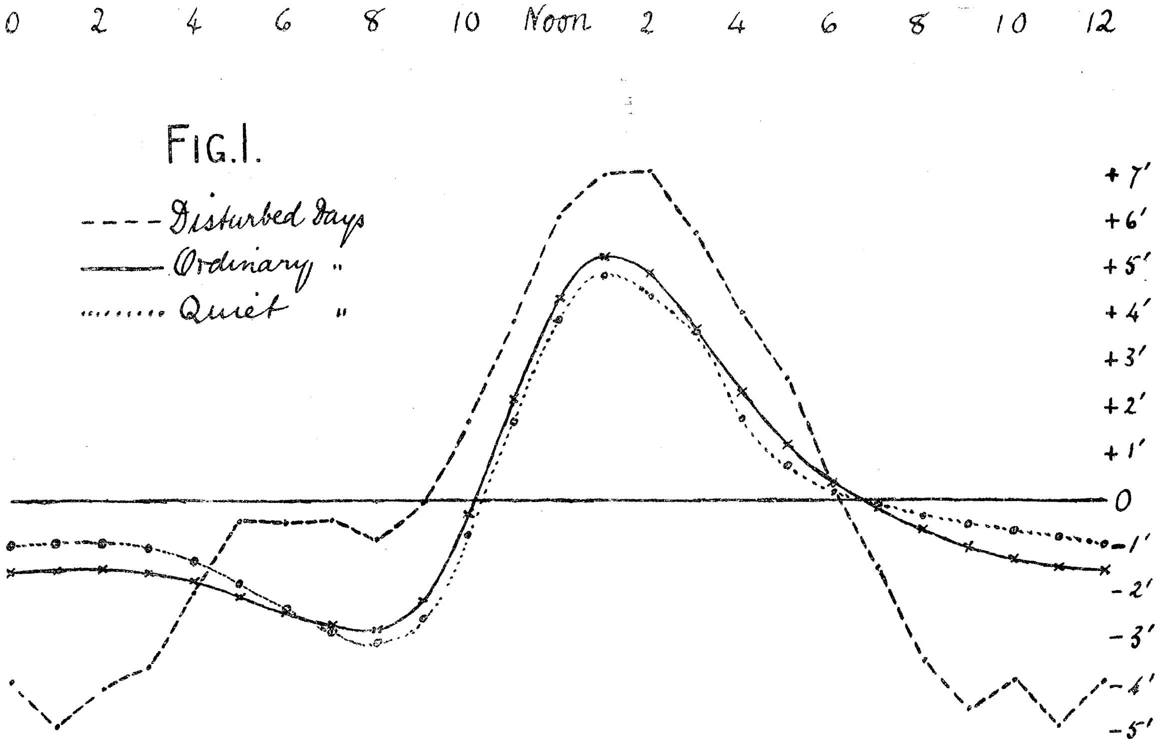

FIG. I.

The curves of fig. 2 represent the *differences* between the diurnal inequalities in years of sunspot maximum and minimum, and between the inequalities in ordinary and quiet days for the year as a whole and the three seasons. The ordinates represent the excess in the westerly declination in years of sunspot maximum (or in ordinary days) over the declination at the same hour in years of sunspot minimum (or in quiet days). The difference curves for sunspot maximum and minimum are of the same general type as ordinary inequality curves; but the difference curves for ordinary and quiet days are of a totally distinct character. These latter curves are double peaked in equinox and summer, but show only one distinct maximum and minimum in winter.

Fig. 3 gives difference curves in the case of the mean diurnal inequality for the whole year from disturbed, ordinary, and quiet day curves. The difference curves involving the disturbed days display a remarkably sudden rise and fall and are comparatively flat topped from 5 a.m. to 5 p.m. Disturbed and quiet days difference curves (not reproduced here) for winter, equinox, and summer all show this rapid rise and fall, and they are all fairly symmetrical with reference to the ordinate for noon. The summer curve has two well-marked maxima, with a secondary minimum near noon; even in the equinox the depression near noon is distinctly visible.

The amplitude of the diurnal inequality varies so much that it is difficult to recognise the difference in type between curves for the different seasons when drawn on the same scale. Fig. 4 shows the inequalities for the three seasons on different scales, so related that the mean of the 24-hourly ordinates is the same for each. This brings out very clearly the fact that the difference in type is mainly between 7 p.m. and 9 a.m., *i.e.*, during the hours when the diurnal movement is least conspicuous.

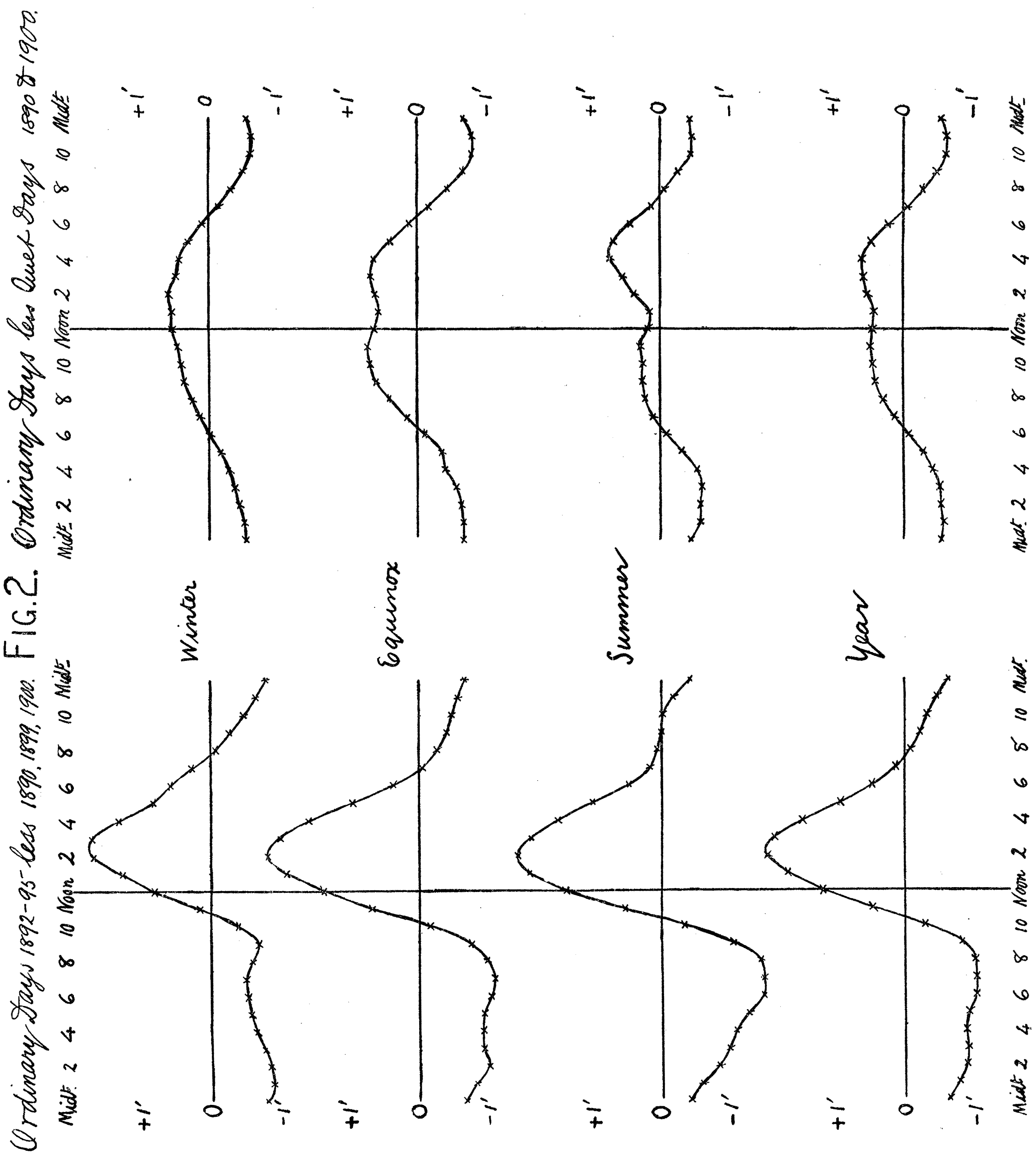
FIG. 2.

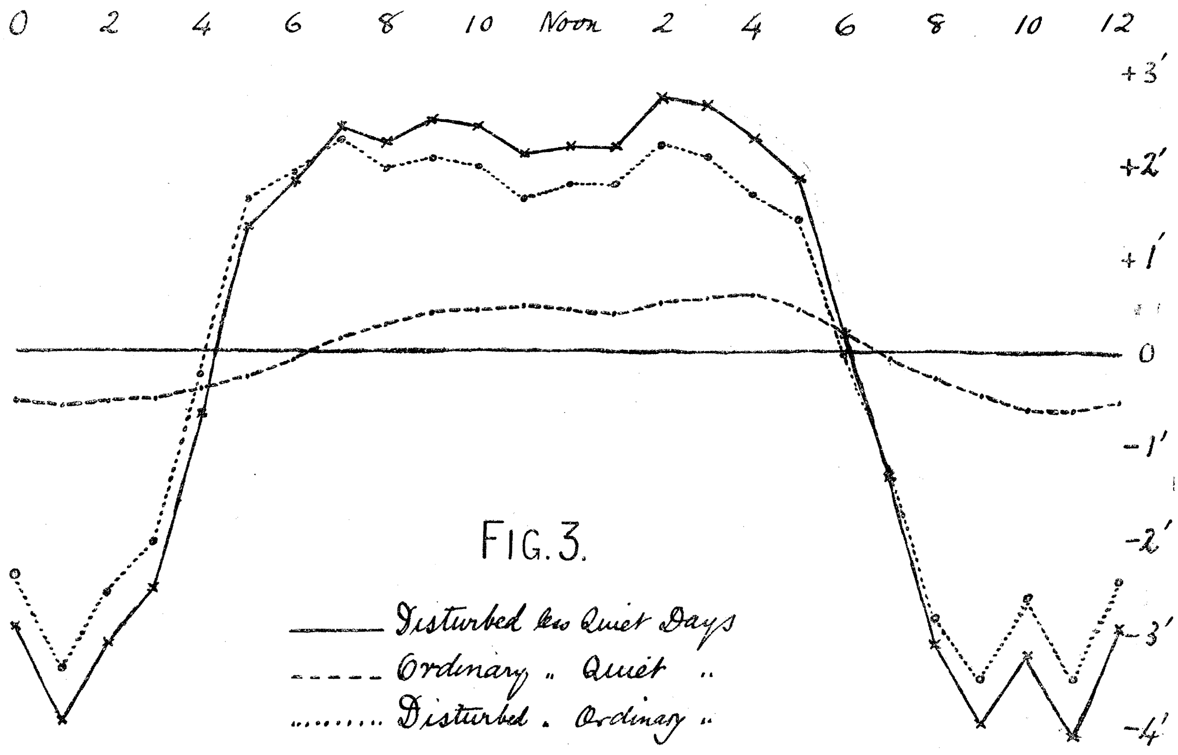
FIG. 3.
0
2
4
6
8
10
Noon
2
4
6
8
10
12
+3′
+2′
+1′
0
−1′
−2′
−3′
−4′
———— Disturbed less Quiet Days
- - - - Ordinary " Quiet "
……… Disturbed " Ordinary "

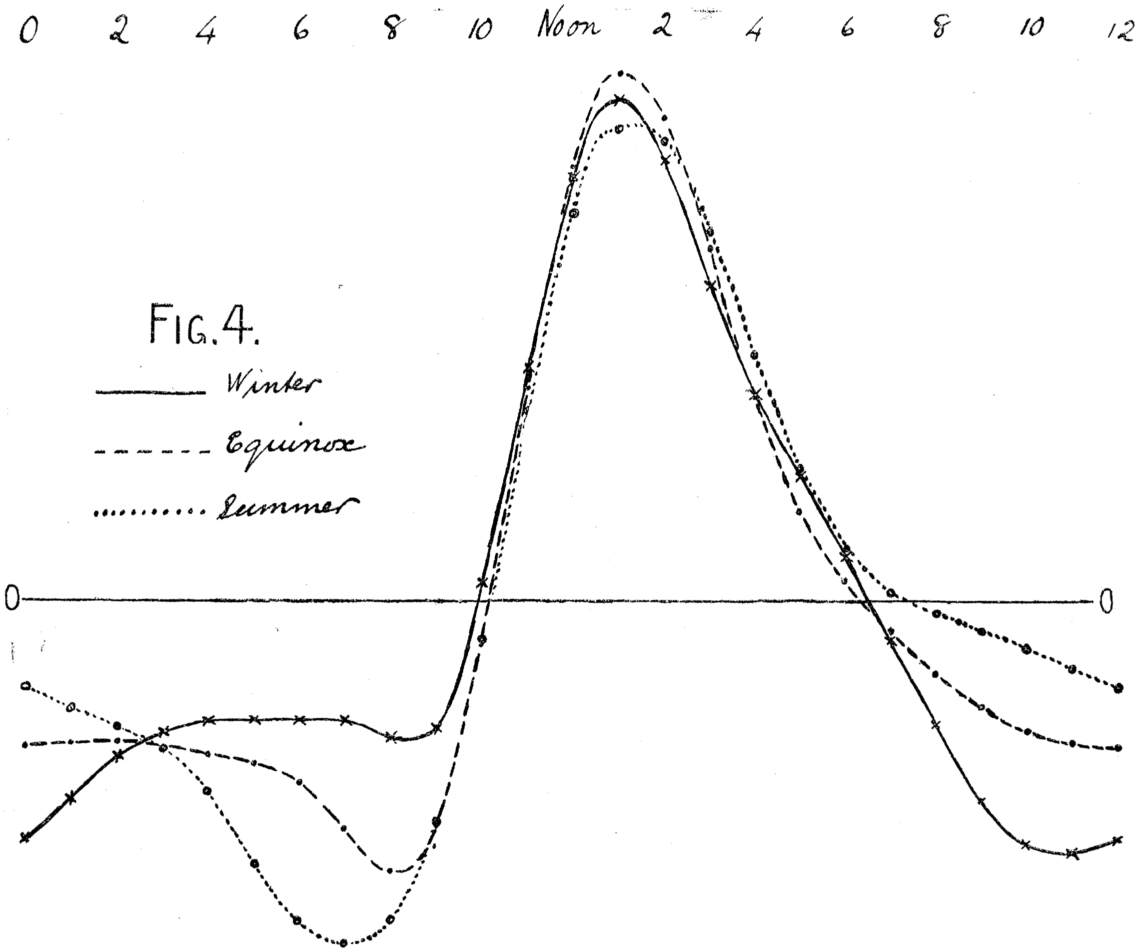
FIG. 4.
0
2
4
6
8
10
Noon
2
4
6
8
10
12
0
0
———— Winter
- - - - - - Equinox
………… Summer

### *Diurnal Inequality. Fourier Coefficients.*

§ 13. The diurnal inequality was analysed in the usual way in a series

$$c_1 \sin (t+\alpha_1) + c_2 \sin (2t+\alpha_2) + \ldots,$$

where $t$ is time counted from midnight (G.M.T.), one hour being taken as equivalent to 15°. Thus $c_1$, $c_2$, $c_3$, $c_4$, denote the amplitudes, $\alpha_1$, $\alpha_2$, $\alpha_3$, and $\alpha_4$ the phase angles of the terms whose periods are respectively 24, 12, 8, and 6 hours. The object of such an analysis is to provide a ready means of tracing affinities and differences between different stations at the same season, and between different seasons at the same station. The most instructive way of presenting the facts is probably to show side by side the corresponding results for the different types of years and for the different kinds of days.

Table VII. contrasts the amplitudes of the 24- and 12-hour terms from ordinary and disturbed days for each month of the year. Similar complete results were calculated for the 8- and 6-hour terms, but only those for ordinary days from the 11-year period are included. A complete set of seasonal values are, however, given

TABLE VII.—Diurnal Inequality. Fourier Coefficients. Amplitudes.

| | $c_1$. | | | | $c_2$. | | | | $c_3$. | $c_4$. |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ordinary days. | | | Disturbed days. | Ordinary days. | | | Disturbed days. | Ordinary days. | Ordinary days. |
| | Sun-spot minimum. | 11 years. | Sun-spot maximum. | 11 years. | Sun-spot minimum. | 11 years. | Sun-spot maximum. | 11 years. | 11 years. | 11 years. |
| | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ |
| January . . . | 1·44 | 1·79 | 2·17 | 4·27 | 0·66 | 0·86 | 1·03 | 1·27 | 0·41 | 0·27 |
| February . . . | 1·73 | 2·41 | 3·17 | 4·49 | 0·84 | 1·11 | 1·35 | 1·25 | 0·57 | 0·30 |
| March . . . . | 2·25 | 3·05 | 3·73 | 6·26 | 1·65 | 1·98 | 2·32 | 2·29 | 1·11 | 0·45 |
| April . . . . | 2·61 | 3·35 | 4·06 | 7·03 | 2·08 | 2·48 | 2·91 | 2·87 | 1·17 | 0·39 |
| May . . . . | 2·81 | 3·57 | 4·36 | 6·73 | 2·00 | 2·38 | 2·75 | 1·79 | 0·87 | 0·17 |
| June . . . . | 3·19 | 3·83 | 4·62 | 5·89 | 2·18 | 2·39 | 2·81 | 0·05 | 0·74 | 0·05 |
| July . . . . | 2·97 | 3·72 | 4·45 | 5·01 | 1·95 | 2·30 | 2·61 | 2·09 | 0·77 | 0·11 |
| August . . . | 3·06 | 3·64 | 4·15 | 4·47 | 2·14 | 2·43 | 2·79 | 2·94 | 1·05 | 0·18 |
| September . . | 2·74 | 3·35 | 3·94 | 5·42 | 1·74 | 2·02 | 2·27 | 2·58 | 1·04 | 0·35 |
| October . . . | 2·09 | 2·69 | 3·39 | 4·55 | 1·42 | 1·69 | 1·92 | 2·38 | 0·92 | 0·48 |
| November . . | 1·44 | 1·94 | 2·28 | 4·90 | 0·88 | 1·06 | 1·30 | 1·71 | 0·51 | 0·32 |
| December. . . | 1·14 | 1·61 | 2·06 | 4·17 | 0·75 | 0·81 | 0·94 | 1·35 | 0·35 | 0·20 |
| Arithmetic means . | 2·29 | 2·91 | 3·53 | 5·27 | 1·52 | 1·79 | 2·08 | 1·88 | 0·79 | 0·27 |

in Table VIII., including data for quiet days. The great difference between different years and between days of different type cannot be brought too clearly home to those combining data from different stations for theoretical purposes. It will be noticed that $c_1$ increases regularly as we pass from years of sunspot minimum through average years to years of sunspot maximum, or as we pass from quiet days through ordinary to disturbed days. But $c_2$, whilst increasing with sunspot frequency, seems practically no larger in ordinary or even in disturbed days than in quiet days.

TABLE VIII.—Diurnal Inequality. Fourier Coefficients. Amplitudes.

| | Season. | Quiet days. | | | Ordinary days. | | | Disturbed days. |
|---|---|---|---|---|---|---|---|---|
| | | Sunspot minimum. | 11 years. | Sunspot maximum. | Sunspot minimum. | 11 years. | Sunspot maximum. | 11 years. |
| | | ′ | ′ | ′ | ′ | ′ | ′ | ′ |
| $c_1$ | Year . . | 1·80 | 2·32 | 2·86 | 2·21 | 2·84 | 3·47 | 5·07 |
| | Winter . . | 0·99 | 1·39 | 1·83 | 1·43 | 1·93 | 2·42 | 4·36 |
| | Equinox . | 1·98 | 2·48 | 2·99 | 2·41 | 3·10 | 3·76 | 5·70 |
| | Summer . | 2·56 | 3·19 | 3·85 | 2·98 | 3·67 | 4·38 | 5·46 |
| $c_2$ | Year . . | 1·54 | 1·79 | 2·11 | 1·51 | 1·76 | 2·04 | 1·76 |
| | Winter . . | 0·75 | 0·91 | 1·12 | 0·78 | 0·96 | 1·15 | 1·34 |
| | Equinox . | 1·74 | 2·01 | 2·34 | 1·71 | 2·02 | 2·33 | 2·50 |
| | Summer . | 2·16 | 2·50 | 2·95 | 2·06 | 2·37 | 2·73 | 1·71 |
| $c_3$ | Year . . | 0·79 | 0·89 | 1·01 | 0·72 | 0·78 | 0·89 | 0·80 |
| | Winter . . | 0·44 | 0·50 | 0·58 | 0·42 | 0·45 | 0·55 | 0·44 |
| | Equinox . | 1·06 | 1·17 | 1·33 | 0·97 | 1·05 | 1·16 | 0·63 |
| | Summer . | 0·90 | 1·01 | 1·14 | 0·77 | 0·85 | 0·97 | 1·38 |
| $c_4$ | Year . . | 0·28 | 0·28 | 0·29 | 0·27 | 0·29 | 0·28 | 0·50 |
| | Winter . . | 0·25 | 0·26 | 0·30 | 0·27 | 0·27 | 0·30 | 0·43 |
| | Equinox . | 0·45 | 0·47 | 0·46 | 0·42 | 0·41 | 0·42 | 1·15 |
| | Summer . | 0·15 | 0·12 | 0·11 | 0·11 | 0·11 | 0·11 | 0·64 |

The influence of disturbance on $c_3$ seems very small. The values of $c_4$ seem almost independent of sunspot frequency, and those derived from ordinary and from quiet days are nearly equal.

The fact that $c_2$, $c_3$ and $c_4$ are so nearly the same for ordinary and quiet days may seem at first sight to imply that the ordinary and quiet day difference curve is necessarily almost a pure sine curve of 24-hour period. This conclusion, however, does not necessarily follow unless the phase angles are nearly the same in the two cases.

### *Diurnal Inequality. Phase Angles.*

§ 14. Tables IX., X., and XI. contrast the phase angles for different species of days and for years of sunspot maximum (1892 and 1895) and minimum (1890, 1899, 1900).

### Table IX.—Diurnal Inequality, 24-hour term. Phase Angle.

| | Quiet days. | | | Ordinary days. | | | Disturbed days. |
|---|---|---|---|---|---|---|---|
| | 1892–95. | 1890–1900. | 1890, 1899, 1900. | 1892–95. | 1890–1900. | 1890, 1899, 1900. | 1890–1900. |
| | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ |
| January . . . | 240 4 | 242 40 | 245 11 | 245 5 | 250 51 | 257 56 | 270 49 |
| February . . . | 232 9 | 233 38 | 240 50 | 237 9 | 241 44 | 249 15 | 265 27 |
| March . . . . | 222 24 | 224 55 | 228 47 | 232 17 | 232 52 | 233 47 | 257 17 |
| April . . . . | 209 35 | 213 26 | 217 42 | 222 1 | 224 30 | 223 35 | 248 9 |
| May . . . . . | 217 7 | 216 47 | 217 58 | 219 57 | 221 2 | 224 10 | 241 30 |
| June . . . . . | 206 55 | 207 24 | 202 39 | 212 46 | 212 15 | 212 8 | 240 15 |
| July . . . . . | 210 35 | 210 58 | 211 20 | 214 32 | 214 18 | 215 12 | 234 26 |
| August . . . . | 221 26 | 224 55 | 227 51 | 225 6 | 227 53 | 229 12 | 260 6 |
| September . . . | 227 46 | 229 2 | 229 41 | 234 5 | 236 37 | 237 23 | 267 12 |
| October . . . | 227 40 | 227 12 | 224 21 | 236 32 | 239 48 | 239 52 | 279 46 |
| November . . . | 232 14 | 240 26 | 251 24 | 242 29 | 248 1 | 254 51 | 289 33 |
| December . . . | 239 53 | 251 53 | 261 50 | 248 37 | 254 47 | 263 35 | 258 32 |

### Table X.—Diurnal Inequality, 12-hour term. Phase Angle.

| | Quiet days. | | | Ordinary days. | | | Disturbed days. |
|---|---|---|---|---|---|---|---|
| | 1892–95. | 1890–1900. | 1890, 1899, 1900. | 1892–95. | 1890–1900. | 1890, 1899, 1900. | 1890–1900. |
| | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ |
| January . . . | 20 35 | 27 43 | 36 25 | 22 50 | 29 13 | 44 45 | – 28 28 |
| February . . . | 30 25 | 31 3 | 34 52 | 26 7 | 27 6 | 33 16 | 9 11 |
| March . . . . | 35 21 | 37 12 | 45 15 | 34 14 | 35 29 | 38 24 | 17 2 |
| April . . . . | 37 48 | 38 0 | 41 47 | 38 23 | 38 36 | 40 55 | 33 48 |
| May . . . . . | 52 8 | 55 3 | 61 14 | 49 44 | 50 12 | 54 13 | 1 55 |
| June . . . . | 46 58 | 47 23 | 43 20 | 46 29 | 46 1 | 44 55 | – 54 54 |
| July . . . . . | 46 20 | 49 0 | 52 20 | 47 12 | 47 26 | 48 50 | 6 46 |
| August . . . . | 57 15 | 57 52 | 63 47 | 56 21 | 56 32 | 59 37 | 5 5 |
| September . . . | 55 32 | 57 27 | 62 3 | 53 38 | 54 38 | 56 49 | 40 19 |
| October . . . | 33 13 | 35 34 | 34 13 | 33 21 | 34 57 | 35 47 | 31 55 |
| November . . . | 24 29 | 33 33 | 50 39 | 23 9 | 27 39 | 38 14 | – 3 49 |
| December . . . | 28 4 | 27 54 | 37 5 | 17 32 | 21 20 | 29 53 | – 29 25 |

For purposes of comparison they reproduce some data for quiet days already published in A. It should be noticed that G.M.T. is used throughout. If local mean time were substituted, the angles would require to be increased, $\alpha_1$ by 19′, $\alpha_2$ by 38′, and so on. The corrections necessary if local solar time is employed will be found in A, Table XIX.

It should be remembered that an increase in phase angle implies an earlier occurrence of the daily maximum, an advance of one hour answering to 15° in $\alpha_1$, to 30° in $\alpha_2$, and so on.

TABLE XI.—Diurnal Inequality. Phase Angles.

| Angle. | Season. | Quiet days. | | | Ordinary days. | | | Disturbed days. |
|---|---|---|---|---|---|---|---|---|
| | | Sunspot maximum. | 11 years. | Sunspot minimum. | Sunspot maximum. | 11 years. | Sunspot minimum. | 11 years. |
| | | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ |
| $\alpha_1$ | Year . . | 221 1 | 222 57 | 224 14 | 238 12 | 230 21 | 232 6 | 257 52 |
| | Winter . . | 235 36 | 240 55 | 248 49 | 242 38 | 248 8 | 255 40 | 271 42 |
| | Equinox . | 221 27 | 223 24 | 224 51 | 230 57 | 233 8 | 233 22 | 261 12 |
| | Summer . | 213 47 | 214 49 | 214 30 | 217 54 | 218 45 | 220 2 | 243 16 |
| $\alpha_2$ | Year . . | 42 57 | 45 3 | 49 33 | 41 15 | 42 28 | 45 58 | 12 26 |
| | Winter . . | 26 3 | 30 18 | 40 25 | 22 50 | 26 31 | 36 17 | −12 43 |
| | Equinox . | 40 59 | 42 25 | 46 24 | 39 58 | 41 2 | 43 14 | 31 16 |
| | Summer . | 50 50 | 52 27 | 55 13 | 49 58 | 50 6 | 51 53 | 4 27 |
| $\alpha_3$ | Year . . | 234 41 | 237 16 | 241 45 | 231 37 | 236 38 | 242 39 | 200 11 |
| | Winter . . | 236 7 | 243 14 | 255 10 | 233 0 | 243 19 | 256 37 | 188 35 |
| | Equinox . | 229 5 | 231 11 | 233 51 | 227 29 | 231 17 | 235 14 | 186 9 |
| | Summer . | 240 29 | 241 26 | 244 29 | 235 51 | 239 35 | 244 28 | 210 15 |
| $\alpha_4$ | Year . . | 52 13 | 56 8 | 59 25 | 56 46 | 57 20 | 56 1 | 105 0 |
| | Winter . . | 49 25 | 55 19 | 64 22 | 51 4 | 53 54 | 59 35 | 65 50 |
| | Equinox . | 57 17 | 60 45 | 59 25 | 60 46 | 59 44 | 56 59 | 147 12 |
| | Summer . | 37 55 | 39 52 | 51 45 | 56 10 | 56 1 | 43 55 | 136 54 |

§ 15. The phenomenon to which I called attention in the case of the quiet days, viz., the increase in the phase angles $\alpha_1$ and $\alpha_2$ as sunspot frequency diminishes, appears equally decisively in the ordinary days. Turning the difference of angle into time, and taking arithmetic means from the individual months, we find for the retardation (in minutes) in the time of occurrence of the maxima in years of sunspot maximum, as compared to years of sunspot minimum, the following results, $q$ denoting quiet, $o$ all ordinary days :—

| | Whole year. | | Winter. | | Equinox. | | Summer. | |
|---|---|---|---|---|---|---|---|---|
| | *q.* | *o.* | *q.* | *o.* | *q.* | *o.* | *q.* | *o.* |
| 24-hour term . . . . | 24·0 | 23·5 | 54·9 | 52·3 | 13·5 | 9·7 | 3·7 | 8·3 |
| 12-hour term . . . . | 15·8 | 12·8 | 27·7 | 28·2 | 10·7 | 6·2 | 9·0 | 3·9 |

§ 16. Contrasting results from ordinary and quiet days, we observe one remarkable difference between the 24- and 12-hour phase angles. As we pass from quiet to ordinary days the angle $\alpha_1$ *invariably* increases, whereas in a majority of months $\alpha_2$ decreases.

Table XII. converts the difference between the ordinary and quiet day phase angles into time. The results are from the seasonal diurnal inequalities, not from individual months.

Table XII.—Difference in Minutes in Times of Occurrence of Maxima in Ordinary and in Quiet Days (+ denoting Later Occurrence in Quiet Days).

| | Whole year. | | Winter. | | Equinox. | | Summer. | |
|---|---|---|---|---|---|---|---|---|
| | 24-hour. + | 12-hour. − | 24-hour. + | 12-hour. − | 24-hour. + | 12-hour. − | 24-hour. + | 12-hour. − |
| Years of sunspot maximum . . | 27·6 | 3·2 | 29·0 | 7·0 | 37·5 | 1·2 | 16·4 | 1·5 |
| Eleven years . . . . . . . . | 27·2 | 4·8 | 26·8 | 7·5 | 39·8 | 2·3 | 15·4 | 4·6 |
| Years of sunspot minimum . . | 27·2 | 6·2 | 26·6 | 6·4 | 34·1 | 5·7 | 20·9 | 6·6 |

In the case of the 24-hour term the difference in phase between quiet and ordinary days seems nearly independent of sunspot frequency. Like the difference in phase between years of sunspot maximum and minimum, it is distinctly least in summer; but unlike that difference it is greater in the equinoctial than in the winter months.

In the case of $\alpha_3$ and $\alpha_4$ the difference between ordinary and quiet days appears small, and it would probably require a very long series of years to give thoroughly representative results. This last remark also applies to the difference between disturbed and ordinary days, though in this case there seems no doubt as to the sign of the difference.

§ 17. Table XIII. converts the difference between the disturbed and ordinary days phase angles into time. The results are again from the seasonal inequalities.

The differences in Table XIII. are very substantial. From Tables XII. and XIII., or directly from Table XI., we see that, taking the whole year, the maximum in the 24-hour term occurs no less than 2¼ *hours* earlier in disturbed than in quiet days.

TABLE XIII.—Difference in Minutes in Times of Occurrence of Maxima in Ordinary and Disturbed Days (+ denoting Later Occurrence in Ordinary Days).

| | Whole year. | | Winter. | | Equinox. | | Summer. | |
|---|---|---|---|---|---|---|---|---|
| | h. | m. | h. | m. | h. | m. | h. | m. |
| 24-hour term . . . . . | +1 | 50 | +1 | 44 | +1 | 52 | +1 | 38 |
| 12-hour „ . . . . . . | −1 | 0 | −1 | 18 | −0 | 20 | −1 | 31 |
| 8-hour „ . . . . . . | −0 | 49 | −1 | 13 | −1 | 0 | −0 | 39 |
| 6-hour „ . . . . . . | +0 | 48 | +0 | 12 | +1 | 27 | +1 | 21 |

We see how, as it were, by filtering out disturbed days we obtain a gradual retardation in the phase. Some of the Astronomer Royal's quiet days are decidedly less quiet than others. Supposing we adopted a still higher standard should we observe even more retardation? On the other hand, our disturbed days vary much in the degree of disturbance, and very considerably in its type. Is there an advance in phase irrespective of the type of disturbance, and is the advance greater in highly disturbed than in moderately disturbed days? Obviously there are many further questions arising out of the above result. Evidently a study of the phase constitutes a method of considerable delicacy for advancing our knowledge of disturbances; but a very obvious consideration is that in order to obtain even approximately smooth diurnal inequalities from highly disturbed days one must deal with a long period of years. When diurnal inequalities are not smooth, merely "accidental" irregularities may introduce a fictitious element into the Fourier coefficients, especially those of shorter period.

The results reached emphasise one difficulty in the way of an exact intercomparison of stations. Even if all stations suffered equally from disturbance, their published data would not be strictly comparable unless the standard for omitting disturbed days when forming the diurnal inequality were absolutely uniform. Under existing conditions all that we do know is that the standard is not uniform, and that there is no obvious way of making it so, whilst there is every reason to believe that the incidence of disturbance is widely different.

We have already referred to the different effects produced by disturbance in the angles $\alpha_1$ and $\alpha_2$. Possibly this difference may be connected in some way with another, viz., that whereas $\alpha_1$ increases as we pass from summer to winter, $\alpha_2$ diminishes. Summarising the results we have in short:—

$\alpha_1$ largest in disturbed days, in winter, in years of sunspot minimum.
$\alpha_1$ least in quiet days, in summer, in years of sunspot maximum.
$\alpha_2$ largest in quiet days, in summer, in years of sunspot minimum.
$\alpha_2$ least in disturbed days, in winter, in days of sunspot maximum.

### *Absolute Ranges.*

§ 18. The regular diurnal inequality is of special interest for theorists, particularly those whose ambition it is to discover an explanation of the phenomena of terrestrial magnetism. There are, however, other facts connected with the daily changes which merit a close study. If we take the case of a surveyor or explorer making frequent use of an accurate compass, it is, no doubt, well that he should know the general features of the regular diurnal inequality; but what immediately concerns him is how far the needle is pointing from its mean position at a given hour of a given day. Now, no examination of past data can supply exact prophetic information as to the future, but the present investigation has provided data which will, I trust, enable the practical man to see more exactly how the matter stands, and will give him a more adequate idea of the risks he runs in accepting individual observational data as representative. The statistical data which seem most likely to serve this purpose consist of the mean values of the *absolute daily range* (absolute maximum less absolute minimum) for different months and years, the relative frequency of absolute ranges of specified size, and the frequency with which the absolute maximum and minimum fall at different hours of the day.

§ 19. Table XIV. gives the average value of the absolute daily range for each month of the eleven years as derived from all days disturbed and undisturbed, with the means thence derived for each separate year, and for the twelve months of the average year. The two last rows contain corresponding monthly means derived respectively from all ordinary days and from the Astronomer Royal's quiet days. The two last columns contain yearly means from ordinary days and from quiet days. It is interesting to compare the mean absolute ranges in the second last line of Table XIV. with the mean inequality ranges in the last line of Table VI., these tables both applying to individual months and depending on the observations of exactly the same days. Taking the ratio borne by the absolute to the inequality range, we obtain the following results :—

| January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2·01 | 1·89 | 1·55 | 1·30 | 1·29 | 1·21 | 1·26 | 1·24 | 1·43 | 1·67 | 1·90 | 1·97 |

The arithmetic mean of these twelve values of the ratio is 1·48. So large an excess in the absolute over the inequality range in ordinary days would hardly, I think, have been anticipated. Relatively considered, the excess of the absolute range is much greater in winter than in summer. The extreme values actually found for the ratio

## Table XIV.—Absolute Daily Ranges.

| Year. | Monthly means from all days. | | | | | | | | | | | | Yearly means. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. | All days. | Ordinary days. | Quiet days. |
| | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ |
| 1890 | 8·33 | 9·25 | 11·44 | 11·11 | 10·49 | 10·79 | 10·96 | 11·55 | 13·01 | 13·18 | 10·79 | 7·09 | 10·67 | 10·49 | 8·34 |
| 1891 | 7·98 | 10·92 | 15·44 | 16·37 | 17·03 | 12·64 | 13·35 | 13·86 | 17·00 | 16·54 | 13·54 | 10·30 | 13·75 | 12·84 | 10·05 |
| 1892 | 12·77 | 20·75 | 24·02 | 17·98 | 20·33 | 17·31 | 20·69 | 17·99 | 16·32 | 17·56 | 12·93 | 13·70 | 17·70 | 15·36 | 12·32 |
| 1893 | 13·71 | 15·19 | 16·89 | 17·10 | 16·01 | 16·41 | 16·51 | 17·55 | 17·16 | 15·69 | 15·14 | 10·08 | 15·62 | 15·17 | 11·81 |
| 1894 | 12·29 | 19·50 | 17·65 | 17·47 | 16·61 | 15·34 | 18·35 | 17·72 | 19·01 | 16·71 | 16·56 | 10·85 | 16·50 | 14·67 | 11·34 |
| 1895 | 12·04 | 16·59 | 17·27 | 17·31 | 16·65 | 17·05 | 15·94 | 13·57 | 14·82 | 17·81 | 16·96 | 10·94 | 15·58 | 14·80 | 10·63 |
| 1896 | 16·55 | 16·96 | 17·48 | 16·02 | 15·67 | 12·78 | 13·64 | 15·04 | 15·16 | 13·17 | 10·70 | 10·92 | 14·51 | 12·92 | 9·53 |
| 1897 | 9·06 | 11·24 | 14·48 | 16·03 | 13·15 | 12·05 | 12·17 | 12·69 | 11·63 | 11·50 | 9·66 | 11·99 | 12·14 | 11·48 | 8·18 |
| 1898 | 9·94 | 10·14 | 15·79 | 12·87 | 13·07 | 12·28 | 12·13 | 13·27 | 15·31 | 13·69 | 9·69 | 9·38 | 12·30 | 11·19 | 8·22 |
| 1899 | 9·85 | 11·99 | 13·58 | 12·75 | 14·40 | 12·92 | 11·29 | 12·02 | 11·64 | 10·21 | 7·62 | 7·84 | 11·34 | 10·54 | 7·86 |
| 1900 | 10·23 | 8·07 | 11·18 | 10·00 | 10·54 | 10·53 | 10·41 | 11·15 | 9·26 | 8·67 | 5·23 | 4·73 | 9·17 | 8·86 | 7·41 |
| Final means from— | | | | | | | | | | | | | | | |
| All days . . . | 11·16 | 13·69 | 15·93 | 15·00 | 14·90 | 13·65 | 14·13 | 14·22 | 14·57 | 14·07 | 11·71 | 9·80 | 13·57 | — | — |
| Ordinary days . | 10·14 | 11·87 | 14·19 | 14·24 | 13·85 | 13·26 | 13·47 | 13·67 | 13·71 | 13·10 | 10·40 | 9·00 | — | 12·57 | — |
| Quiet days . . | 6·12 | 7·57 | 10·59 | 11·84 | 12·09 | 11·95 | 11·60 | 11·93 | 10·86 | 9·16 | 6·54 | 5·08 | — | — | 9·61 |

when individual months were considered were 2·34 in November, 1895, and 1·12 in June, 1900.

Inequality ranges from quiet days are generally less, but only slightly less, than those from ordinary days. Thus, taking the mean diurnal inequalities for the eleven years, the range is 7′·90 for the quiet as against 8′·03 for the ordinary days, the former being thus 98 per cent. of the latter. But the final mean of all the absolute ranges for quiet days in Table XIV., viz., 9′·61, is only 77 per cent. of the corresponding mean for ordinary days. The ratio borne by the quiet day to the ordinary day absolute range is much larger in summer than in winter, varying from 0·90 in June to 0·56 in December. Similarly the ratio borne by the quiet day absolute range to that from all days varies from 0·88 in June to 0·52 in December.

§ 20. The annual variation in the amplitude of the diurnal range presents some interesting features which will be most readily recognised on consulting Table XV.,

TABLE XV.—Monthly Values of Daily Ranges as Percentages of their Arithmetic Mean.

| | | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Inequality ranges | Quiet days . . . | 54 | 63 | 110 | 130 | 135 | 131 | 128 | 134 | 120 | 93 | 60 | 43 |
| | Ordinary days . | 59 | 74 | 107 | 129 | 126 | 128 | 125 | 129 | 113 | 92 | 64 | 54 |
| Absolute ranges | Quiet days . . . | 64 | 79 | 110 | 123 | 126 | 124 | 121 | 124 | 113 | 95 | 68 | 53 |
| | Ordinary days . | 81 | 94 | 113 | 113 | 110 | 105 | 107 | 109 | 109 | 104 | 83 | 72 |
| | All days. . . . | 82 | 101 | 117 | 111 | 110 | 101 | 104 | 105 | 107 | 104 | 86 | 72 |

where the monthly values are represented as percentages of their arithmetic mean. For comparative purposes data are given for the inequality ranges as well as the absolute ranges.

The two features which the figures are intended to bring out are: (i.) the reduction in the relative importance of the annual variation as we pass from inequality ranges to absolute ranges, and from quiet days to ordinary and to disturbed days; (ii.) the prominence given to a secondary minimum at midsummer and to maxima at the equinoxes in the case of the absolute ranges from ordinary and all days, more especially the latter.

### *Frequency of Absolute Daily Ranges of Specified Amplitude.*

§ 21. Table XIV. shows how the mean value of the absolute range varies from month to month, and from year to year, but this supplies only part of the information wanted. For instance, the mean of the absolute ranges for March was 17 per cent.

TABLE XVI.—Ranges. Number of Occurrences in 11 Years.

| Month. | | 0′ to 5′. | 5′ to 10′. | 10′ to 15′. | 15′ to 20′. | 20′ to 25′. | 25′ to 30′. | 30′ to 35′. | 35′ to 40′. | >40′. |
|---|---|---|---|---|---|---|---|---|---|---|
| January | | 51 | 145 | 69 | 37 | 24 | 7 | 4 | 3 | 1 |
| February | | 26 | 99 | 84 | 51 | 26 | 10 | 4 | 2 | 8 |
| March | | 1 | 72 | 138 | 61 | 32 | 21 | 8 | 1 | 7 |
| April | | 0 | 43 | 167 | 73 | 27 | 10 | 6 | 3 | 1 |
| May | | 0 | 57 | 157 | 85 | 20 | 12 | 3 | 0 | 7 |
| June | | 0 | 56 | 185 | 67 | 15 | 1 | 3 | 1 | 2 |
| July | | 0 | 59 | 185 | 70 | 14 | 5 | 2 | 2 | 4 |
| August | | 0 | 37 | 202 | 75 | 22 | 1 | 2 | 0 | 2 |
| September | | 1 | 68 | 153 | 71 | 19 | 5 | 4 | 5 | 4 |
| October | | 3 | 103 | 111 | 67 | 34 | 10 | 11 | 2 | 0 |
| November | | 42 | 140 | 81 | 28 | 14 | 9 | 8 | 5 | 3 |
| December | | 64 | 166 | 56 | 29 | 14 | 7 | 1 | 1 | 3 |
| Sums | Year | 188 | 1045 | 1588 | 714 | 261 | 98 | 56 | 25 | 42 |
| | Winter | 183 | 550 | 290 | 145 | 78 | 33 | 17 | 11 | 15 |
| | Equinox | 5 | 286 | 569 | 272 | 112 | 46 | 29 | 11 | 12 |
| | Summer | 0 | 209 | 729 | 297 | 71 | 19 | 10 | 3 | 15 |

larger than the mean for June. But this may arise in more than one way. It might signify an excess of range in most March days over most June days, or simply that of the comparatively small number of days of very large range a larger proportion occur in the former month than in the latter.

To elucidate this point, the ranges for each month of each year were collected in groups, the first group containing all ranges not exceeding 5′, the second group those exceeding 5′ but not exceeding 10′, and so on. Table XVI. summarises these results for the several months of the year. Totals are also given for the whole period and for the seasons. It seemed simpler to give the actual totals, but any one using the table must remember to divide the figures by 11 if he wishes average results for the months and seasons of a single year. The total number of days included amounted to 4017, of these 1322 occurred in winter, 1342 in equinox, and 1353 in summer. The ranges exceeding 40′ were so few and at the same time so variable that they have been combined to save space. The range exceeded 20′ on 482 days, *i.e.*, on almost exactly 12 per cent. of the days; but in March this percentage rose to 20, whereas in June it fell to 7. One was quite prepared to find that ranges exceeding 20′ are most numerous in the equinoctial months, but their greater frequency at midwinter than at midsummer was quite unexpected.

Table XVII. is based on the same data as Table XVI., but arranges the results under the different years. It also gives means for the average year of the eleven, for the average of the years 1890, 1899, and 1900 of sunspot minimum, and for the average of the years 1892 to 1895 of sunspot maximum.

TABLE XVII.—Ranges. Number of Occurrences in Individual Years.

| Year. | 0′ to 5′. | 5′ to 10′. | 10′ to 15′. | 15′ to 20′. | 20′ to 25′. | 25′ to 30′. | 30′ to 35′. | 35′ to 40′. | >40′. |
|---|---|---|---|---|---|---|---|---|---|
| 1890 | 12 | 161 | 155 | 25 | 10 | 1 | 1 | 0 | 0 |
| 1891 | 16 | 77 | 157 | 69 | 29 | 5 | 5 | 5 | 2 |
| 1892 | 2 | 42 | 132 | 108 | 35 | 16 | 14 | 2 | 15 |
| 1893 | 5 | 47 | 124 | 132 | 37 | 11 | 6 | 2 | 1 |
| 1894 | 2 | 53 | 159 | 88 | 27 | 13 | 4 | 6 | 13 |
| 1895 | 6 | 57 | 136 | 99 | 32 | 18 | 14 | 3 | 0 |
| 1896 | 14 | 71 | 157 | 61 | 34 | 15 | 5 | 4 | 5 |
| 1897 | 19 | 116 | 155 | 45 | 21 | 5 | 1 | 1 | 2 |
| 1898 | 21 | 122 | 149 | 40 | 22 | 6 | 2 | 0 | 2 |
| 1899 | 35 | 123 | 147 | 39 | 10 | 6 | 2 | 2 | 1 |
| 1900 | 56 | 176 | 117 | 8 | 4 | 2 | 2 | 0 | 0 |
| Yearly averages— | | | | | | | | | |
| 1890 to 1900 | 17 | 95 | 144 | 65 | 24 | 9 | 5 | 2 | 4 |
| 1890, 1899 and 1900 | 34 | 153 | 140 | 24 | 8 | 3 | 2 | 1 | 0·3 |
| 1892 to 1895 | 4 | 50 | 138 | 107 | 33 | 14 | 9 | 3 | 7 |

Ranges of from 10′ to 15′ are about equally numerous in the two classes of years; but ranges over 15′ were $4\frac{1}{2}$ times as numerous in the representative year of sunspot maximum as in the representative year of sunspot minimum, whereas ranges under 10′ were nearly $3\frac{1}{2}$ times as numerous in the representative year of sunspot minimum as in the representative year of sunspot maximum.

### *Frequency of Occurrence of Maxima and Minima at Different Hours of the Day.*

§ 22. Table XVIII. gives the number of occasions during the 11 years when the maximum and minimum for the day fell between 0 and 1 a.m., between 1 and 2 a.m., and so on. The times were measured to the nearest minute. An occurrence at an exact hour, *e.g.* at 2h. 0m., was assigned to the following hour, in the case mentioned 2 to 3. When, as occasionally happened, two hours had equal claims to a maximum or minimum —two measurements agreeing to 0′·1—the occurrence was entered as 0·5 under each hour. Table XVIII. contains results for the three seasons as well as the whole year. Results were really got out for each month, and for the sunspot minimum years 1890, 1899 and 1900, and the sunspot maximum years 1892 and 1895 separately, as well as for the whole 11-year period. The brief abstracts in Tables XIX. and XX. are based on these figures. In these tables the numbers represent percentages, whereas in Table XVIII. they represent the actual number of occurrences. The total occurrences are less in Table XVIII. than in Table XVI., because information was lacking as to the exact hours of maximum or minimum on a few days, more especially in January.

TABLE XVIII.—Number of Occurrences of Maxima and Minima at Different Hours of the Day.

| Hour. | Year. | | Winter. | | Equinox. | | Summer. | |
|---|---|---|---|---|---|---|---|---|
| | Maxima. | Minima. | Maxima. | Minima. | Maxima. | Minima. | Maxima. | Minima. |
| 0 to 1 | 17 | 338 | 8 | 189·5 | 5 | 97·5 | 4 | 51 |
| 1 ,, 2 | 15 | 142 | 7 | 56 | 2 | 48 | 6 | 38 |
| 2 ,, 3 | 23 | 98·5 | 14 | 34·5 | 5 | 36 | 4 | 28 |
| 3 ,, 4 | 18 | 84 | 12 | 23 | 4 | 35 | 2 | 26 |
| 4 ,, 5 | 15 | 56 | 6 | 16 | 5 | 16 | 4 | 24 |
| 5 ,, 6 | 19 | 173·5 | 8 | 17 | 5 | 18 | 6 | 138·5 |
| 6 ,, 7 | 26 | 376·5 | 12 | 5 | 10 | 39 | 4 | 332·5 |
| 7 ,, 8 | 9 | 554·5 | 7 | 15 | 2 | 155 | 0 | 384·5 |
| 8 ,, 9 | 9 | 507 | 6 | 77·5 | 1 | 286·5 | 2 | 143 |
| 9 ,, 10 | 10 | 100·5 | 5 | 45·5 | 4 | 45 | 1 | 10 |
| 10 ,, 11 | 17·5 | 2 | 14 | 1 | 3·5 | 1 | 0 | 0 |
| 11 ,, noon | 159 | 0 | 75·5 | 0 | 40·5 | 0 | 43 | 0 |
| Noon ,, 1 | 1293·5 | 0 | 476 | 0 | 456·5 | 0 | 361 | 0 |
| 1 ,, 2 | 1638·5 | 0 | 431·5 | 0 | 639 | 0 | 568 | 0 |
| 2 ,, 3 | 518·5 | 4 | 121 | 4 | 116·5 | 0 | 281 | 0 |
| 3 ,, 4 | 96·5 | 6 | 26 | 5 | 24·5 | 1 | 46 | 0 |
| 4 ,, 5 | 33·5 | 33 | 23 | 29 | 2·5 | 4 | 8 | 0 |
| 5 ,, 6 | 28 | 65 | 20 | 25 | 2 | 38 | 6 | 2 |
| 6 ,, 7 | 20 | 125 | 18 | 55 | 2 | 60 | 0 | 10 |
| 7 ,, 8 | 4 | 211·5 | 2 | 107·5 | 1 | 84 | 1 | 20 |
| 8 ,, 9 | 5 | 273 | 2 | 138·5 | 2 | 105·5 | 1 | 29 |
| 9 ,, 10 | 5 | 283 | 3 | 164 | 1 | 95 | 1 | 24 |
| 10 ,, 11 | 4 | 271·5 | 0 | 154 | 2 | 78 | 2 | 39·5 |
| 11 ,, midt. | 7 | 303·5 | 4 | 159 | 2 | 95·5 | 1 | 49 |
| Totals . . | 3991 | 4008 | 1301 | 1321 | 1338 | 1338 | 1352 | 1349 |

§ 23. Considering the large excess of the average absolute range over the average inequality range, it is surprising to find that such a very large proportion of the maxima occur within $1\frac{1}{2}$ hours of the time of the maximum in the inequality range for the year. It is no less surprising to find that on no single day of the whole 4008, for which information existed, did the minimum fall between 11 a.m. and 2 p.m. In the case of the minima the frequency of occurrence shows an unmistakable double period at all seasons; the maxima of frequency fall at about midnight, and between 7 and 9 a.m., the former being the more important in winter, but the latter at the other seasons. There is probably also a double period in the frequency of occurrence of the maxima, but the secondary maximum of frequency is very small, and a longer period of years would be required to show the exact hour of its occurrence at the different seasons.

## TABLE XIX.—Incidence of Maxima. Percentages of Totals.

| | Year. | | | | | | Winter. | | | | | | Equinox. | | | | | | Summer. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sunspot minimum. | | 11 years. | | Sunspot maximum. | | Sunspot minimum. | | 11 years. | | Sunspot maximum. | | Sunspot minimum. | | 11 years. | | Sunspot maximum. | | Sunspot minimum. | | 11 years. | | Sunspot maximum. | |
| Midt. to 10 a.m. | | 3·6 | | 4·1 | | 4·6 | | 7·1 | | 6·5 | | 6·0 | | 1·6 | | 3·2 | | 4·9 | | 2·2 | | 2·4 | | 2·9 |
| 10 a.m. ,, 11 a.m. | 0·3 | 94·9 | 0·4 | 93·3 | 0·3 | 91·9 | 0·8 | 89·2 | 1·1 | 88·0 | 0·6 | 87·2 | 0·0 | 98·1 | 0·3 | 95·7 | 0·2 | 93·3 | 0·0 | 97·3 | 0·0 | 96·1 | 0·0 | 95·1 |
| 11 a.m. ,, noon | 4·5 | | 4·0 | | 3·0 | | 6·9 | | 5·8 | | 4·2 | | 3·3 | | 3·0 | | 2·3 | | 3·5 | | 3·2 | | 2·6 | |
| Noon ,, 1 p.m. | 40·2 | | 32·4 | | 27·4 | | 46·9 | | 36·6 | | 28·6 | | 40·5 | | 34·1 | | 30·4 | | 33·3 | | 26·7 | | 23·4 | |
| 1 p.m. ,, 2 p.m. | 38·7 | | 41·1 | | 43·9 | | 29·2 | | 33·2 | | 37·7 | | 47·7 | | 47·8 | | 48·7 | | 39·0 | | 42·0 | | 45·0 | |
| 2 p.m. ,, 3 p.m. | 10·1 | | 13·0 | | 14·4 | | 4·8 | | 9·3 | | 12·7 | | 5·2 | | 8·7 | | 9·5 | | 20·1 | | 20·8 | | 21·0 | |
| 3 p.m. ,, 4 p.m. | 1·1 | | 2·4 | | 2·9 | | 0·6 | | 2·0 | | 3·4 | | 1·4 | | 1·8 | | 2·2 | | 1·4 | | 3·4 | | 3·1 | |
| 4 p.m. ,, midt. | | 1·5 | | 2·6 | | 3·5 | | 3·7 | | 5·5 | | 6·8 | | 0·3 | | 1·1 | | 1·8 | | 0·5 | | 1·5 | | 2·0 |

## TABLE XX.—Incidence of Minima. Percentages of Totals.

| | Year. | | | Winter. | | | Equinox. | | | Summer. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sunspot minimum. | 11 years. | Sunspot maximum. | Sunspot minimum. | 11 years. | Sunspot maximum. | Sunspot minimum. | 11 years. | Sunspot maximum. | Sunspot minimum. | 11 years. | Sunspot maximum. |
| Midt. to 10 a.m. | 62·5 | 60·6 | 62·2 | 33·7 | 36·2 | 40·0 | 64·6 | 58·1 | 57·9 | 88·6 | 87·1 | 88·5 |
| 10 a.m. ,, 4 p.m. | 0·3 | 0·3 | 0·4 | 0·6 | 0·8 | 0·8 | 0·3 | 0·2 | 0·2 | 0·0 | 0·0 | 0·0 |
| 4 p.m. ,, midt. | 37·2 | 39·1 | 37·4 | 65·7 | 63·0 | 59·2 | 35·1 | 41·7 | 41·9 | 11·4 | 12·9 | 11·5 |

Table XIX. is principally intended to bring out two facts: (1) that the hour of most frequent occurrence of the daily maximum is earlier in years of sunspot minimum than in years of maximum; (2) that the distribution of maxima is more concentrated, *i.e.* less uniform throughout the 24 hours, in years of sunspot minimum than in years of maximum. The phenomenon first mentioned is most conspicuous in winter. As regards the second phenomenon, there is an apparent exception in winter, the occurrences between midnight and 10 a.m. then diminishing slightly with increased sunspot frequency. This diminution is, however, more than made up for by the increase in the occurrences between 4 p.m. and midnight, and it probably merely represents the tendency to a closer approach to equality between the morning and evening occurrences which is seen in sunspot maximum years at the other seasons.

In the case of the daily minima, the differences between the phenomena in years of sunspot maximum and minimum are small. Table XX. does, however, show that in winter and equinox there is, in the years of sunspot maximum, a reduction in the disproportion of the evening and morning occurrences.

### *Annual Variation. Fourier Coefficients.*

§ 24. The mean monthly values of an element during the year may be analysed in a Fourier series

$$M+P_1 \sin (t+\theta_1)+P_2 \sin (2t+\theta_2)+\ldots,$$

where $t$ denotes time counted from January 1st, 30° being taken as the equivalent of one month. M denotes the arithmetic mean of the 12 monthly values, $P_1$ and $P_2$ the amplitudes of the annual and 6-month terms, while $\theta_1$ and $\theta_2$ represent the phase angles. One month of time answers, of course, to 30° in $\theta_1$, to 60° in $\theta_2$, and so on.

In determining the constants the observed monthly values were treated as if separated by exactly equal intervals of time. This is not strictly true, and there is a corresponding slight uncertainty in the results. Practically the same uncertainty enters, however, into the several groups of years and the different species of days, and the principal object of the investigation was to detect *differences* between the phenomena of the different groups of years or of the different classes of days.

Table XXI. shows the results obtained, including for comparison some already published for quiet days. In the case of the diurnal inequality, the first place has been given to the sum of the 24 differences from the mean for the day. This element is much less dependent on the accident of local time than is the range, and is probably a more accurate measure of the activity of the forces to which the diurnal inequality is due.

Contrasting ordinary and quiet days, we see that whilst M is invariably greater for the former, this is not the case with $P_1$. Thus $P_1/M$—or the fraction of the

TABLE XXI.—Annual Variation. Fourier Coefficients.

| Element. | Nature of days. | Period. | M. | P₁. | P₂. | $\theta_1$. | $\theta_2$. | $P_1/M$. | $P_2/M$. | $P_2/P_1$. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ′ | ′ | ′ | ° | ° | | | |
| Sum of 24 hourly differences . | Ordinary | 1892 to 1895 | 59·17 | 19·54 | 6·69 | 282 | 283 | 0·330 | 0·113 | 0·34 |
| ,, ,, ,, . | ,, | 11 years | 49·19 | 17·60 | 5·83 | 278 | 285 | 0·358 | 0·118 | 0·33 |
| ,, ,, ,, . | ,, | 1890, 1899, 1900 | 39·15 | 15·96 | 4·33 | 273 | 289 | 0·408 | 0·110 | 0·27 |
| ,, ,, ,, . | Quiet | 1892 to 1895 | 50·60 | 19·80 | 4·47 | 278 | 297 | 0·391 | 0·088 | 0·23 |
| ,, ,, ,, . | ,, | 11 years | 41·68 | 17·54 | 4·97 | 274 | 291 | 0·421 | 0·119 | 0·28 |
| ,, ,, ,, . | ,, | 1890, 1899, 1900 | 33·75 | 16·52 | 3·39 | 275 | 282 | 0·490 | 0·101 | 0·21 |
| Inequality range . . . . . | Ordinary | 11 years | 8·44 | 3·36 | 0·94 | 279 | 280 | 0·398 | 0·111 | 0·28 |
| ,, . . . . . | Quiet | ,, | 8·03 | 3·81 | 1·22 | 275 | 273 | 0·474 | 0·152 | 0·32 |
| $c_1$ . . . . . . . . . . . | Disturbed | ,, | 5·27 | 1·05 | 0·76 | 319 | 228 | 0·199 | 0·144 | 0·72 |
| $c_1$ . . . . . . . . . . . | Ordinary | 1892 to 1895 | 3·53 | 1·20 | 0·29 | 280 | 296 | 0·339 | 0·083 | 0·25 |
| $c_1$ . . . . . . . . . . . | ,, | 11 years | 2·91 | 1·05 | 0·25 | 276 | 300 | 0·361 | 0·086 | 0·24 |
| $c_1$ . . . . . . . . . . . | ,, | 1890, 1899, 1900 | 2·29 | 0·94 | 0·18 | 272 | 311 | 0·411 | 0·080 | 0·20 |
| $c_1$ . . . . . . . . . . . | Quiet | 1892 to 1895 | 2·91 | 1·23 | 0·18 | 277 | 318 | 0·422 | 0·063 | 0·15 |
| $c_1$ . . . . . . . . . . . | ,, | 11 years | 2·37 | 1·09 | 0·17 | 274 | 304 | 0·459 | 0·073 | 0·16 |
| $c_1$ . . . . . . . . . . . | ,, | 1890, 1899, 1900 | 1·86 | 0·97 | 0·12 | 274 | 303 | 0·519 | 0·063 | 0·12 |
| Absolute range . . . . . . | All | 11 years | 13·57 | 1·67 | 1·64 | 295 | 287 | 0·123 | 0·121 | 0·98 |
| ,, . . . . . . | Ordinary | ,, | 12·57 | 2·15 | 1·40 | 281 | 285 | 0·171 | 0·112 | 0·65 |
| ,, . . . . . . | Quiet | ,, | 9·61 | 3·34 | 1·14 | 280 | 282 | 0·347 | 0·118 | 0·34 |

element which takes part in the annual variation—is in all cases less for the ordinary than for the quiet days. $P_2$, on the contrary, distinctly increases as we pass from quiet to ordinary days, and sometimes in a larger proportion than M. The importance of the 6-month term as compared to the 12-month term is thus, in general, notably greater for the ordinary than the quiet days. It seems specially great for the disturbed days.

$P_1$ and $P_2$ both rise with increase in sunspot frequency, but $P_1$ increases less relatively than M, and $P_1/M$ falls notably.

We thus see that, relative to the mean value of the element, the term whose period is 12 months is most conspicuous on quiet days and when sunspots are few.

Coming to the phase, as I have pointed out before, $\theta_1$ and $\theta_2$ for quiet days both increase with sunspot frequency, *i.e.* the times of occurrence of the maxima are earlier for both the 12-month and 6-month terms in years of sunspot maximum than in years of sunspot minimum. The value of $\theta_1$ for ordinary days exhibits the same phenomenon, but to an enhanced degree. Taking the 24 differences, the inequality range, and $c_1$, the mean difference in time was only 3·4 days in the case of the quiet days, whereas for the ordinary days the mean difference in time from the 24 differences and $c_1$ is 8·9 days. Ordinary days show, however, a diminution in $\theta_2$, or a retardation of phase in the 6-month term, as we pass from sunspot minimum to sunspot maximum.

Comparing ordinary and quiet day phases, we find that $\theta_1$ is greater for the former, except in years of sunspot minimum. Taking a mean from the 11-year data for the 24 differences, the inequality range, and $c_1$, the maximum in the 12-month term occurs 3·1 days earlier for the ordinary than the quiet days. The advance of phase is still more notable in the cases of $c_1$ from disturbed days, and of the absolute range from all days. The results for the influence of disturbance on $\theta_2$ appear somewhat contradictory.

### *Sunspot Relationships.*

§ 25. In the previous part of the paper there have been a number of references to sunspot frequency, but all with the object of illustrating the differences that exist between the phenomena of different years. The remainder of the paper is exclusively devoted to a study of the sunspot relationship, but from a somewhat different point of view.

In A, I investigated whether the average sunspot frequency after WOLFER was less for the Astronomer Royal's quiet days than for days as a whole. The quiet days are practically free from magnetic disturbance, thus, if disturbance is intimately connected with the *simultaneous* sunspot frequency, one would expect the mean sunspot frequency from the quiet days of a month to be notably less than that from the month as a whole. The comparison was made for the 11 years 1890 to 1900 (A, pp. 433, 434), and showed that if any real difference existed between sunspot frequency for quiet days and for other days, it must be exceedingly small. Assuming Wolfer's frequencies an appropriate measure of the phenomenon, this seemed practically conclusive against any theory which postulates a direct relationship without time lag between sunspot frequency and magnetic disturbance.

It is clear, however, as I fully recognised at the time, that the result does not necessarily militate against any theory which supposes a day or more to elapse between the phenomenon on the sun and the corresponding phenomenon on the earth. Since the paper was written, Arrhenius and others have advanced theories—and evidence regarded as favourable to the theories—which postulate the transfer from the sun of electrified matter or ions at a rate very slow compared to that of light. Arrhenius considers two days as about the time required to reach the earth. Again, there are a considerable number of days for which Wolfer has no sunspot data, and in some months this was the case for more than one of the Astronomer Royal's quiet days. I accordingly decided to repeat the investigation, at the same time widely extending its scope and replacing Wolfer's frequencies by the Greenwich daily values of sunspot areas. These, being based on data from India and Mauritius, as well as Greenwich, are seldom lacking for more than 2 or 3 days in the year.

Sunspot areas, as given at Greenwich, are of two kinds, *projected* areas and *corrected* areas. The former are the areas as seen and measured in photographs, expressed as millionths of the sun's apparent disc; the latter are corrected for foreshortening. I have made use of the projected areas, principally because these are collected and presented in a convenient table in the annual Greenwich volumes. The corrected areas are of course the more correct measure of the state of spottedness of the visible hemisphere, but if the action exerted by the sun is a species of bombardment, as seems postulated by the views of Arrhenius, Maunder, and others, the projected area should be the more appropriate for the present purpose.

§ 26. The first results I shall discuss relate to the quiet and disturbed days. The days of each month were arranged in three approximately equal groups, according to sunspot areas. Normally the first and third groups contained respectively the 10 days of largest and the 10 days of least sunspot area, the second group containing the intermediate days. It was then investigated into which groups the quiet and the disturbed days fell.* This was done for each month of the 11 years. If the sole cause of magnetic disturbance lay in simultaneous solar action dependent on sunspots, what we would expect to find would be all the disturbances falling under Group I. days, and all quiet days under Group III.

In carrying the scheme into execution a difficulty was encountered, viz., that in 1890, 1899, and 1900 there were months—21 in all—in which more than 10 days were wholly free from spots. It being impossible to get equal groups in these

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* The more natural process would have been to compare the mean sunspot areas for the quiet and the disturbed days with the mean area for the month; but this would have entailed the calculation of the monthly means, which do not seem to be given in the Greenwich volumes.

months, they are omitted in Table XXII. which summarises the results of the investigation.

The conclusions drawn from Table XXII. will, I suspect, depend a little on the temperament of the reasoner. There is a deficit of quiet days and an excess of disturbed days in the group of days of largest sunspot area, the excess of disturbed days being the more conspicuous. But whilst the mean from the whole 11 years appears favourable to a *slight* connection between disturbance and simultaneous sunspot area, there are individual years (*e.g.* 1895 and 1899) which associate quiet days with large sunspot area, and some (1895, 1897, and 1899) which associate disturbances with small sunspot area.

TABLE XXII.—Occurrences of Quiet and of Disturbed Days.

| | Quiet days. (Number found in each group.) | | | Disturbed days. (Number found in each group.) | | |
|---|---|---|---|---|---|---|
| Groups . . . | I. | II. | III. | I. | II. | III. |
| 1890 | 5 | 6 | 4 | 0 | 0 | 0 |
| 1891 | 19 | 18 | 23 | 4 | 11 | 6 |
| 1892 | 17 | 23 | 20 | 8 | 16 | 6 |
| 1893 | 20 | 16 | 24 | 6 | 2 | 3 |
| 1894 | 20 | 18 | 22 | 10 | 7 | 4 |
| 1895 | 21 | 21 | 18 | 4 | 6 | 9 |
| 1896 | 22 | 18 | 20 | 15 | 11 | 11 |
| 1897 | 18 | 22 | 20 | 5 | 2 | 7 |
| 1898 | 16 | 23 | 21 | 8 | 7 | 4 |
| 1899 | 14 | 21 | 10 | 6 | 3 | 8 |
| 1900 | 7 | 9 | 9 | 2 | 0 | 0 |
| Totals . . . | 179 | 195 | 191 | 68 | 65 | 58 |
| Percentages . | 31·7 | 34·5 | 33·8 | 35·6 | 34·0 | 30·4 |

The mean sunspot areas for the whole 11 years were, in the Greenwich units, 1626 from the group of largest areas, as against 312 from the group of least area. Thus the difference between the days of Groups I. and III. as regards sunspot area was very large. Taking this into account, we must, I think, conclude that the results of Table XXII. are incompatible with any theory which regards magnetic disturbance as dependent directly *in any large degree* on the *simultaneous* extent of the projected sunspot area. Further, even if we assume that no appreciable accidental element enters into the mean results of Table XXII., and that they would be reproduced in means derived from a whole century, it would not *necessarily* prove the slightest connection of the kind mentioned.

Sunspot area, it is true, shows a far from regular progression from day to day; the area on one day is not infrequently a considerable multiple of that on the preceding day. But, as a rule, days of large area and days of small area occur in groups. In one or two months the 10 days of largest area were absolutely consecutive, and it was rather the rule than the exception for a considerable proportion of the days of both Groups I. and III. to be consecutive. Thus the phenomena of Table XXII. might be expected to occur though there were no direct connection between disturbance and the simultaneous solar phenomena, provided there were an effect on the earth within a few days of the occurrence on the sun. The results, in short, might be easily reconciled with theories such as that of ARRHENIUS.

§ 27. The next and much more laborious investigation was intended to throw light on ARRHENIUS' and similar theories. If there is an influence originating in the sun, whose intensity increases synchronously with sunspot area, which is propagated to the earth in two or three days and there causes magnetic storms, then there ought to be a marked association between the amplitude of the absolute daily range and the sunspot area two or three days previously. To investigate this point the 10 days of largest and the 10 days of least absolute range in each month were taken to form two contrasted groups. The sunspot areas answering to each of these days and the three preceding days were entered in four successive columns, and means were formed for each month. One thus got for each month four mean sunspot areas S, $S_{-1}$, $S_{-2}$, $S_{-3}$, answering: S to the 10 days of largest absolute range, $S_{-1}$ to the 10 days immediately preceding these, and so on, and four mean areas $S'$, $S'_{-1}$, $S'_{-2}$, $S'_{-3}$, answering to the 10 days of least absolute range, to the 10 days preceding these, and so on.

What appears in Table XXIII. is the algebraic excess of the 12 monthly values of S, $S'$ . . . over the mean sunspot area for the year as given by the Astronomer Royal. The second last line gives the algebraic mean of the above results from the 11 years. The last line gives the final mean obtained when the entries under each individual year are expressed as percentages of the mean sunspot area for that year. In the headings of the columns, $n$ is intended to denote the representative day of large (or small) absolute range; $n-1$, $n-2$, and $n-3$ the three preceding days in order.

If magnetic disturbance were entirely or even largely due to solar influence, whose activity at its source was largely dependent on sunspot area, and whose time of propagation to the earth varied only within narrow limits, then what one would expect to see would be a notable excess in the mean $S_{-1}$, $S_{-2}$, or $S_{-3}$, and a corresponding deficit in the mean $S'_{-1}$, $S'_{-2}$, or $S'_{-3}$.

If the principal source of magnetic disturbance is of the kind postulated, but the time of propagation to the earth varies largely from under a day to several days, then what one would expect is an excess of all or most of the S's, with corresponding deficits in $S''$s.

It is the second hypothesis, if either, which derives support from Table XXIII. In

TABLE XXIII.—Algebraic Excess of Sunspot Areas over the Mean for the Year.

| Year. | Days of largest range. | | | | Days of least range. | | | |
|---|---|---|---|---|---|---|---|---|
| | $n$. | $n-1$. | $n-2$. | $n-3$. | $n$. | $n-1$. | $n-2$. | $n-3$. |
| 1890 | − 26 | − 23 | − 17 | − 5 | + 8 | 0 | − 6 | − 12 |
| 1891 | − 13 | − 24 | − 19 | − 12 | + 31 | + 82 | + 53 | + 22 |
| 1892 | + 38 | +108 | +155 | +226 | −125 | −141 | −203 | −201 |
| 1893 | + 4 | + 33 | + 72 | +100 | + 6 | − 20 | − 62 | −122 |
| 1894 | +170 | +147 | +127 | +108 | −177 | −187 | −179 | −165 |
| 1895 | + 14 | + 2 | − 47 | − 92 | + 6 | + 20 | + 40 | + 85 |
| 1896 | + 28 | + 37 | + 35 | + 48 | − 72 | − 71 | − 51 | − 6 |
| 1897 | + 23 | + 7 | + 24 | + 48 | + 37 | + 15 | − 10 | − 36 |
| 1898 | +118 | +106 | + 93 | + 66 | −143 | −130 | −114 | − 85 |
| 1899 | + 5 | + 8 | + 13 | + 19 | + 31 | + 27 | + 14 | + 6 |
| 1900 | + 24 | + 27 | + 20 | + 26 | − 7 | − 8 | − 15 | − 23 |
| Means . . . | + 35 | + 39 | + 41 | + 48 | − 37 | − 38 | − 48 | − 49 |
| Percentages . | +4·4 | +5·1 | +4·9 | +6·8 | −2·5 | −2·9 | −5·1 | −6·4 |

some individual years, *e.g.* 1892, 1893, 1894, 1898, and 1900, the phenomena are so far distinctly favourable to views such as ARRHENIUS', if we suppose the velocity of propagation from the sun highly variable. But even in these years the balance in excess of the S's, and of deficit in the $S''$s, appears very small when we consider the great disproportion which exists between the means of the ten largest and the ten least absolute ranges.

A remarkable feature in Table XXIII. is the comparative regularity in the values of the successive S's and $S''$s in any one year. But whether the trend of the sequence is to a rise or a fall seems largely fortuitous. Thus we have a regular rise from S to $S_{-3}$ in 1892, but a regular fall in 1894. The phenomenon is probably due in part to the tendency for days of largest and of least sunspot area to occur in groups.

Whilst the mean results in Table XXIII. suggest a closer connection of the range with the sunspot area two or three days previously than with that of the day itself, still we have a difference of 6·9 between the final percentage values in the first and fifth columns of Table XXIII. as against a corresponding difference of 13·2 between the fourth and eighth columns. Any theory which requires as much as one day for the minimum time of transfer of disturbance from the sun to the earth has thus the evidence in its favour very considerably weakened. In every year, it should be mentioned, individual months gave results diametrically opposed to the final mean.

§ 28. The excess of S over $S'$, and the pre-eminence of $S_{-3}$ in the final means, pointed to the desirability of further enquiry. The scheme of operations leading up to Table XXIII. was accordingly repeated, but with this difference, that the comparison instituted was between the *five* days of largest and the five of least range in the month, and it was extended to include the fourth previous day and the day following that to which the range belonged.

The increase in the difference between the mean ranges in the two groups of days due to the reduction of the number of days in the group from 10 to 5 is shown in Table XXIV. The final means from the 11 years for the groups of largest and of least range bear the ratio of 2·18 when the monthly groups contain 10 days, but 2·92 when they contain 5 days. Thus what we should expect in Table XXV., which summarises the investigation for 5-day groups, is a repetition of the phenomena apparent in Table XXIII., but in a considerably enhanced degree. The tables were prepared exactly in the same way and the headings have the same meanings; $n+1$ denotes of course the day following that to which the magnetic range belongs. The column under the first heading, $n+1$, is spoken of as the first column.

TABLE XXIV.—Mean Absolute Ranges.

| Year. | Groups of 10. | | Groups of 5. | |
|---|---|---|---|---|
| | Largest. | Least. | Largest. | Least. |
| | ′ | ′ | ′ | ′ |
| 1890 | 14·37 | 7·57 | 16·32 | 6·88 |
| 1891 | 19·80 | 9·03 | 23·59 | 8·24 |
| 1892 | 26·88 | 11·03 | 34·74 | 9·97 |
| 1893 | 21·03 | 11·28 | 24·27 | 10·29 |
| 1894 | 24·89 | 10·77 | 31·79 | 9·84 |
| 1895 | 22·32 | 10·26 | 25·72 | 9·29 |
| 1896 | 21·76 | 9·28 | 26·13 | 8·40 |
| 1897 | 17·71 | 7·93 | 21·35 | 7·00 |
| 1898 | 18·51 | 7·78 | 22·99 | 7·02 |
| 1899 | 16·41 | 7·49 | 19·90 | 6·77 |
| 1900 | 12·41 | 6·42 | 14·58 | 5·94 |
| Means . . . . . | 19·64 | 8·99 | 23·76 | 8·15 |

It will be seen that the final excesses in the means for columns 2 to 5 over those for columns 8 to 11 is greater in Table XXV. than in the corresponding columns of Table XXIII. This result is favourable to the view that the difference is not purely fortuitous, but betokens some physical connection.

The marked rise in the mean of the second column, as compared to that of the first column in Table XXV., is also distinctly favourable to this view. On the other hand, the mean for the seventh column is nearly as large numerically as those for columns 8 to 10, and larger than the means for columns 11 and 12. This is equivalent to the effect occurring 24 hours in advance of the cause. An explanation may, to some extent, be forthcoming from the fact that there is a tendency for days of large range and of small range to occur in groups. This tendency is, however, markedly less than the corresponding tendency in the case of sunspot areas already alluded to (a difference of significance in itself), and it is unusual to have more than two or three successive days on which the ranges are all markedly greater or markedly less than the mean for the month.

TABLE XXV.—Algebraic Excess of Sunspot Areas over the Mean for the Year.

| Year. | Days of largest range. | | | | | | Days of least range. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $n+1$. | $n$. | $n-1$. | $n-2$. | $n-3$. | $n-4$. | $n+1$. | $n$. | $n-1$. | $n-2$. | $n-3$. | $n-4$. |
| 1890 | − 46 | − 35 | − 41 | − 41 | − 28 | − 11 | + 28 | + 31 | + 18 | + 1 | − 13 | − 28 |
| 1891 | − 44 | − 59 | − 84 | − 56 | − 32 | + 1 | − 24 | − 26 | − 46 | − 64 | − 69 | − 98 |
| 1892 | − 105 | + 32 | + 161 | + 223 | + 321 | + 408 | − 53 | − 186 | − 205 | − 230 | − 98 | − 142 |
| 1893 | − 49 | + 90 | + 196 | + 240 | + 245 | + 207 | + 140 | + 163 | + 186 | + 162 | + 160 | + 83 |
| 1894 | + 106 | + 184 | + 201 | + 182 | + 154 | + 212 | − 320 | − 366 | − 364 | − 334 | − 296 | − 251 |
| 1895 | − 130 | − 152 | − 161 | − 194 | − 229 | − 216 | − 53 | − 27 | − 29 | + 8 | + 130 | + 220 |
| 1896 | + 57 | + 72 | + 69 | + 83 | + 67 | + 30 | − 128 | − 123 | − 112 | − 127 | − 108 | − 114 |
| 1897 | − 20 | + 28 | + 15 | + 33 | + 76 | + 135 | + 78 | + 78 | + 80 | + 46 | + 30 | − 42 |
| 1898 | + 207 | + 171 | + 180 | + 158 | + 110 | + 70 | − 246 | − 258 | − 208 | − 166 | − 130 | − 64 |
| 1899 | + 46 | + 50 | + 53 | + 51 | + 56 | + 41 | + 11 | + 24 | + 47 | + 48 | + 42 | + 34 |
| 1900 | + 27 | + 54 | + 57 | + 55 | + 57 | + 66 | − 8 | − 9 | − 13 | − 4 | − 3 | + 15 |
| Means . . | + 4 | + 40 | + 59 | + 67 | + 72 | + 86 | − 52 | − 64 | − 59 | − 60 | − 32 | − 35 |

§ 29. A minute comparison of Tables XXV. and XXIII. brings out some very curious features, which seem explicable only in the view that accident plays a large part in the mean results for any single year. In 1890, 1891, and 1895, the entries under $n$, $n-1$, $n-2$, and $n-3$ for the days of largest range are not merely negative in Table XXV., but are conspicuously more so than the corresponding entries in Table XXIII. In 1893 the entries under $n-1$, $n-2$, and $n-3$ for the days of least range in Table XXIII. were negative, but in Table XXV. the corresponding entries are positive and large. Thus in this year the phenomena for the five days of largest and the five of least range a month differ notably from the phenomena for the average day, but they differ in the same direction. With the exception of 1894, 1898 is the year in which the sunspot phenomena from the two groups of days differ most; but this difference is largest for the columns headed $n+1$, *i.e.* for the days *subsequent* to those of largest range.

§ 30. Considering the contradictions in Table XXV., it appeared desirable to obtain corresponding results for the different months of the year from the 11 years combined. They appear in Table XXVI. The headings have the same meaning as before. As,

TABLE XXVI.—Magnetic Ranges and Sunspot Areas in Contrasted Groups of Five Days.

| Month. | Five days of largest range. | | | | | | | Five days of least range. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Range. | Mean sunspot areas. | | | | | | Range. | Mean sunspot areas. | | | | | |
| | | $n+1$. | $n$. | $n-1$. | $n-2$. | $n-3$. | $n-4$. | | $n+1$. | $n$. | $n-1$. | $n-2$. | $n-3$. | $n-4$. |
| | ′ | | | | | | | ′ | | | | | | |
| January . . . . | 22·90 | 795 | 807 | 776 | 716 | 691 | 758 | 5·07 | 980 | 1001 | 986 | 940 | 1006 | 943 |
| February . . . . | 27·21 | 1094 | 1168 | 1198 | 1239 | 1296 | 1323 | 6·55 | 1042 | 997 | 1065 | 1006 | 1055 | 886 |
| March . . . . . | 29·87 | 809 | 842 | 852 | 851 | 869 | 878 | 8·93 | 647 | 590 | 564 | 563 | 567 | 605 |
| April. . . . . . | 23·69 | 733 | 802 | 874 | 891 | 893 | 822 | 10·31 | 838 | 822 | 810 | 807 | 794 | 757 |
| May . . . . . . | 25·36 | 760 | 774 | 747 | 753 | 782 | 786 | 9·50 | 706 | 741 | 763 | 798 | 852 | 914 |
| June. . . . . . | 19·92 | 973 | 1030 | 1101 | 1116 | 1117 | 1063 | 9·89 | 771 | 750 | 754 | 778 | 848 | 913 |
| July . . . . . . | 22·49 | 918 | 982 | 1134 | 1299 | 1394 | 1467 | 9·96 | 805 | 802 | 806 | 823 | 838 | 889 |
| August . . . . . | 21·27 | 1232 | 1297 | 1287 | 1189 | 1124 | 1103 | 10·05 | 1040 | 978 | 945 | 929 | 935 | 948 |
| September . . . . | 24·55 | 1133 | 1180 | 1190 | 1211 | 1212 | 1242 | 9·52 | 772 | 733 | 752 | 804 | 848 | 914 |
| October. . . . . | 23·92 | 624 | 631 | 665 | 670 | 679 | 717 | 8·01 | 927 | 981 | 993 | 969 | 963 | 979 |
| November . . . . | 23·58 | 706 | 675 | 615 | 541 | 505 | 547 | 5·64 | 638 | 642 | 674 | 693 | 681 | 615 |
| December . . . . | 20·43 | 911 | 918 | 916 | 956 | 939 | 955 | 4·36 | 839 | 834 | 816 | 804 | 859 | 851 |
| Means . . . | 23·77 | 891 | 926 | 946 | 953 | 958 | 972 | 8·15 | 834 | 823 | 827 | 826 | 854 | 851 |

however, the mean sunspot areas from all days were not known for individual months, absolute sunspot areas are given in the several columns. The corresponding magnetic ranges are shown.

Table XXVI. shows that contradictions exist between different months, just as between different years. In several months the left-hand side of the table (*i.e.* the half dealing with the days of largest range) supports the view that magnetic disturbance is even largely dependent on the sunspot area three or four days previously. February and July are outstanding examples, the increase in sunspot area from day $n+1$ to day $n-4$ being most marked. Again, in the majority of months—*e.g.* February, March, June, July, August, September and December—the areas in the several columns of the left-hand side exceed those in any of the columns of the right-hand side. But diametrically opposite phenomena appear in more than one month. In May and November, taking corresponding columns from the two halves of the table, the sunspot area on the right-hand side is the larger from day $n-1$ to day $n-4$. In January and October the smallest sunspot area on the right-hand side is larger—and notably larger—than the largest area on the left-hand side. A seasonal change in the amplitude of a phenomenon causes no surprise, but a seasonal change which absolutely alters the sign of a phenomenon, so that January is opposed to December, and October to September, is, I think, without precedent.

As regards the right-hand side of Table XXVI., we know already, through Table XXV., that the means from the months combined are all below the mean sunspot area for the 11 years. This is almost the only feature favourable to an association of sunspots and magnetic ranges of the kind suggested by the mean values on the left-hand side. In April, indeed, the sunspot area shows a progressive though small decline from day $n+1$ to day $n-4$, but May shows the opposite phenomenon, and so do June, July, and September, from day $n$ to day $n-4$.

§ 31. An independent investigation was made on the lines of § 27, taking the ten days of largest and the ten days of least sunspot area in each month as the contrasted groups, and comparing the absolute magnetic ranges on these days and the three *following* days. The results obtained were generally similar to those in § 27, but the apparent association of sunspot frequency and magnetic range in the final means from the 11 years was only about half that shown by Table XXIII.

An investigation was also made on the lines of § 27, but employing Greenwich projected areas of faculæ for those of sunspots. This was limited to a single year, 1892, the results obtained being at least as contradictory and as unfavourable to any *intimate* relationship of cause and effect as the corresponding results from sunspot area.

## *Discussion of Remarkable Special Cases.*

§ 32. During the investigation into sunspot areas, some individual instances were noticed of a highly suggestive character. In August, 1890, the largest range occurred in a day which with its three preceding days showed no sunspot. In October, 1890, the largest spotted area encountered on the five days of largest range, or during the 4-day periods preceding them was only 120, whereas the mean of the sunspot areas for the four days of smallest range and the 4-day periods preceding them were as follows:—

| Day . . . . | $n$. | $n-1$. | $n-2$. | $n-3$. | $n-4$. |
|---|---|---|---|---|---|
| Sunspot area . . . . | 1095 | 1089 | 970 | 714 | 597 |

In this instance the ranges in the two cases were widely different, the means being 22′·9 for the five days of largest range, and only 6′·7 for the four days of least range.

February 1, 1893, was a "quiet" day, and had a range 3′ less than that on any other day of the month. It had, however, the largest spot area of the month, and the four immediately preceding days in January had all spot areas larger than that of any single day in February.

In April, 1894, the two days of largest range were the days of least spot area for the month, and the four preceding days in each case were included in the group of ten days of least spot area.

In November, 1895, not one of the nine days of largest range came into the group of ten days of largest spot area, and the day of the absolutely largest range was the day of absolutely least spot area.

In February, 1896, the two days of largest spot area were both "quiet" days, and had the smallest ranges of any in the month.

In October, 1896, not one of the nine days of largest range—four of them disturbed—nor of the four days preceding them came into the group of ten days of largest spot area.

In October, 1897, the day of largest range but one—itself a disturbed day—and the four previous days were all free from spots, though only three other days in the month were similarly situated.

During February, 1899, there were three "disturbed" days—one showing a range of 45′—and all three were free from any sunspot, though sunspots occurred on 17 days of the month.

In 1900 the sunspot area was absolutely nil from November 24 to December 31. December is the month of minimum range, and so the amplitude of the regular diurnal variation naturally would vary but little throughout the month. Thus if an intimate connection of any kind—possessing a time lag of any length up to six days—really existed between range and sunspot area, what we would have expected to find would have been a nearly constant daily range. What actually did happen is shown by the following figures:—

| Mean of absolute ranges on the ten days of— | | Mean of absolute ranges on the five days of— | |
|---|---|---|---|
| Largest range. | Least range. | Largest range. | Least range. |
| ′<br>7·3 | ′<br>3·0 | ′<br>9·4 | ′<br>2·7 |

The two days having the absolutely largest ranges were the 27th and 28th, and so were preceded by over 30 days free from spots.

The above instances are probably amongst the most striking examples of their kind, but many others scarcely less striking could be adduced. No doubt a similar number of striking associations of large ranges and large sunspot areas exists, but if the one set of phenomena must be ascribed to chance, may not also the other?

The phenomena of December, 1900, alone suffice to demonstrate that considerable variations are possible in the range without the occurrence for a month previously of any sunspot of measurable area. Thus, unless a time lag exceeding a month is postulated, we seem obliged to conclude that there are agencies other than those associated with visible sunspots which exert a potent influence on the range of the magnetic needle. The immediate source may, of course, be the sun, if the visible sunspot is only an accidental concomitant of the electrical disturbance and not an essential phenomenon. But it seems equally possible that the disturbances at the sun, visible as sunspots, and the enlargement of the magnetic range, are due to a common cause, operating throughout the solar system, but with an intensity which at any given instant may vary widely at points as far apart as the earth and sun.

One possibility which may be mentioned, if only to show that it was not overlooked, is that the ions, electrons, emanations—or whatever is the appropriate term for the entity supposed to be propagated from the sun—may have properties which show only a gradual decay when in the earth's atmosphere. Thus the condition on any given day, in that part of space—if external to the earth's surface—whence originate the causes of magnetic movements, regular and irregular, may be represented by an integral which receives contributions from a number of previous days. This is at least consistent with the continuous large amplitude of the diurnal inequality which is characteristic of years of many sunspots.

It must be remembered, however, that disturbances seldom continue large for more than two or three days, often less, and that quiet days often follow hard on them; on the other hand, magnetic storms often reach a great intensity within a few hours after a prolonged quiet or but slightly disturbed time. The immediate cause of at least some forms of magnetic disturbance must thus be something which is capable of very rapid changes, and whose effects may die out, if not instantaneously, at least very rapidly.

## *Applications of* Wolf's *Formula.*

§ 33. If any element, R, varies in a linear way with sunspot frequency, its value must be expressible by a formula of the type

$$R = a+bS,$$

where S denotes sunspot frequency, while $a$ and $b$ are constants. This formula, originally due to Wolf, has been applied to the range and the sum of the 24 differences in the diurnal inequality derived from individual months of the year. The inequalities employed in the calculation were not those from individual years, but those from the sunspot maximum years 1892 to 1895 combined, the sunspot minimum years 1890, 1899, and 1900 combined, and the whole 11 years combined. The method followed was that explained in A, p. 418. The results appear in Table XXVII.

Table XXVII.—Diurnal Inequality from all Ordinary Days.

| | Range. | | | Sum of 24 differences. | | |
|---|---|---|---|---|---|---|
| | $a$. | $b \times 10^4$. | $(b/a) \times 10^4$. | $a$. | $b \times 10^3$. | $(b/a) \times 10^4$. |
| January . . . . | 3·97 | 238 | 60 | 21·26 | 207 | 98 |
| February . . . . | 4·26 | 422 | 99 | 24·04 | 357 | 149 |
| March . . . . . | 6·72 | 665 | 99 | 35·03 | 523 | 149 |
| April . . . . . | 8·69 | 542 | 62 | 45·36 | 352 | 78 |
| May . . . . . | 8·46 | 509 | 60 | 45·97 | 328 | 71 |
| June . . . . . | 8·84 | 458 | 52 | 48·96 | 305 | 62 |
| July . . . . . | 8·18 | 537 | 66 | 45·65 | 338 | 74 |
| August . . . . | 9·40 | 354 | 38 | 52·44 | 190 | 36 |
| September . . . | 7·39 | 466 | 63 | 40·83 | 355 | 87 |
| October . . . . | 6·11 | 388 | 64 | 34·22 | 341 | 100 |
| November . . . | 4·28 | 312 | 73 | 23·16 | 272 | 118 |
| December . . . | 3·44 | 254 | 74 | 17·95 | 201 | 112 |
| Year . . . . . | 6·65 | 428 | 67 | 36·24 | 314 | 94 |
| Winter . . . . | 3·99 | 304 | 76 | 21·60 | 259 | 119 |
| Equinox . . . . | 7·23 | 515 | 72 | 38·86 | 393 | 103 |
| Summer . . . . | 8·72 | 465 | 54 | 48·25 | 290 | 61 |

The values assigned to the year and the seasons are arithmetic means from the months included. The results correspond exactly to those given in A, Table XLI., for quiet days.

Absolutely considered, $b$ is least in winter, but relatively to $a$ it is then greatest. In this respect the phenomena are similar to those observed on quiet days, but $b/a$ is less variable with the season on ordinary than on quiet days.

It will be noticed that $b/a$ is larger for the sum of the differences than for the range; the same phenomenon appeared in the case of the quiet days, but less conspicuously.

§ 34. The formula was also applied to the means of the 12 monthly values for individual years of the inequality range from ordinary days, and to the absolute ranges from quiet days, ordinary days, and all days. The method of least squares was employed.

Table XXVIII. gives the results found. It also gives $\overline{D}$, the arithmetical mean of the differences between the observed and calculated yearly values, and E, the corresponding probable error. The mean difference and the probable error are also expressed as percentages, the former of the mean value of the element, the latter of the range of the element (or difference between the greatest and least of the yearly values).

Table XXVIII.—Values of Constants in Wolf's Formula, and Resulting Accuracy.

| | $a$. | $b \times 10^4$. | $(b/a) \times 10^4$. | Mean differences calculated and observed. $\overline{D}$. | Probable error. E. | $\frac{\overline{D} \times 100}{\text{Mean value}}$. | $\frac{E \times 100}{\text{Range}}$. |
|---|---|---|---|---|---|---|---|
| | | | | ′ | ′ | | |
| Inequality range, all ordinary days | 6·68 | 441 | 66 | 0·18 | 0·15 | 2·2 | 4·0 |
| Absolute range, quiet days | 7·23 | 571 | 79 | 0·44 | 0·37 | 4·6 | 7·5 |
| Absolute range, all ordinary days | 9·48 | 741 | 78 | 0·51 | 0·43 | 4·0 | 6·6 |
| Absolute range, all days | 9·95 | 867 | 87 | 0·65 | 0·64 | 4·8 | 7·5 |

In the case of the inequality range, the agreement between the observed values and those calculated from Wolf's formula is remarkably close. In five out of the eleven years the difference between the observed and the calculated value was less than 0′·1, and the largest difference was only 0′·33. This is noteworthy, considering that the element varied from 6′·83 to 10′·74. In the case of the absolute ranges the agreement is very decidedly less good, but, absolutely considered, it is still very fair, especially for the ordinary days.

The cost of measuring and tabulating the curves was defrayed in large measure by a grant obtained in 1904 from the Government Grant Committee. The arithmetic necessary for the construction of the tables was very heavy, and I have had valuable assistance in this direction from several members of the staff of the National Physical Laboratory, especially Mr. B. Francis and Mr. G. Badderly. In smoothing the curves and in other directions I had much assistance from Mr. T. W. Baker, the Chief Assistant of the Observatory Department, who had charge of the magnetic instruments during the whole period dealt with. Every care has been taken to secure accuracy in the calculations.