A Discussion of Atmospheric Electric Potential Results at Kew from Selected Days during the Seven Years 1898 to 1904

C. Chree

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VI. *A Discussion of Atmospheric Electric Potential Results at Kew from Selected Days during the Seven Years* 1898 *to* 1904.

By C. Chree, *Sc.D., LL.D., F.R.S.*

(*From the National Physical Laboratory.*)

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Contents.

§ 1. In 1894 special observations were commenced with the object of determining the influence of its position on the records from the Kew water-dropping electrograph, and also of ascertaining whether any alterations were desirable. The results were discussed in a paper* communicated to the Society in 1896.

The experiments led to certain changes in the apparatus, and an auxiliary system of eye observations was introduced with the object of obtaining quantitative results possessing a definite significance.

The original water tank was replaced by another of much larger diameter and small depth. The new tank is situated on the wooden roof of a detached portion of the north-west room on the ground floor, which contains the recording part of the electrograph. The wire connecting the water-dropping tube to the electrograph is

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* 'Roy. Soc. Proc.,' vol. 60, 1896, pp. 96–132.

much shorter than under the old arrangement, thus reducing the risk of defective insulation. Again, the down tube from the tank to the horizontal discharge tube is about $5\frac{1}{3}$ feet long, instead of a few inches as formerly, so that the pressure under which the jet issues is practically constant.

Lastly, the jet is emitted parallel to the wall of the building, instead of perpendicular to it as before. This tends to increased uniformity in the conditions, as the potential varies rapidly in the direction perpendicular to the building, but little, if at all, in a horizontal direction taken parallel to it. The discharge tube, which projects from a window in the west wall, is situated about 10 feet to the north of the old tube, but nearly at the same level above the ground.

A flower border used to run the whole length of the west wall, containing shrubs 3 or 4 feet high. The northern half of this border was cleared of shrubs and laid down in grass, which has been kept short the whole year round. These changes were made with the object of securing that no appreciable fictitious element should be introduced into the annual change of potential gradient.

A definite test of the insulation of the apparatus was introduced, and is applied each morning. It is not always possible to improve defective insulation immediately when discovered, but at the worst the test shows when a day's record is to be regarded with suspicion.

The surface of the ground outside the building is not absolutely level, so the height of the spot where the jet breaks into drops can hardly be given with mathematical precision. It is very approximately 11 feet (3·35 metres). The perpendicular distance from the general outline of the west wall is $50\frac{1}{8}$ inches (127·3 centims.).

§ 2. If these distances, the environment, and the insulation of the apparatus could be kept absolutely uniform, the potential recorded on the electrograms would only require multiplication by an absolute constant to become converted into potential gradient per metre of height in the open. This ideal is not, however, practically attainable, and experience showed the desirability of obtaining a multiplier by reference to absolute eye observations made regularly in the open.

The eye observations are taken with a Kelvin portable electrometer, supported on a small level platform having three vertically projecting points, which prevent the electrometer from slipping. The platform is carried on a brass rod, fitting inside a hollow brass tube sunk in the ground. The rod can be raised in the tube and clamped at any convenient height. The original idea was to observe at two heights, a given distance apart. Having regard, however, to time and other considerations, it has been judged best not to vary the level, and the electrometer fuse has been used in a horizontal position at a fixed height above the ground. Thus the potential observed has referred to a fixed level, approximately 1·465 metres above the general level of the ground in the immediate vicinity. The ground is practically flat for a considerable space round the stand. The adjacent grass is kept short, and there is no tree, shrub, or building within what seems a reasonably satisfactory distance.

If P_1 be the potential shown by the portable electrometer, and P_2 that shown by the electrograph at the same instant, $P_1 \div (1{\cdot}465\,P_2)$ is a value for the factor by which the potential shown by the electrograph is to be multiplied to convert curve potentials into volts per metre of height in the open. Observations are taken with the portable electrometer nearly every day when the weather allows, and a mean value for the factor is calculated from each month's comparisons.

§ 3. When potential changes are very sudden, readings from the electrograph are doubtless partly dependent on its electrical capacity, and when the changes are very large, part of the trace is pretty sure to be lost. These large and sudden changes are mostly confined to times of rainfall, being specially prominent during thunderstorms. Further, during rain, drops are falling from all parts of the efflux tube, so that its record may not be solely, or possibly even mainly, determined by the jet at the end. For these and other reasons, it was decided to confine the tabulation of the electrograms to days when there was no rainfall, and to be content with 10 days a month. In selecting the 10 days one aimed at distributing them throughout the month, avoiding days in which negative potential was recorded, or there was reason to suspect the insulation. In some months there was a considerable excess of days to choose from, but in others it was difficult, and in a few cases impossible, to get as many as 10 suitable days. In one very wet month, in order to secure even 8 days, it was necessary, in two or three instances, to take in place of the natural day successive periods of 24 hours, comprising parts of two successive days. With this exception, a day always meant 24 hours, extending from midnight to midnight, G.M.T. All the data, except in Table IX., refer to Greenwich time, but the difference from this of local time is only $1\frac{1}{4}$ minutes.

Since 1902 the Annual Reports of the Observatory Department of the National Physical Laboratory have contained tables showing the mean monthly diurnal variation of the potential gradient from the selected days. Potential gradient is an exceptionally fluctuating element, and measurements of the actual photographic trace, taken at exact hours, may be far from representative of the mean value during 60 consecutive minutes. The practice adopted has been to draw in pencil a continuous curve, following as nearly as the eye can judge the general trend of the trace, and to measure the ordinates of this curve at exact hours, G.M.T.

During the past two years, the data for earlier years have been similarly treated, and the present paper deals with the results from the seven years 1898 to 1904.

Mean Monthly and Annual Values of the Potential Gradient.

§ 4. Table I. gives the mean value of P (the potential gradient in the open in volts per metre) for each individual month and for each year, and likewise the mean annual inequality based on the seven years' results. The annual inequality is exhibited graphically in fig. 1 by the continuous line curve; the ordinates represent the mean values of P for the individual months, expressed as fractions of their arithmetic mean from the 12 months.

TABLE I.—Potential Gradient (Volts per Metre).

	1898.	1899.	1900.	1901.	1902.	1903.	1904.	Mean.
January . . .	174	285	189	238	164	162	194	201
February . .	244	298	182	247	232	174	190	224
March . . .	216	203	180	141	152	191	177	180
April	109	139	107	140	149	165	160	138
May	97	151	96	127	93	167	130	123
June	104	105	73	114	115	156	106	111
July	104	90	86	95	86	105	117	98
August . . .	125	127	104	87	111	129	118	114
September . .	163	83	118	117	104	135	130	121
October . . .	161	175	133	191	123	141	147	153
November . .	250	167	157	215	178	172	259	200
December . .	184	328	263	162	237	250	273	243
Mean . .	161	179	141	156	145	162	167	159

Table I. shows at once how variable an element P is. It is at least doubtful whether even seven years are sufficient to give an annual inequality which can be relied on as fully representative in its details. There is unquestionably a well-marked minimum near midsummer. There seems also to be a second minimum in January, but whether this would be shown—or if shown would be as prominent—if we had 70 years instead of 7 is open to doubt. The fact that the largest mean monthly value did not occur in January in any one of the seven years, whilst occurring four times in December, is so far confirmatory. In November, December, and January, however, fog is a very uncertain while very important influence. During thick fog in winter P is usually abnormally high, 400 to 600 volts—or practically double the ordinary gradient—being not infrequently met with. Thus in winter the mean value of P varies much from day to day even in fair weather. For instance, in December, 1898, the last three of the selected days gave a mean value for P of 380 volts, whilst the corresponding mean from the first seven days only slightly exceeded 100 volts. So, again, in January, 1899, the mean values of P from the first five and the last five of the selected days were roughly 160 and 400 volts respectively. The figures in Table I. itself, *e.g.*, those for December in the years 1899 and 1901, afford examples almost as striking.

The mean value for the year appears lower for the three consecutive years 1900 to 1902—which cover the period of sun-spot minimum—than for the others. As this phenomenon also appears when we confine ourselves to the six summer months, April to September, when climatic influences are comparatively uniform, it *may* be a real one. If so, P tends to be *lower* than usual near sun-spot minimum. The difference shown, however, in Table I. may be accidental; it is certainly too small to rely on, considering the limited number of years and the many sources of uncertainty.

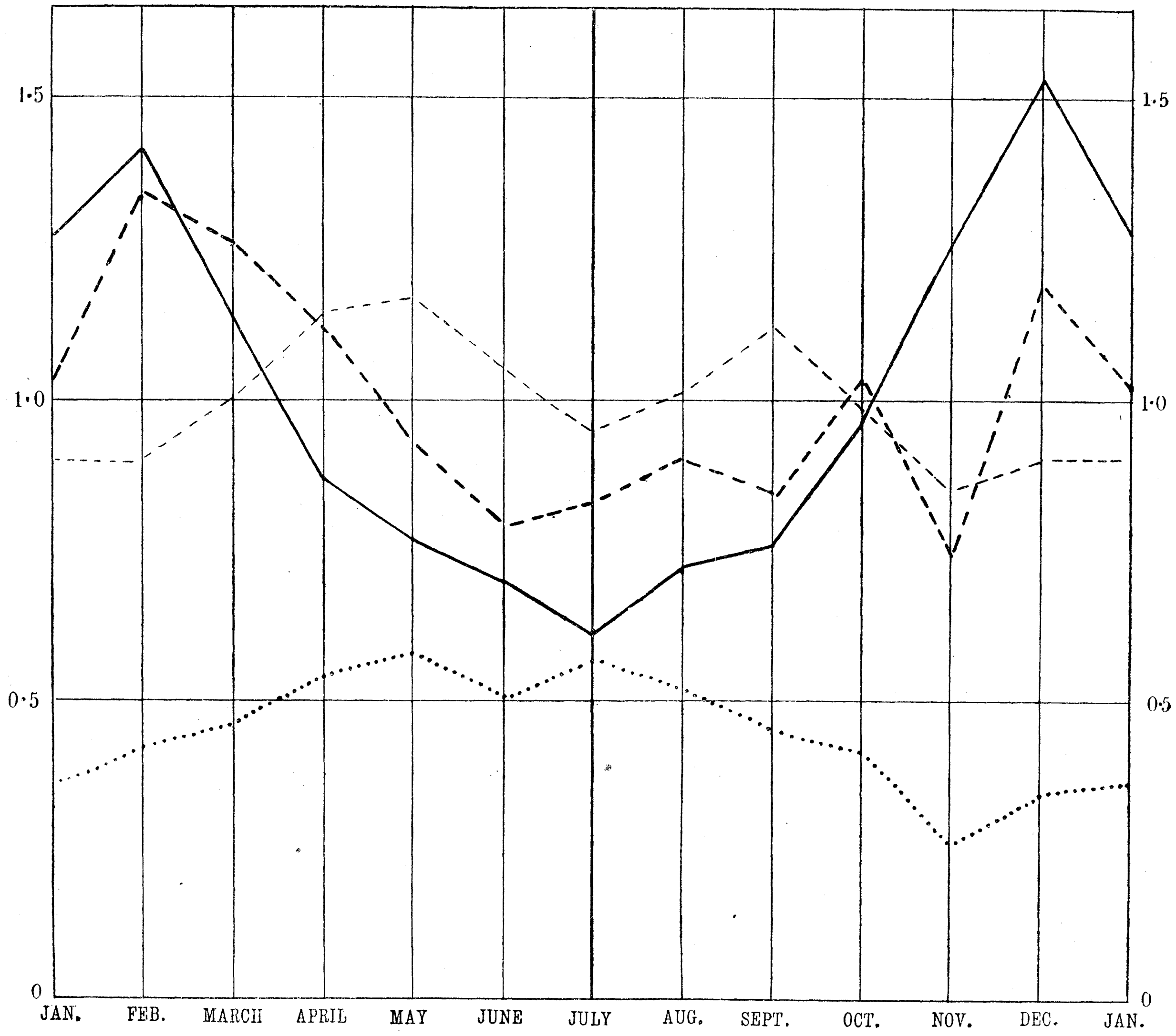


Fig. 1.

——— Mean monthly values of potential gradient.

········· (Daily range) ÷ (mean monthly value).

— — — Sum 24 hourly differences potential gradient.

- - - - - Sum 24 hourly differences barometric pressure.

Non-cyclic Effect.

§ 5. In meteorological elements such as temperature, where there is a conspicuous annual variation, there is, at certain seasons of the year, a steady tendency to an increase, and at other seasons to a decrease, during the 24 hours.

In such a case the value assigned to midnight in the mean data for a particular month varies slightly according as one makes midnight the first or the last hour of the day.

When, instead of all the days in the month, one takes a limited number of a particular kind, a non-cyclic, or a-periodic, element may present itself in the diurnal inequality, though there is no such element present to an appreciable extent in the average day of the month. This phenomenon, for instance, as I have pointed out, is conspicuous in the horizontal component of the earth's magnetic field on magnetically "quiet" days.

There are two courses open in such a case, viz., to give the mean hourly values taken direct from the observations, with data for *both* midnights, or else to eliminate the non-cyclic element from the diurnal variation while stating its amount.

The latter course has been adopted here. The size of the *algebraic* mean non-cyclic element for the selected days in individual months is recorded in Table II., in volts per metre.

Table II. shows on the whole a rise of P throughout the average selected day, but the mean value of the non-cyclic element is very small, and its sign even varies from year to year. Coming to individual months, we see that in May the non-cyclic effect was negative in six out of the seven years; but in three years, 1900, 1901, and 1903, there were more individual days in which it was plus than minus. The only months in which there seems a decided tendency for P to rise during the 24 hours of a selected day are December and January. In the former month 42 days out of 68, and in the latter month 38 days out of 65, showed a rise. In December there was an excess of days showing a plus effect in six years out of the seven.

TABLE II.—Non-cyclic Effect (Volts per Metre).

	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.
1898	+17	−17	+ 8	− 6	−25	+ 4	+23	+ 9	+ 4	+39	−22	+ 1	+ 3
1899	+11	− 4	−51	+ 8	−12	+14	+12	−14	− 8	+18	+ 8	+30	+ 1
1900	−39	+ 8	+40	+ 8	− 2	+12	− 2	+ 3	− 4	+ 9	+11	+29	+ 6
1901	+ 9	+17	−33	+21	−22	− 5	−13	− 2	− 8	−11	+20	+50	+ 2
1902	+26	+ 3	+54	+15	− 4	+22	− 1	−16	−11	+26	+11	+ 4	+11
1903	+64	−23	− 2	−11	+ 7	+ 6	− 6	−21	−12	−32	−10	+12	− 3
1904	+25	−17	0	− 9	−18	− 6	−18	− 9	−14	−18	−24	+34	− 6
Mean	+16	− 5	+ 2	+ 4	−11	+ 7	− 1	− 7	− 8	+ 4	− 1	+23	+ 2

Diurnal Inequality.

§ 6. Table III. shows the mean diurnal inequality—after elimination of the non-cyclic effect—for the individual months and the year, and also for three seasons, viz., Winter (November to February), Equinox (March, April, September and October) and Summer (May to August). Each hourly value depends on approximately 70 readings, and as these were taken to at least the nearest 10, sometimes the nearest 5 volts, the table gives the results to the nearest 0·1 volt. Distinct maxima and minima appear in heavy type.

The *ranges* in the penultimate column represent the excess of the largest mean hourly value over the smallest. The last column gives the sum of the 24 hourly differences from the mean for the day to the nearest volt.

The diurnal inequalities for the individual months and the year are illustrated by the curves in fig. 2 which are all drawn to a common scale. They pass through all the observational points and thus enable the reader to judge for himself of the sufficiency of the data. The curve for the year and those for a majority of the months, notably April, June, August and October, possess a smoothness which leaves little to be desired. A few isolated observational points catch the eye, *e.g.*, 1 p.m. in January and in September. I have satisfied myself that the cause is not arithmetical error, but if the number of year's data were largely increased the outstanding values for individual hours would very probably disappear. In the four months November to February there is a slight flattening or depression of the curve shortly after the evening maximum which looks hardly natural. Whether this would disappear if a larger number of year's data were employed is, however, more doubtful. It seems to arise from a slight variability in the hour of maximum in the same month of different years.

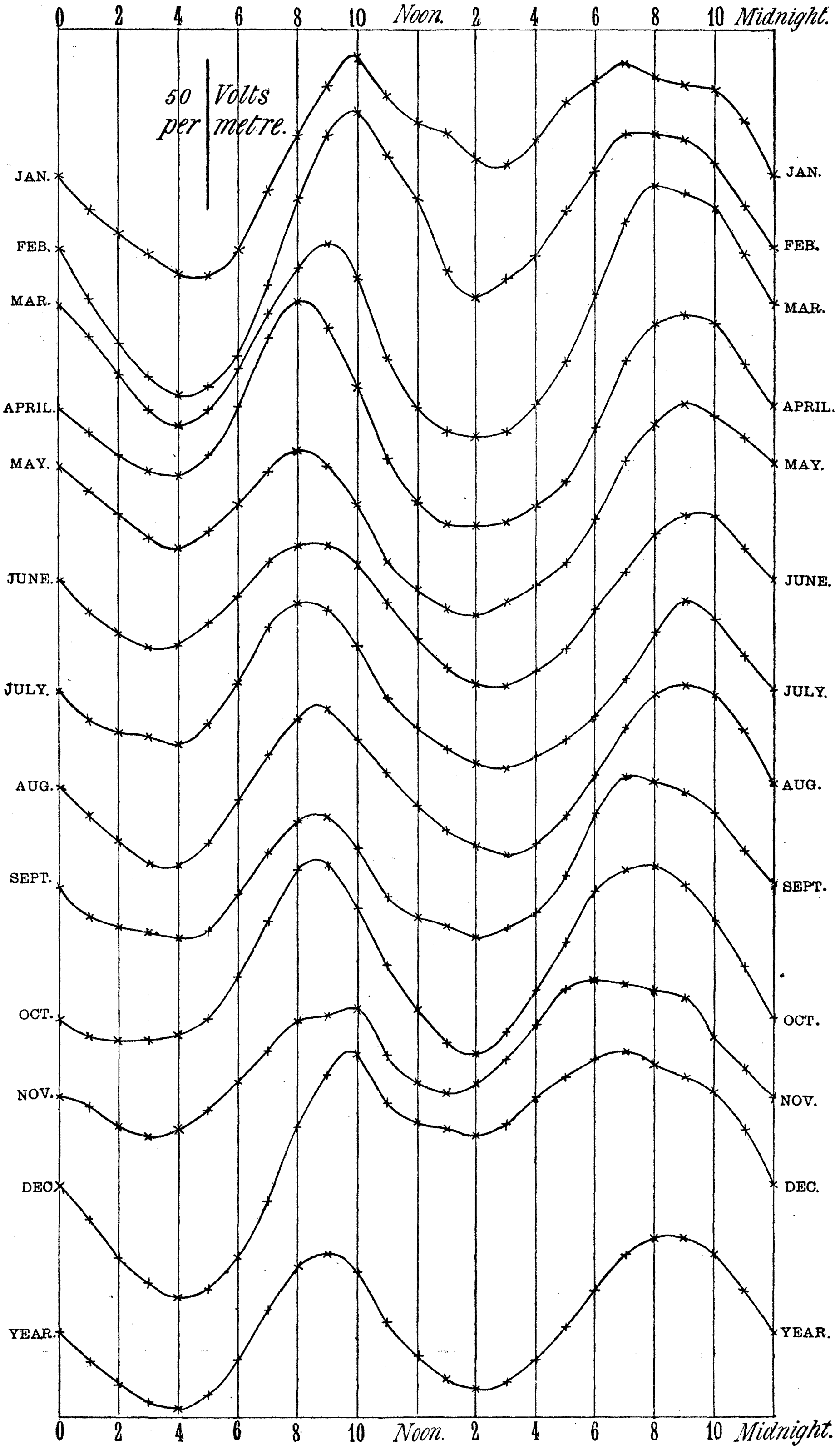
The double daily period, though most prominent in summer, is shown clearly in every instance. December is the month showing the nearest approach to a single maximum and minimum, November and January coming next; but even in these three months there is not the slightest doubt as to the existence of an afternoon minimum, while the forenoon maximum exceeds that of the late afternoon in January and February, and is practically equal to it in December. The early morning minimum is the principal one only in the four midwinter months and in August and September. The equinoctial months show the afternoon minimum just about as prominently as the midsummer months.

The morning minimum occurs near 4 a.m., its time varying very little throughout the year. The afternoon minimum is only a little more variable, its time of occurrence falling usually near 2 p.m. The hours of maxima are rather more variable, the day interval between the two being less in the winter than in the summer months.

When, as in the present case, there is a well-marked double maximum and minimum, the amplitude of the range is probably not so satisfactory a measure of the activity of

TABLE III.—Diurnal Inequalities (Volts per Metre).

Hour . .	Forenoon.												Afternoon.												Range.	Sum of 24 differences.
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.		
January .	−20·4	−27·9	−34·7	−41·6	**−42·3**	−33·9	−13·7	+ 4·7	+21·0	**+30·6**	+17·7	+ 8·6	+ 5·3	− 3·7	**− 5·1**	+ 2·6	+15·6	+22·6	**+28·7**	+23·9	+21·3	+20·0	+ 9·3	− 8·9	72·9	464
February .	−19·5	−34·9	−45·7	**−51·7**	−48·9	−33·5	−15·1	+13·2	+34·6	**+42·3**	+27·8	+13·5	−10·8	**−18·8**	−13·1	− 5·5	+ 9·5	+22·9	**+35·3**	+35·1	+33·3	+25·9	+11·1	− 2·9	94·0	610
March. . .	− 2·0	−14·9	−26·8	**−31·5**	−26·5	−12·9	+ 5·2	+20·5	**+28·4**	+17·2	− 9·3	−25·3	−33·8	**−35·2**	−33·8	−24·6	−10·6	+12·0	+35·8	**+48·0**	+45·1	+41·0	+25·2	+ 8·5	83·2	574
April . . .	− 3·8	−11·5	−16·9	**−18·1**	−11·5	+ 4·8	+27·2	**+39·2**	+30·8	+12·1	−12·8	−26·6	−34·8	**−34·9**	−34·1	−27·8	−20·4	− 2·1	+19·8	+31·8	**+34·6**	+32·4	+18·8	+ 4·4	74·1	511
May. . . .	+ 6·4	− 0·9	− 8·8	**−11·9**	− 6·6	+ 2·7	+13·0	**+20·0**	+14·4	+ 2·2	−16·9	−25·8	−32·2	**−34·9**	−30·0	−24·0	−17·0	− 2·0	+16·8	+28·8	**+35·8**	+31·5	+24·5	+15·8	70·7	423
June . . .	− 3·5	−10·9	**−15·0**	−14·5	− 6·9	+ 1·8	+13·1	**+18·8**	+18·4	+12·8	− 0·2	−12·2	−21·9	−27·0	**−28·0**	−22·3	−15·5	− 2·2	+10·3	+22·7	**+28·7**	+28·1	+17·8	+ 7·3	56·7	360
July. . . .	− 9·2	−13·2	−14·5	**−17·3**	−10·2	+ 3·3	+21·4	**+29·3**	+27·4	+15·7	− 1·9	−11·6	−18·5	−23·6	**−25·0**	−20·9	−15·6	− 7·5	+ 4·3	+19·7	**+30·3**	+24·3	+12·4	+ 0·5	55·3	378
August . .	−10·1	−18·8	−26·5	**−27·1**	−19·6	− 5·2	+ 9·6	+21·1	**+24·8**	+14·4	+ 3·5	− 7·4	−15·6	−20·4	**−23·5**	−19·5	−10·4	+ 3·8	+18·4	+29·4	**+32·5**	+29·1	+17·8	− 0·4	59·6	409
September	−14·2	−17·4	−19·1	**−21·2**	−18·8	− 6·4	+ 7·0	+17·5	**+19·2**	+ 8·6	− 7·4	−14·2	−17·0	**−20·8**	−17·5	−12·2	− 0·7	+20·2	**+32·8**	+30·6	+27·2	+20·3	+ 7·9	− 3·1	54·0	381
October . .	−23·9	**−25·3**	−24·6	−23·4	−18·0	− 4·1	+14·4	+31·6	**+33·0**	+19·1	− 0·3	−14·3	−26·0	**−29·6**	−22·4	− 8·3	+ 7·7	+25·1	+31·7	**+32·7**	+26·9	+14·9	− 0·3	−17·6	62·6	475
November	−16·7	−23·8	**−26·9**	−24·5	−18·4	− 8·7	+ 1·3	+11·1	+13·2	**+15·8**	− 0·5	− 8·9	**−12·8**	− 9·5	− 1·5	+ 9·3	+22·6	**+24·8**	+23·6	+21·6	+19·5	+ 5·6	− 3·5	−13·7	51·7	338
December	−24·0	−37·4	−45·4	**−50·4**	−47·6	−36·1	−18·3	+ 6·3	+23·3	**+30·3**	+14·2	+ 7·6	+ 6·0	**+ 3·4**	+ 7·2	+16·2	+22·7	+23·7	**+31·7**	+27·0	+23·0	+17·9	+ 5·7	−13·0	82·1	543
Year . . .	−11·8	−19·8	−25·4	**−27·8**	−23·0	−11·1	+ 5·4	+19·4	**+24·0**	+18·4	+ 1·1	− 9·7	−17·7	**−21·3**	−18·9	−11·4	− 1·0	+12·2	+24·1	+29·3	**+29·8**	+24·2	+12·2	− 1·9	57·6	401
Winter . .	−20·1	−31·0	−38·2	**−42·0**	−39·3	−29·3	−11·4	+ 8·8	+23·0	**+29·8**	+14·8	+ 5·2	− 3·1	**− 7·1**	− 3·1	+ 5·7	+17·6	+24·8	**+29·8**	+26·9	+24·3	+17·4	+ 5·7	− 9·6	71·8	468
Equinox .	−11·0	−17·3	−21·9	**−23·5**	−18·7	− 4·7	+13·4	+27·2	**+27·9**	+14·2	− 7·5	−20·1	−27·9	**−30·1**	−26·9	−18·2	− 6·0	+13·8	+30·0	**+35·8**	+33·5	+27·1	+12·9	− 2·0	65·9	472
Summer .	− 4·1	−11·0	−16·2	**−17·7**	−10·8	+ 0·7	+14·3	**+22·3**	+21·2	+11·3	− 3·9	−14·3	−22·0	−26·5	**−26·6**	−21·7	−14·6	− 2·0	+12·5	+25·1	**+31·8**	+28·3	+18·1	+ 5·8	58·4	383


0
2
4
6
8
10
Noon.
2
4
6
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10
Midnight.
50 per
Volts metre.
JAN.
FEB.
MAR.
APRIL.
MAY.
JUNE.
JULY.
AUG.
SEPT.
OCT.
NOV.
DEC.
YEAR.

Fig. 2.

the forces to which the diurnal inequality is due as is the size of the 24 hourly differences from the mean. Both these quantities, as recorded in Table III., agree in representing a maximum of activity in February and a minimum in November, though the latter month differs but little from June, July, August and September. The annual variation of the sum of the 24 differences is represented by the heavy broken line in fig. 1, unity representing the mean of the 12 monthly values.

§ 7. In view of theories as to the cause of the diurnal variation, interest attaches to the comparative size of the potential changes during the day and the night. The forenoon maximum and afternoon minimum occur at Kew when the sun is above the horizon, the afternoon maximum and the morning minimum when the sun is below the horizon. I have thus taken the difference between the first-mentioned maximum and minimum as a measure of the change of potential during the day, and the difference between the other maximum and minimum as a measure of the change of potential during the night, terming the first the "Day fall," the latter the "Night fall."

Table IV.

	Absolute values, volts per metre—		Ratios borne to corresponding mean monthly values of potential gradient by—		
	Day fall.	Night fall.	Day fall.	Night fall.	Range.
January	35·7	71·0	0·178	0·353	0·363
February	61·1	87·0	0·273	0·389	0·420
March	63·6	79·5	0·354	0·442	0·462
April	74·1	52·7	0·535	0·381	0·535
May	54·9	47·7	0·447	0·388	0·575
June	46·8	43·7	0·423	0·395	0·513
July	54·3	47·6	0·556	0·488	0·567
August	48·3	59·6	0·422	0·520	0·520
September	40·0	54·0	0·330	0·446	0·446
October	62·6	58·0	0·409	0·379	0·409
November	28·6	51·7	0·143	0·259	0·259
December	33·7	82·1	0·139	0·338	0·338
Arithmetic means for—					
Year	50·3	61·2	0·351	0·398	0·451
Winter	39·8	73·0	0·183	0·335	0·345
Equinox	60·1	61·0	0·407	0·412	0·463
Summer	51·1	49·7	0·462	0·448	0·544

Table IV. shows the day and night falls from the diurnal inequalities of the several months, and also the ratio borne by these two quantities and by the daily range to the mean monthly value of P. Considered absolutely, the day fall has a conspicuous minimum in the three months November to January, the night fall a conspicuous maximum from December to March. The regular causes, whatever they are, to which the day and night falls are due, are at Kew nearly equal in intensity in the average month both of equinox and summer.

The daily range when considered absolutely is, as we have already seen, greater in winter than summer; but relative to the mean value of P for the day, the day and night falls and the range all show a decided minimum in November, December and January. If the potential gradient is due to a negative charge on the earth, the density of that charge is on the average greater in winter than in summer, but the diminished charge of summer is, relatively considered, more influenced by the causes to which the regular diurnal inequality is due.

The figures in the last column of Table IV. are shown graphically in the dotted curve of fig. 1.

Analysis of Diurnal Inequality in Fourier Series.

§ 8. The diurnal inequalities in Table III. have been analysed in Fourier series

$$c_1 \sin (t+\alpha_1)+c_2 \sin (2t+\alpha_2)+c_3 \sin (3t+\alpha_3)+c_4 \sin (4t+\alpha_4),$$

where t represents time counted from midnight (G.M.T.), one hour being taken as equivalent to 15°. The amplitudes c_1, &c., and the phase angles α_1, &c., for the individual months, the year, and the three seasons are shown in Table V. In the case of the amplitudes, unity represents, as before, a potential gradient of one volt per metre. The variation of c_1 and c_2 throughout the year is illustrated by the heavier full and dotted line curves respectively of fig. 3. The ordinates represent the ratios borne by the monthly values to their arithmetic mean.

The annual variation of c_1 is of a most unusual character. The mid-winter maximum and mid-summer minimum are extraordinarily pronounced. The phase angle α_1 also shows a remarkable annual variation, the times of maximum in "summer" and "winter" differing by nearly 8 hours. In July and December the 24-hour waves are nearly in opposite phases.

The 12-hour term presents very different features. Its amplitude, c_2, is slightly less for winter than for summer, and there are maxima at the equinoxes, but the annual variation is comparatively small. The variation shown by the phase angle α_2 is also comparatively small, the difference between the times of maximum in winter and equinox being little over half an hour.

The 8-hour and 6-hour terms are so small that considerable uncertainty must attach to the results for individual months. Still, there is a regularity about the figures, especially those for the 8-hour term, which seems to justify our acceptance of at least the general features. The annual variation of c_3 is somewhat similar to

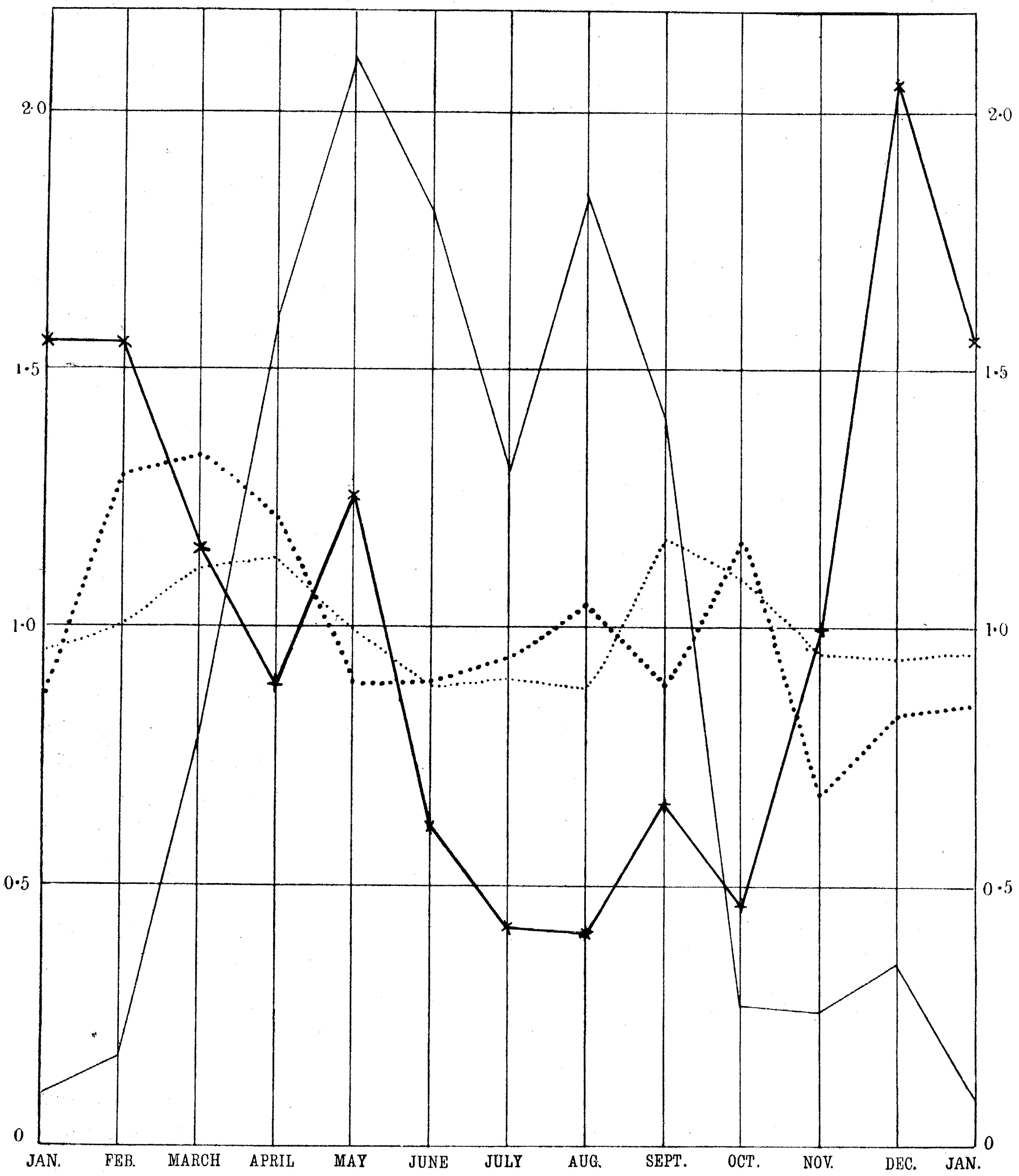

Fig. 3.

1 = mean of the twelve monthly values.

━━━━ Annual variation of c_1 potential gradient.
──── " " c_1 barometric pressure.
●●●●●●●●● " " c_2 potential gradient.
………… " " c_2 barometric pressure.

that of c_1, the values for the winter months being conspicuously greater than those for the summer months. There is also a fairly systematic annual variation in the phase angle α_3; but this angle is largest at the season when α_1 is least, and conversely. The 6-hour term shows an annual variation similar on the whole to that exhibited by the 12-hour term. In equinox and summer the 6-hour wave seems fully larger than the 8-hour wave.

TABLE V.—Diurnal Inequality. Amplitudes and Phase Angles.

	c_1.	α_1.	c_2.	α_2.	c_3.	α_3.	c_4.	α_4.
		° ′		° ′		° ′		° ′
January . .	22·33	206 5	21·50	169 42	6·82	10 36	1·87	234 39
February . .	22·32	203 37	32·72	170 55	10·31	9 6	2·64	224 36
March . . .	16·61	123 8	33·54	185 31	4·68	35 53	5·11	307 8
April . . .	12·79	71 39	30·57	192 33	4·78	96 17	6·28	313 55
May . . .	18·21	85 57	22·40	188 25	3·14	100 22	3·69	313 31
June . . .	8·98	78 52	22·57	182 45	1·32	124 59	1·40	276 49
July . . .	6·12	48 13	23·77	185 8	3·40	124 29	4·44	292 39
August . .	5·96	142 14	26·30	181 30	1·50	106 39	2·70	312 45
September .	9·50	153 51	22·63	198 45	2·93	16 15	3·51	329 46
October . .	6·58	191 52	29·60	205 46	6·35	18 21	3·25	288 23
November .	14·14	201 40	16·98	211 53	5·43	38 17	1·56	237 34
December .	29·69	208 24	21·09	175 12	7·11	35 44	2·89	249 3
Year . . .	8·40	165 4	24·75	186 50	3·82	39 29	2·80	292 38
Winter . .	22·10	205 32	22·23	178 50	7·21	21 8	2·21	236 50
Equinox . .	8·78	124 43	28·83	195 5	3·98	40 26	4·42	310 32
Summer . .	8·82	86 7	23·74	184 20	2·29	113 36	2·98	301 38

Annual Variation. Fourier Series.

§ 9. The annual variation may be represented by a series of the type

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

where M is the arithmetic mean of the 12 monthly values, t is the time counted from the beginning of the year, 1 month being taken as equivalent to 30°, while P_1, $P_2, \ldots$, θ_1, $\theta_2, \ldots$ are constants.

Table VI. gives for a variety of elements the values of the amplitudes and phase angles of the yearly and half-yearly terms, and the ratios borne by these amplitudes to the mean value of the element and to one another. As before, in the amplitudes unity represents 1 volt per metre. The angles are given only to the nearest degree.

The representation of the annual variation by two terms of the series is, as a matter of fact, not very close in any one of the elements. This may mean that other shorter period terms are by no means negligible, or merely that a larger number of year's data are necessary for high precision.

The annual term is, in all cases, the more important of the two. The relative importance of the semi-annual term is much greater for the day fall than for the other elements; it is least for the mean value for the day.

TABLE VI.—Annual Variation. Amplitudes and Phase Angles.

	P_1.	θ_1.	P_2.	θ_2.	P_1/M.	P_2/M.	P_2/P_1.
		°		°			
Mean value for the day	63·8	81	7·49	84	0·40	0·05	0·12
Sum 24 hourly differences . . .	92·0	44	26·7	315	0·20	0·06	0·29
Range	15·7	37	2·80	358	0·23	0·04	0·18
Day fall	11·3	342	8·95	267	0·22	0·18	0·79
Night fall	15·9	70	6·49	15	0·26	0·11	0·41
c_1 (diurnal inequality)	8·60	59	2·61	91	0·60	0·18	0·30
c_2 („ „)	8·44	53	3·26	294	0·33	0·13	0·39

Comparison with Previous Results for Kew.

§ 10. In the 'Phil. Trans.' for 1868, pp. 347–361, atmospheric electricity data from Kew for a 2-year period (June, 1862, to May, 1864) were discussed by Professor J. D. EVERETT. The data were from all days of the year. EVERETT calculated Fourier coefficients corresponding to our c_1, c_2, α_1, α_2 for the mean diurnal inequality of each individual month, and for each of the two years, and then for the 12 months and the year from the two year's data combined. His amplitudes were expressed in terms of an arbitrary unit. The results for corresponding months of the two years vary somewhat largely, and there is considerable difference between the mean results for the two years. Thus even the values from the two year's data combined, at least those for individual months of the year, are clearly exposed to rather large uncertainties.

It should be noticed that EVERETT's hour angles (*loc. cit.*, p. 358) are counted from noon. Thus, in comparing his results with mine, 180° must be added to his E_1 (my α_1); his E_2 and my α_2 are immediately comparable. The following remarks apply to his values for the two years combined:—

My value for α_1 is above EVERETT's from September to February, the mean excess being 18° 1′, and below his from March to August, the mean deficiency being 27° 10′. In the mean diurnal inequality for the year, however, EVERETT's value for α_1 exceeds mine by only 1° 6′, corresponding to 4·4 minutes of time. As regards α_2, my value is above EVERETT's in six months, viz., May and July to November, the mean excess being 11° 7′, and below his in the other six months, the mean deficiency being 12° 40′. In the mean diurnal inequality for the year his value of[*] α_2 exceeds mine by 2° 10′, answering to 4·3 minutes of time. The differences in the phase angles in the two investigations, though comparatively small, especially in the case of the 12-hour term, are too systematic to be ascribed to chance, but several explanations are possible.

EVERETT'S table on his p. 358 agrees with my Table V. in making c_1 (his A_1) greatest in December and January, and least in July and August; and his difference between the maximum and minimum values is even greater than mine. Also his largest values for c_2 (his A_2) occur, like mine, in February and March, his least values occurring in May, June, and November. There is thus a fairly close *general* resemblance between our results for the amplitudes. There is, however, a very important difference as regards the relative importance of c_1 and c_2. We have, in short,

	EVERETT (1862–4).	CHREE (1898–1904).
$\dfrac{\text{arithmetic mean of 12 monthly values of } c_2}{\text{arithmetic mean of 12 monthly values of } c_1} =$	0·85	1·75
$\dfrac{c_2 \text{ in mean diurnal inequality for the year}}{c_1 \text{ in mean diurnal inequality for the year}} =$	0·97	2·95

Some further aspects of this difference are considered later in § 13.

EVERETT also expressed the annual variation in the mean daily potential gradient as a Fourier series with annual and semi-annual terms. His times were measured from the middle of January, so that his phase angles (E_1 and E_2 in his notation) have to be diminished accordingly for comparison with mine. His results from the two years combined are in the notation of Table VI., counting time from the beginning of the year,

θ_1.	θ_2.	P_1/M.	P_2/M.	P_2/P_1.
90°	249°	0·36	0·02	0·05

EVERETT'S results for the annual term are thus fairly similar to mine, but he makes the amplitude of the semi-annual term even less than I do, and his value for its phase angle is quite different from mine. This is not, however, very surprising, as the phase angles for his two years taken separately differ by 100°, and the amplitude for the second year is only $\frac{3}{8}$ of that for the first. Also inspection of EVERETT'S annual variation curve in his plate XXI. shows that its representation by only annual and semi-annual terms must be very rough.

Comparison with CHAUVEAU'S *Results for other Stations.*

§ 11. The intercomparison of results from different stations is difficult owing to uncertainty as to the real significance of the units employed. The length and the height above ground of the discharge tubes of water droppers vary greatly. Some are in low, others in lofty buildings, so that even if all were of one length and at one height they would not give comparable results.

To meet this difficulty so far as possible, in the article on "Atmospheric Electricity" in the 10th edition of the 'Encyclopædia Britannica,' I expressed each hourly value in a diurnal inequality as a percentage of the mean value for the day.

The principal maximum and minimum, for example, in EVERETT's mean diurnal inequality for the year at Kew were given as 139 and 71, and thence the range would be 68. In an important and very comprehensive paper,* Mr. A. B. CHAUVEAU has employed a method of representing the ranges which differs from the above only in taking the mean of the 24 hourly values as 1 instead of 100. He compares in particular what he calls day and night ranges (*amplitude diurne*, *amplitude nocturne*). For both ranges he takes the late evening maximum, so that

amplitude diurne = night maximum less afternoon minimum,

amplitude nocturne = night maximum less early morning minimum.

He did so because in all the cases he considered, with the single exception of Lyons, the evening maximum exceeded the forenoon maximum throughout the year.

Finding that at most places the diurnal inequality was nearly the same for May, June, July and August, CHAUVEAU obtains "summer" values for his day and night ranges from a diurnal inequality based on days selected from these four months. For corresponding winter values he usually confines himself to days selected from December and January only. In dealing, however, with the Bureau Central Météorologique in Paris—the station which he considers most fully—his winter includes as well days from late November and early February. CHAUVEAU also records the ratio borne by the mean value of P from the selected winter days to the corresponding summer value. In most cases he confines himself to fine weather days.

Table VII. summarises the chief results given by CHAUVEAU, with the addition of corresponding results for Kew from Tables I and III.

CHAUVEAU apparently regards the conditions at the Bureau Central as having somewhat deteriorated since 1893 through the growth of trees. As against this, the data there for 1893–4 depend on a somewhat limited number of days, and any single year may not be fully representative. The site at Perpignan is considered by CHAUVEAU amongst the best. As to Kew and Greenwich, I shall quote CHAUVEAU'S own words (*loc. cit.* p. C 52). "La modification progressive de la variation d'été dans les observations de M. EVERETT, de M. WHIPPLE et dans celles de Greenwich nous paraît être en rapport avec des conditions de moins en moins bonnes dans l'installation du collecteur."

The results at Greenwich and at the Collège de France show a rather striking similarity which CHAUVEAU notes, but he regards them both as abnormal in several respects.

A mean from the two sets of results for the Bureau Central presents fairly similar

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* 'Annales du Bureau Central Météorologique de France,' Année, 1900, I Mémoires, pp. C 1 to C 120.

features to the latest Kew results, though both the day and night ranges appear to be larger at the former station. The Kew summer data are from the diurnal inequality in Table III. for the four summer months combined. If the quantities had been found for each of the months independently, the arithmetic means would have slightly exceeded the values in the table, viz., amplitude diurne 0·54, amplitude nocturne 0·45. The Kew results for winter are arithmetic means from December, January and February treated independently. Omitting February, the values would be less, viz., amplitude diurne 0·14, amplitude nocturne 0·35.

As regards the different Kew data, it should be taken into account that Birt's were obtained with the old Ronalds apparatus, the point at which the potential was measured being some 16 feet above the dome and more than 80 feet above the general level of the ground. Also the observations were from the even hours only, which inevitably leads to smaller ranges than when hourly observations are taken. Birt grouped his data in several classes. That taken by Chauveau included only low positive potentials, *i.e.*, excluded all cases where the potential was negative or exceptionally high. Everett's data included all readings positive or negative, Whipple's all but days of negative potential.

Table VII.—Abstract of Chauveau's Results and Comparison.

Place.	Period.	Mean length of tube. Metres.	Amplitude diurne.		Amplitude nocturne.		Ratio of mean values of potential gradient. Winter/Summer.
			Winter.	Summer.	Winter.	Summer.	
Lisbon	1884–7	0·85	0·28	0·41	0·87	0·69	2·15
Perpignan	1885–95	1·5	0·39	0·38	0·67	0·46	1·45
Florence	1885	1·75	0·48	0·46	0·78	0·61	1·38
Moncalieri	—	—	0·36	0·47	0·47	0·40	1·69
Lyons	1885–90	—	0·16	—	0·36	—	2·14
Parc St. Maur	1889–90	—	0·34	0·65	0·58	0·52	1·29
Collège de France	1885–7	—	0·23	0·86	0·42	0·30	2·00
Eiffel Tower	1893	1·7	—	—	—	0·48	—
,, ,,	1896–8	0·55	—	—	—	0·37	—
Bureau Central Météorologique	1893–4	1·6	0·16	0·76	0·40	0·57	2·01
Bureau Central Météorologique	1894–9	1·4	0·21	0·57	0·56	0·50	1·53
Kew	1845–8	—	0·09	0·30	0·49	0·68	1·27
,,	1862–4	1·0	0·54	0·59	0·92	0·62	1·75
,,	1880	1·3	0·35	0·75	0·64	0·54	2·58
,,	1898–1904	1·3	0·18	0·52	0·36	0·44	2·00
Greenwich	1890–3	1·8	0·17	0·80	0·45	0·28	2·54

§ 12. Chauveau also analyses the several sets of data for the diurnal inequalities at the Bureau Central and the Eiffel Tower in Fourier series. He takes five terms, one more than I have taken for Kew, and says that the additional, or 4·8-hour term, distinctly improves the agreement with observation. I have expressed CHAUVEAU'S values for the amplitudes in terms of the corresponding mean values of P taken as unity, and have calculated corresponding results for Kew from EVERETT'S data as well as my own. In the latter case the values assigned to "summer" and "winter" are derived from the seasonal data at the foot of Table V., making use of the mean values of P given in Table I. For September and October I have taken the arithmetic means of the c's and α's for the two months. It seemed hardly worth while analysing a mean diurnal inequality from the two months combined, though that would have been more strictly correct. In the case of EVERETT'S data the values refer in each case to a mean diurnal inequality for the period stated. Table VIII. gives the values thus found for the amplitudes, and Table IX. applies similarly to the phase angles. In this table the Kew angles have been modified so as to answer to local solar time, so as to be strictly parallel to CHAUVEAU'S angles.

TABLE VIII.—Diurnal Inequality. Comparison of Amplitudes.

	Winter.				September and October.				Summer.			
	c_1.	c_2.	c_3.	c_4.	c_1.	c_2.	c_3.	c_4.	c_1.	c_2.	c_3.	c_4.
Kew, 1862–4	0·283	0·160	—	—	0·284	0·207	—	—	0·127	0·229	—	—
Kew, 1898–1904	0·102	0·103	0·033	0·010	0·060	0·190	0·033	0·025	0·079	0·213	0·021	0·027
Bureau Central, 1893	—	—	—	—	—	—	—	—	0·223	0·203	0·072	0·084
Bureau Central, 1894–8	0·220	0·104	0·035	0·031	0·144	0·211	0·060	0·055	0·130	0·200	0·040	0·068
Eiffel Tower, 1893	—	—	—	—	—	—	—	—	0·188	0·044	0·003	0·028
Eiffel Tower, 1896–8	—	—	—	—	0·157	0·036	0·007	0·015	0·133	0·085	0·023	0·021

TABLE IX.—Diurnal Inequality. Comparison of Phase Angles.

	Winter.				September and October.				Summer.			
	α_1.	α_2.	α_3.	α_4.	α_1.	α_2.	α_3.	α_4.	α_1.	α_2.	α_3.	α_4.
	°	°	°	°	°	°	°	°	°	°	°	°
Kew, 1862–4	184	193	—	—	170	189	—	—	111	179	—	—
,, 1898–1904	206	180	23	239	171	198	11	301	87	186	116	304
Bureau Central, 1893 . .	—	—	—	—	—	—	—	—	96	200	190	8
,, 1894–8 .	223	206	45	0	182	213	358	11	95	197	157	352
Eiffel Tower, 1893 . . .	—	—	—	—	—	—	—	—	196	207	114	25
,, 1896–8 . .	—	—	—	—	212	185	122	331	216	171	79	330

§ 13. It will be convenient to discuss the two tables together, and it must be remembered that amplitude now means the ratio borne by the actual amplitude of the periodic term to the mean value of the element during the day.

Comparing corresponding results from the Bureau Central and the Eiffel Tower, we infer that the amplitude of the 24-hour term varies but little, if at all, with moderate changes of height above the ground. Its value, however, at both places was much lower in the later series of years than in 1893. CHAUVEAU seems disposed to attribute this diminution to the fact that the efflux tube had been shortened, the reduction in the amplitude representing the increased disturbing influence of the building and other surroundings. A similar phenomenon, however, is seen at Kew in comparing the older and more recent data, and in an enhanced degree especially in winter and autumn, and at Kew the efflux tube was a foot *longer* in the later period than in the earlier. The phase angles in the 24-hour term at Kew and the Bureau Central both vary largely with the season, but are fairly similar at corresponding seasons, and the values from the earlier and later series of years are in fairly close agreement, notwithstanding the great differences in the amplitudes. On the other hand, the similarity in amplitude at the Bureau Central and the Eiffel Tower is accompanied by a large difference in phase, at least in summer. CHAUVEAU infers, from the similarity of the summer and autumn values of α_1 at the Eiffel Tower to the winter value at the Bureau Central, that the large seasonal change in α_1 at the latter station is a phenomenon confined to the lowest strata of the atmosphere. Experimental evidence is, however, necessary to justify the acceptance of this conclusion.

The 12-hour term shows very different phenomena. The amplitude apparently diminishes rapidly with the height, while the phase is comparatively little affected. Further, the phase angle at the Bureau Central, as at Kew, varies but little with the season, while both amplitude and phase angle vary but little with the epoch from which the data are derived. The phase angles at Kew and the Bureau Central do not differ much, but the angles at the former station appear consistently the smaller. The maxima at Kew are thus somewhat later in the day than at the Bureau Central, the difference in time from the mean of the three seasons in the latest sets of data being about half an hour.

§ 14. In consequence apparently of the rapid diminution in its amplitude with height CHAUVEAU seems disposed to regard the 12-hour term as of subsidiary importance, and due to special conditions in the very lowest strata, if not to purely local causes. A somewhat similar view has been expressed by Professor F. EXNER,* who bases his conclusions largely on observations he has made in the tropics. At some places, *e.g.*, in Ceylon, he seems to have found but little trace of the ordinary double maximum and minimum in the diurnal inequality. EXNER attributes the double maximum and minimum to a thin atmospheric layer near the ground, which

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* *Cf.* 'Terrestrial Magnetism,' vol. 7, 1902, p. 89.

exerts, he says, at some stations a large effect in the early afternoon hours through absorbing the sun's radiation of shortest wave-length. This absorbent stratum he believes especially characteristic of arid and dusty regions, while comparatively non-existent in moist climates, or where foliage is luxuriant. The conditions at Kew—a station situated in an extensive grass-covered park—are hardly such as EXNER associates with a large 12-hour wave. It is possible, of course, that the large extension of London since 1864 may have profoundly altered the electrical conditions even as far west as Kew; but if so, one would expect an enormous difference to manifest itself when the direction of the wind changes from east to west. I am not prepared to say that such a change of direction is wholly without effect—as it is difficult to distinguish between the direct effect of change of wind direction and the indirect effect of the change of weather conditions accompanying it—but if it exists it is by no means conspicuous. Also the difference between the earlier and later Kew data is not an increase in the 12-hour wave, but a diminution in the 24-hour wave. Faulty conditions or local peculiarities seem *a priori* more likely to introduce or enhance fictitious waves than to wipe out real periodic terms. The observed 24-hour wave, it must be remembered, shows a phase angle which varies largely with the season of the year, but the differences between the phase angles observed in 1862–4 and 1898–1904 are in most months comparatively small. If, then, the reduction in the amplitude apparent in the later series is due to some disturbing cause, that cause must have itself a phase which nearly keeps step with that of the real 24-hour potential wave throughout the year.

Before attaching much importance to views which after all are mainly theoretical, it should be remembered that the older Kew data refer to *all* days, the later only to *fair weather* conditions. Future investigations may show the 24-hour term to be more dependent on the meteorological conditions than the 12-hour term. Also in considering the relative importance of the two terms we should make allowance for the fact that it is the conditions close to the ground that are at present of most immediate practical importance both to human beings and to agriculture.

§ 15. Returning to the consideration of Tables VIII. and IX., it will be seen that with the exception of the values of α_4 in winter—when the amplitude at Kew was so small that considerable uncertainty must exist—the Kew and Bureau Central values of α_3 and α_4 are sufficiently close to raise a strong presumption that the 8- and 6-hour terms represent a true atmospheric electricity effect. The comparative agreement between the phase angles from the earlier and later series of observations at the Bureau Central and the Eiffel Tower favour the same conclusion.

The 8- and 6-hour waves are decidedly smaller at Kew than at the Bureau Central. The difference in this case may not improbably be partly due to greater homogeneity in the Kew data. The fact that the 8- and 6-hour terms are also much less at the Eiffel Tower than at the Bureau Central must, however, have some other explanation; it is most natural to ascribe it to the influence of height.

Irregular Diurnal Changes.

§ 16. Hitherto we have exclusively considered the regular diurnal changes, those for each month being derived by taking hourly means from about 70 days and eliminating any non-cyclic element. The amplitude of these periodic changes gives, however, a very inadequate idea of the phenomena. Even in the finest weather the regular diurnal change is accompanied by numerous irregular changes, and very often the latter so predominate that the former is but inconspicuously shown in the photographic trace. I have thus gone into the individual day's results with some minuteness. My object was chiefly to ascertain the effect of different meteorological conditions—a subject considered later—but also partly to see whether any sort of proportionality existed between the size of the regular and irregular movements throughout the year. The results of this latter investigation are summarised in Table X.

TABLE X.—Results from Individual Days.

	Mean of maximum and minimum.	Range.	Non-cyclic change. ±	Ratios to mean value for the 24 hours.			Ratio of the mean of individual daily ranges to the range in the diurnal inequality.
				Mean of maximum and minimum.	Range.	Non-cyclic change. ±	
January . . .	212	203	93	1·05	1·01	0·46	2·79
February . .	234	218	86	1·05	0·98	0·39	2·32
March . . .	197	210	85	1·10	1·17	0·47	2·52
April	153	164	62	1·11	1·19	0·45	2·22
May	135	143	53	1·10	1·17	0·44	2·03
June	120	132	45	1·09	1·19	0·41	2·33
July	109	117	40	1·12	1·20	0·41	2·12
August . . .	123	129	41	1·08	1·13	0·36	2·17
September . .	129	141	54	1·07	1·16	0·45	2·61
October . . .	163	196	80	1·06	1·28	0·52	3·13
November . .	206	186	74	1·03	0·93	0·37	3·60
December . .	247	213	96	1·02	0·88	0·40	2·59
Year	169	171	67·5	1·071	1·107	0·426	2·54
Winter . . .	225	205	87·2	1·037	0·949	0·403	2·83
Equinox . . .	161	178	70·4	1·083	1·200	0·473	2·62
Summer . . .	122	130	44·9	1·094	1·173	0·403	2·16

The first numerical column of Table X. gives the monthly and seasonal mean values of the arithmetic mean of the largest and smallest hourly values in individual days; the fourth column shows the ratio which the value thus found for the month or season bears to the corresponding mean value of P.

The second column gives the monthly and seasonal mean values of the excess of the largest over the smallest hourly value in individual days, the non-cyclic effect *not* being eliminated. The fifth column shows the ratio borne by the mean range thus found for the month or season to the corresponding mean value of P.

The third and sixth columns similarly relate to the non-cyclic effects treated *numerically*.

The unit in the first three columns is, as in Tables I. to VI., 1 volt per metre.

The last column gives the ratios borne by the ranges in the second column to the corresponding amplitudes of the regular diurnal inequality as given in Table III.

The monthly means in the first three columns of Table X. were really calculated to one significant figure beyond that recorded, and these more exact results were employed in deducing the seasonal means and the ratios.

Several interesting and novel results appear.

The mean of the largest and smallest hourly values exceeds in every case the true mean from the 24 hours; but the excess is not large, and, though slightly less in winter than in the other seasons, varies comparatively little throughout the year.

The mean of the individual daily ranges is, on the average, no less than 2½ times the amplitude of the regular diurnal inequality.

The ratio borne by the irregular to the regular range is distinctly greater in the winter and equinoctial than in the summer months, showing a fairly well marked maximum in October and November.

Taking the year as a whole, the mean of the individual daily ranges exceeds the mean value of P by about 10 per cent.—a somewhat remarkable fact; the ratio borne by the former quantity to the latter falls slightly below unity in three of the winter months, but seems nearly uniform from March to September.

The (numerical) non-cyclic effect resembles the mean of the individual daily ranges in being largest, absolutely considered, in winter, while showing the largest ratio to the mean value of P in the equinoctial season. The large size of the average non-cyclic effect, when taken independent of sign, is an important element in determining the significance to be attached to the results obtained in Table II. where it is treated algebraically.

Special Meteorological Features of the Selected Days.

§ 17. In confining ourselves to 10 selected days a month we have followed a precedent set by the annual selection of 5 magnetically "quiet" days a month by the Astronomer Royal. In the case of the magnetically quiet days, so far as is known at present, there is no systematic departure from average conditions in anything but the phenomena of Terrestrial Magnetism. In the present case, however, it is otherwise. We have eliminated all the rainy days, which constitute a considerable proportion of the days in most winter months, and not infrequently even in summer months. The meteorological conditions on the average selected day thus represent a climate which at some seasons of some years is far from being representative of Kew. It seemed important to ascertain what this difference really amounted to. Fortunately, Kew is a first order meteorological station, so that exceptionally full information is available as to the hourly and the mean daily and monthly values of the meteorological elements.

A comparison was accordingly instituted between mean values deduced for each month from the 10 selected days and the corresponding published means taken from all days of the month. This was done for the mean barometric pressure of the day, the mean temperature, the mean hourly wind velocity, and the daily record of bright sunshine. All these elements are recorded directly by self-recording instruments of high accuracy, and the pressure and temperature daily means are based on hourly readings. The means from all days of the month are regularly calculated and recorded by the Meteorological Office; the means from the selected days were specially calculated by members of the Observatory staff.

The results of the comparison appear in Table XI.

It is at once apparent that the 10 selected days represent a climate having more sunshine and a higher barometer than Kew, but which has a distinctly lower winter temperature, and in most months of the year appreciably less wind. In summer the temperature of the selected days is, if anything, slightly above the normal, but the difference is too small to rely on. Absolutely considered, the difference as regards sunshine is largest in summer; but relative to the average amount actually experienced the difference is really greater in winter.

TABLE XI.—Mean Excess of Element on the 10 Selected Days as compared to All Days of the Month.

	Barometric pressure (inches).	Temperature, Fahrenheit.	Wind run, miles per hour.	Sunshine, hours per day.
		°		
January	+0·132	−2·98	−1·98	+1·02
February.	−0·001	−1·70	−2·28	+0·33
March	+0·083	−0·98	−1·93	+0·38
April	+0·090	−0·79	−1·30	+1·75
May	+0·096	−0·14	−1·09	+1·79
June	+0·068	+0·17	−0·09	+1·40
July	+0·010	+0·50	+0·12	+0·96
August	+0·055	−0·01	−0·48	+1·36
September	+0·017	+0·40	−0·78	+1·13
October	+0·042	−1·12	+0·79	+0·95
November	+0·101	−2·35	−0·91	+0·12
December	+0·101	−3·08	−3·21	+0·02
Year	+0·066	−1·01	−1·10	+0·93
Winter	+0·083	−2·53	−2·10	+0·37
Equinox	+0·058	−0·62	−0·80	+1·05
Summer	+0·057	+0·13	−0·39	+1·38

Connection of Atmospheric Potential with Meteorological Elements.

§ 18. There are so many possible ways in which a connection may subsist between electric potential and a meteorological element that it is difficult to know how to attack the problem. Suppose, for instance, that a particular June had a very high mean temperature, then there might be an effect either on the mean value of P, or on the amplitude of the daily changes, or on both. Possibly, however, there might be no appreciable effect on either quantity, and yet an appreciable difference might exist between the electric phenomena of the hotter and colder days of the average June. The former phenomenon would usually be interpreted to mean that no direct connection exists between potential gradient and temperature; the latter would naturally be interpreted in the opposite sense; and yet neither interpretation would be justifiable without further investigation. A very warm June would differ from the average June in other respects besides temperature, and a true direct temperature effect might be practically annulled by some other effect. Again, during an ordinary June, a hot and a cold day usually present notable differences in other meteorological elements besides temperature.

The first method I have applied is to divide the 7 Januarys, 7 Februarys, and so on, into two groups, one of three the other of four, according to the size of the mean potential gradient, and to find the difference between the meteorological elements for these two groups, taking first the selected days only, and then all the days of the month. The sub-division of each seven months was done from consideration of the mean potential only, the choice being decided by whether the biggest gap in the values of P occurred between the third and fourth, or between the fourth and fifth on the list, when the months were arranged in the order of the size of P. It is necessary to deal with the months of the year separately. The combination of days from all seasons of the year inevitably leads to error. The cold days, for instance, then come mainly from winter, and the hot days from summer, and the effects of the regular annual variation get mixed up with any true temperature effect.

Table XII. gives the results of the comparison; *s* stands for the mean from the selected days only, *a* for that from all days of the month. The excess is shown for P as well as for the meteorological elements, as the size of the potential difference should be taken into account in considering the part that chance may play in the results.

Table XII.—Mean Excess of Values of Meteorological Elements for Group of Years of Larger as compared to Group of Smaller Potential Gradient from *s* (selected days) and *a* (all days of month).

	Potential gradient.	Barometric pressure, in inches.		Temperature, Fahrenheit.		Wind, miles per hour.		Sunshine, hours per day.	
		s.	*a.*	*s.*	*a.*	*s.*	*a.*	*s.*	*a.*
January .	67	−0·061	−0·058	−1·1	−1·1	+0·1	+1·2	−0·15	+0·10
February .	73	+0·015	+0·064	−0·9	−2·5	−1·2	−3·0	−0·32	−0·03
March . .	40	+0·023	+0·042	+1·1	+0·8	+2·1	+0·8	+1·61	+1·01
April . .	34	−0·059	+0·033	−3·3	−0·6	+4·5	+1·2	−1·58	−0·61
May . .	49	+0·076	+0·057	+0·4	+2·0	−0·3	−0·1	+2·32	+0·99
June . .	31	+0·031	−0·014	−0·4	−1·3	+1·3	+0·1	+0·59	+0·04
July . .	20	0·000	0·000	−2·0	−1·9	+1·3	+0·7	−0·27	−0·88
August. .	22	−0·021	+0·005	+2·5	+2·0	+2·7	+2·0	+0·34	+0·76
September.	37	+0·037	+0·071	+2·2	+0·4	+0·1	+0·6	+1·36	+0·70
October .	40	+0·041	+0·015	−1·8	−0·4	−2·4	−1·5	−0·31	−0·17
November.	72	−0·016	+0·062	−1·7	−3·2	−2·7	−1·5	+0·13	+0·13
December .	84	−0·146	−0·047	−1·9	−1·4	−2·0	−1·7	−0·39	−0·44
Year . .	47	−0·006	+0·019	−0·58	−0·60	+0·29	−0·10	+0·28	+0·13
Winter. .	74	−0·052	+0·005	−1·40	−2·05	−1·45	−1·25	−0·18	−0·06
Equinox .	38	+0·011	+0·040	−0·45	+0·05	+1·08	+0·28	+0·27	+0·23
Summer .	30	+0·022	+0·012	+0·12	+0·20	+1·25	+0·68	+0·74	+0·23

The difference between the mean values of P for the two groups is considerably larger in winter than in summer, but in every case it represents a very appreciable fraction of the mean from the whole 7 years. As a rule, the meteorological results have the same sign whether we take all the days of the month or the selected days only.

In the four summer months there seems an association of high potential with high barometer, high temperature, high wind velocity and much sunshine; but the association with temperature in particular is very doubtful, two months going one way and two the other. Equinox agrees on the whole with summer, but the association is less clear. In winter the results seem the exact opposite of those in summer, but the association with sunshine is small and uncertain.

The association of high potential with low temperature in winter is the most consistent. It will be remembered that the selected days in winter show a markedly lower temperature and less wind velocity than the average day of the month, and these meteorological conditions, as we now see from Table XII., appear to be associated at that season with large values of P.

§ 19. The second method adopted was to split the ten selected days in each individual month into two groups of 5, the one containing the days of highest mean P, the other those of lowest mean P. In the case of March, for instance, we thus split

70 days into two groups, to the one of which each year contributes the five days in which P was greatest, while to the other it contributes the five days in which P was least. Table XIII. shows the excess of the mean P in the former group and of the corresponding mean values of certain meteorological elements as compared to the means from the second group.

This second method gives notably larger differences of potential between the two groups, and so is more likely *a priori* to present decisive results than Table XII. In Table XIII. there seems in winter a very distinct association of high potential with low temperature and with low wind velocity. This is so far in accordance with Table XII.; but the association of high potential with low temperature in Table XIII. extends to every month of the year except July, whereas in Table XII. March, May, August and September are exceptions to the rule.

TABLE XIII.—Mean Excess of Values of Meteorological Elements for Groups of Days of Larger as compared to Groups of Days of Smaller Potential Gradient.

	Potential gradient.	Barometric pressure in inches.	Temperature, Fahrenheit.	Wind, miles per hour.	Sunshine, hours per day.
			°		
January	128	+0·191	−5·09	−3·33	+0·40
February	109	−0·009	−5·99	−3·22	+1·26
March	89	+0·021	−2·88	−1·40	+1·26
April	73	+0·006	−2·94	−2·62	−0·59
May	59	+0·009	−4·72	+0·04	−0·53
June	52	−0·009	−1·40	+2·07	−0·26
July	45	+0·008	+1·94	−0·26	+2·65
August	47	−0·006	−0·81	−0·63	+0·81
September	50	−0·023	−2·71	+0·45	+0·43
October	81	−0·058	−3·28	+1·11	+0·91
November	115	+0·109	−5·49	−2·13	+0·79
December	130	+0·054	−6·22	−0·64	+0·05
Year	81	+0·024	−3·30	−0·88	+0·60
Winter	120	+0·086	−5·70	−2·33	+0·62
Equinox	73	−0·014	−2·95	−0·62	+0·50
Summer	51	0·000	−1·25	+0·30	+0·67

Table XIII. shows also a greater apparent association of high potential with much sunshine than does Table XII.

As regards barometric pressure, Table XIII. shows from April to August almost no trace of any association with potential gradient, and the results for the six months, September to February, in Tables XII. and XIII. differ in sign even. The results for barometric pressure are thus exceedingly contradictory.

§ 20. The months which show a high mean value of P show also a large average daily range, but it by no means follows that the causes to which the two phenomena are due are the same. I thus split the 10 days of each month into two groups, according to the size of the potential range, and have compared the mean results from the two groups of 35 days derived in this way from the seven years. Except as regards the criterion by which the 10 days were subdivided, the procedure was exactly the same as that followed in calculating Table XIII. The results of the new subdivision are shown in Table XIV.

TABLE XIV.—Mean Excess of Values of Meteorological Elements for Groups of Days of Larger as compared to Groups of Days of Smaller Potential Range.

	Potential range.	Barometric pressure in inches.	Temperature, Fahrenheit.	Wind, miles per hour.	Sunshine, hours per day.
			°		
January	116	+0·194	−2·14	−1·39	+0·54
February	104	+0·027	−2·35	−1·35	+1·15
March	113	+0·012	−2·33	−1·74	+1·23
April	87	+0·036	−2·78	−2·74	−0·41
May	83	−0·072	−3·98	+0·33	−1·27
June	66	−0·048	0·00	+2·30	+0·05
July	71	−0·022	+2·22	+0·02	+2·12
August	62	0·000	−0·29	−1·02	−0·37
September	57	+0·001	−1·59	−0·30	−0·61
October	117	−0·013	−1·93	+1·13	+0·50
November	113	+0·094	−3·58	−1·71	−0·21
December	113	+0·150	−3·88	−0·08	+0·14
Year	92	+0·030	−1·89	−0·55	+0·24
Winter	112	+0·116	−2·99	−1·13	+0·40
Equinox	94	+0·009	−2·16	−0·91	+0·18
Summer	70	−0·035	−0·51	+0·41	+0·13

Comparing Tables XIII. and XIV., we find that the signs of the meteorological differences agree in the large majority of instances. The meteorological conditions which are associated with high potential thus appear associated with a large diurnal range. The phenomenon may mean nothing more than that the size of the daily range tends *ceteris paribus* to increase or diminish according as the mean value of P is greater or less. The association, however, with low temperature, low wind velocity, and long sunshine, seems decidedly less in Table XIV. than in Table XIII. There is considerably greater regularity in the results for barometric pressure in Table XIV. than Table XIII., but the relationship with P seems decidedly opposite in summer to what it is in winter. The natural inference is that there is little if any *direct* connection between the absolute height of the barometer and the size of either the daily mean or the irregular daily range of P. On the other hand, in winter it seems clear that the weather conditions which accompany a high barometer favour the existence of high values and big diurnal changes in P.

TABLE XV.

	Excess from groups of days of highest barometric pressure.					Excess from groups of days of highest temperature.				
	Barometric pressure in inches.	Mean potential.	Potential range.	Non-cyclic effect.		Temperature, Fahrenheit.	Mean potential.	Potential range.	Non-cyclic effect.	
				Algebraic.	Numerical.				Algebraic.	Numerical.
						°				
December	+0·447	+36	+52	+ 2	+51	+8·17	−108	−46	+ 6	−29
January	+0·540	+59	+10	+ 4	+ 4	+7·76	− 80	+ 1	+39	−21
June	+0·204	+ 6	− 7	+13	− 7	+7·04	− 18	−20	− 2	−18
July	+0·205	− 2	− 7	+16	0	+7·15	+ 6	+11	+ 2	−11
August	+0·252	+13	+11	+31	+ 9	+5·44	− 10	− 9	−12	+ 5

§ 21. Instead of the mean value of P, or of the range of P, one may take for the criterion in grouping the selected days the value of some one meteorological element. This is a delicate mode of analysis, so far as the particular element is concerned; but to carry it out for each element, for each month of the year, would have involved a very serious amount of arithmetic. The method has thus been applied only to some of the elements, and only for a selection of months.

Table XV. gives the results thus found in the case of mean barometric pressure and mean daily temperature. December and January were selected as the months when according to Tables XIII. and XIV. the most decisive results might be expected. June, July and August were selected partly as representing summer, and partly in consequence of the exceptional nature of the July results in Tables XIII. and XIV. There appears in Table XV., as in the tables just mentioned, a decided association of high potential and large range with high barometer in December and January. In summer the range of barometric pressure is much less, so we should not in any case expect the effects on the potential to be so conspicuous. The results, however, are not merely smaller numerically in the three summer months, but they differ in sign amongst themselves. Table XV. thus agrees with Tables XIII. and XIV. in pointing to the conclusion that any association of mean potential or potential range with barometric pressure in summer is small and doubtful. In all five months there is in Table XV. an apparent tendency for P to increase more (or diminish less) throughout the 24 hours when pressure is high than when it is low; curiously, however, this effect seems much larger in the summer than in the winter months. The exceptionally large size of the non-cyclic effect, when taken irrespective of sign, in December when pressure is high, and the correspondingly large size of the range, are both probably due in considerable measure to fog. This is an element whose intensity at two consecutive midnights is usually widely different.

In the case of temperature, July stands out from the other months exactly as it did in Tables XIII. and XIV. The association of high temperature with low potential is again most conspicuous in the winter months.

Accompanying the diminished value of P we have a diminution in the non-cyclic effect treated numerically. The apparent absence of temperature effect on the potential range in January, and the exceptionally large tendency to an increase in P during days when temperature was high, are probably due to some common cause.

§ 22. If there were a direct causal connection between *any one* meteorological element and potential gradient or range, we ought to get the same or at least closely similar results for the ratio (difference of potential)/(difference of element) when the ratio is derived from a Table such as XV., and when it is derived from a Table such as XIII. or XIV. If such an influence though not unique were dominant, the two ratios so found should be at least of the same order. Combining the results from the two months, December and January, I find for the ratios of the differences—the units being for temperature 1°, for pressure 1 inch—

	$\frac{\text{Mean potential}}{\text{Temperature}}$.	$\frac{\text{Potential range}}{\text{Temperature}}$.	$\frac{\text{Mean potential}}{\text{Barometric pressure}}$.	$\frac{\text{Potential range}}{\text{Barometric pressure}}$.
By Table XV.	– 12	– 3	+ 96	+ 63
,, Tables XIII. and XIV.. .	– 23	– 38	+ 1053	+ 666

The case of mean potential and temperature is the only one in which the ratios are of the same order.

The mean temperature of the selected days in December and January was 38°·3 F.

If instead of December and January we had taken June and August, we should have got altogether different results for the potential-temperature ratios, while taking July the sign even would have changed. Thus, if any direct relationship exists between potential and temperature, it must give a ratio between potential change and temperature change, which alters rapidly, and which changes sign at a temperature between 64°·5 (the mean temperature for the selected days in July) and 60°·3 (the mean temperature for the selected days of June and August).

It may be the purest accident, but somewhat similar ideas present themselves when we consider the mean seasonal values of potential and temperature. For these, taking the temperatures of the selected days, I find—

	Mean potential.	Mean temperature.
		°
Winter	217	39·2
Equinox.	148	48·8
Summer	111	59·3

For the ratio of (potential decrease)/(temperature increase) we have from—

	Winter and equinox.	Winter and summer.	Equinox and summer.
Ratio	7·2	5·3	3·5
Mean of temperatures . . .	44°·0	49°·2	54°·0

The values thus diminish markedly as the mean temperature alters. Further, for nearly equal increments in the mean temperatures we have nearly equal decrements in the ratio. Also, if the ratio were to diminish at the same rate as the mean temperature rose further, we should have it vanishing altogether below 64°, *i.e.*, below the mean temperature of the selected days in July.

§ 23. The only other meteorological element which I have investigated in the same way as pressure and temperature is the duration of sunshine. Several authorities, *e.g.*, ELSTER and GEITEL at one time, have regarded ultra-violet radiation from the sun as probably a most important agent in the phenomena of atmospheric electricity. If this were the case, one would expect to find a conspicuous difference in summer between days of much and of little sunshine. The grouping of the days according to sunshine in the way described above led to the following results for the excesses in the groups of days of most sunshine :—

TABLE XVI.

	Sunshine, hours per day.	Mean potential.	Potential range.	Non-cyclic effect.	
				Algebraic.	Numerical.
June	7·2	− 9	− 4	− 27	+ 2
July	6·7	+ 23	+ 28	+ 9	+ 2
August	6·0	+ 7	− 8	+ 14	− 4

If the July data alone existed, then the conclusion one would naturally draw from the above figures—just as from the corresponding figures in Tables XIII. and XIV.—is, that with long duration of sunshine there is a very appreciable rise both in the mean potential and in its daily range. If June and August however are combined, we get for practically the same excess in hours of sunshine a wholly negligible effect on the value of the mean potential; whilst the apparent effect on the range, such as it is, is opposite in sign to that observed in July.

§ 24. The effects of temperature, barometric pressure, wind and sunshine on the simultaneous values of the potential gradient at Kew were also considered in my previous paper* of 1896, which dealt however only with eye observations at one or two hours during some months of 1895 and 1896. The results obtained are generally similar, except that in 1896 I found an apparent association of low potential with long previous sunshine. Even here the contradiction may be more apparent than real, as the influence of sunshine may depend on the hour of the day. An intensification for instance of the afternoon minimum may be accompanied by a compensating increase of potential during the night. Considerations of this kind must in fact be borne in mind in other cases besides that of sunshine.

§ 25. In 1896 I paid special attention to aqueous vapour, as EXNER's theory, which associated potential gradient and aqueous vapour in a definite formula, was then rather in the ascendant. I advanced grounds—whose cogency will now, I think, be hardly questioned—for believing the theory in its general form to be untenable. The 1895–6 data were from a Kelvin portable electrometer, whose insulation was never in doubt. The present data are from an electrograph, whose insulation may depend, especially at night—sometimes it may be feared not inappreciably—on the greater or less dryness of the air. Also, for one and the same amount of aqueous vapour in the air, it seems all important so far as potential is concerned whether fog forms or not, and in the long nights of winter no satisfactory data exist as to the occurrence of fog, or its thickness when present. I have thus omitted consideration of the effects of aqueous vapour as too large a subject to be included in the present paper.

A similar remark applies to wind direction. There are here two main difficulties: first the fact that the direction is perpetually shifting, and the extent of the variation in a single day is often large; second the fact that when the wind is light—and there are few fine weather days when this does not happen sometime during the 24 hours—the record of direction is often uncertain, the strength of the wind being insufficient to turn the vane of the Robinson cup anemograph. In particular is this true of foggy days in winter, the precise days in which the potential tends to be highest.

APPENDIX.

On the Relation between the Regular Diurnal Changes of Barometric Pressure and Potential Gradient.

§ 26. The only meteorological element whose diurnal inequality presents two prominent maxima and minima is the barometric pressure. EVERETT seems to have been the first to call attention to the similarity between the regular diurnal inequalities of potential and barometric pressure, and the potential data which he considered more especially in this connection were those from Kew. Having no Kew barometric data, EVERETT employed instead some from Halle. Confining himself to the mean

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* *Loc. cit.* (for summary of results, see pp. 130, 131).

diurnal inequalities for the year, he found that "the barometric curve for Halle bears a strong resemblance to the Kew electrical curve, but is upwards of an hour later in phase." Several other writers have since called attention to general resemblances of this kind. Of late years, additional interest has attached to the possibility of the connection, owing to Elster and Geitel's discovery that air drawn from the soil is ionized, and their consequent suggestion that change of barometric pressure may influence potential gradient, by modifying the rate at which this ionized air escapes into the atmosphere.

The diurnal inequality of barometric pressure is an element considerably dependent on local conditions, and it thus appeared essential to an adequate discussion to have barometric data for Kew. Diurnal inequalities were accordingly got out by the Observatory staff for each month of the year for an 11-year period 1890 to 1900, making use of the data published by the Meteorological Office in the 'Hourly Means.'

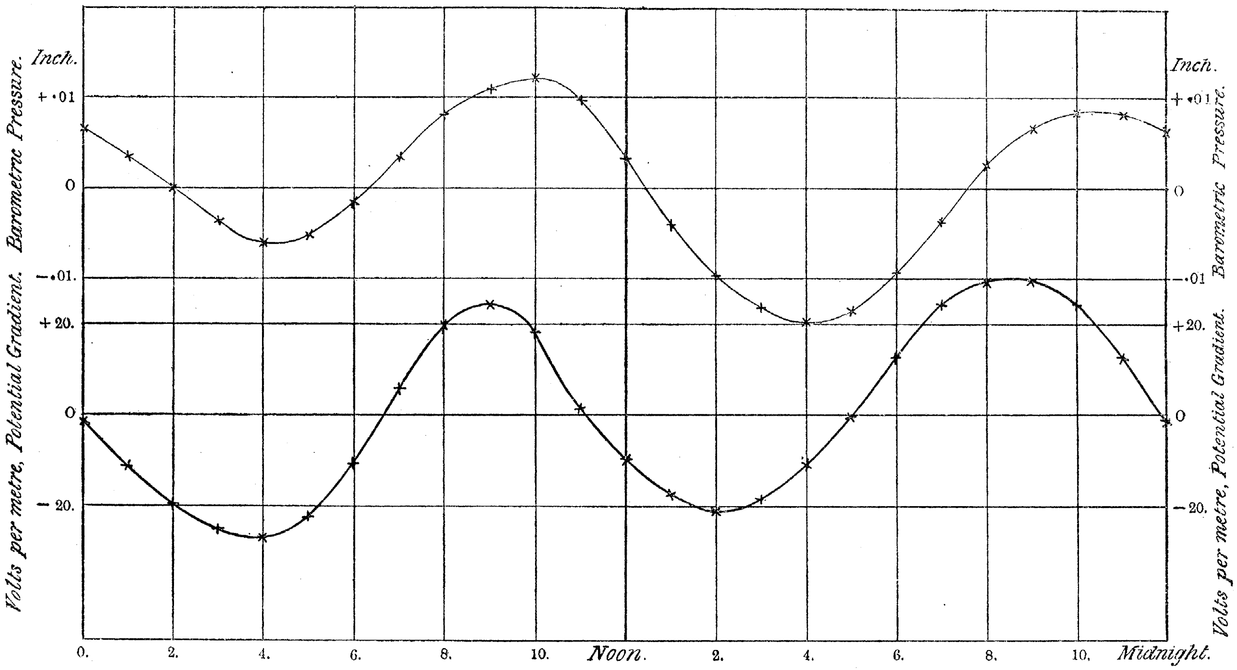

Fig. 4.

The *regular* diurnal change is a small quantity, and accordingly means were calculated to 0·0001 inch This is perfectly legitimate, as the curves are read to 0·001 inch, and each hourly value in the mean diurnal inequality for a month was based on over 300 individual readings. For our present purpose full details of the diurnal inequalities are not absolutely necessary, and I have consequently omitted them to economise space.

§ 27. That Everett had a substantial basis in claiming a resemblance between the mean diurnal inequalities for the year in barometric pressure and potential gradient is apparent on comparing the two curves of fig. 4. The heavy curve, representing potential gradient, is drawn on a more open scale than the curves of fig. 2; the light curve representing barometric pressure is drawn on a scale such as to make its apparent range nearly equal to that of the other curve.

Whilst the resemblance is very striking, as between two different elements, there are differences which seem of a fundamental character. During the forenoon the curves are nearly in the same phase. The barometer curve lags a little, but very little, behind the other. In the afternoon, however, the lag in the barometer curve becomes conspicuous, amounting to about two hours at the times of the afternoon maximum and minimum.

This change in apparent lag throughout the day does not seem to have been noticed previously, but it persists with wonderful regularity throughout the year. Treating the maxima and minima as occurring *at the exact hours* when the algebraically greatest and least hourly values occur, I find that the hour of the forenoon minimum is the same for the two elements in every month from January to October; the mean lag for the barometric pressure for the 12 months comes to $\frac{5}{12}$ of an hour, but the exceptionally early hour of the potential minimum in October is responsible for more than half this difference.

In the case of the forenoon maximum there is exact agreement in the hour in eight months, and the mean lag in barometric pressure for the 12 months is only $\frac{1}{3}$ hour.

December is the only month when the afternoon minima accord in time, and the mean lag for the barometric pressure is $1\frac{1}{2}$ hours. The corresponding quantity for the afternoon maxima is $2\frac{1}{3}$ hours.

If the relation is a case of cause and effect, the fact that it is the barometer curve that lags relative to the other would naturally lead one to regard the potential variation rather as the cause than the effect.

§ 28. When we consider the variation from month to month in the amplitudes of the diurnal inequalities other differences appear. This will be seen on comparing Table XVII. with Tables III. and IV. The first column in Table XVII. gives the range, or difference between greatest and least hourly values, in the diurnal inequality of barometric pressure; the second column the numerical sum of the 24 hourly differences from the mean for the day. The corresponding potential quantities will be found in the two last columns of Table III. The ranges and the sum of the differences show analogous phenomena, but the latter are the better for comparison, because they give a smoother annual variation when the number of years considered is limited.

Comparing, then, the second column of Table XVII. and the last column of Table III., we see that in B (barometric pressure) the values for the winter months November to February are decidedly the least, and the values for April, May, June, and September the largest. In P (potential gradient), on the other hand, the largest values occur in December, February, and March, and these are much in excess of the

TABLE XVII.—Barometric Pressure. Diurnal Inequality (Unit 0·0001 inch).

	Range.	Sum of 24 differences.	Day fall.	Night fall.
January	280	1655	280	187
February	262	1657	262	176
March	298	1840	298	166
April	320	2101	320	166
May	339	2157	328	138
June	307	1933	307	128
July	282	1747	268	157
August	328	1852	328	93
September	345	2052	345	151
October	250	1822	250	210
November	284	1561	284	147
December	295	1649	295	188
Arithmetic mean	299	1835	297	159
From mean diurnal inequality for year	268	1699	268	152

values in the summer months. The annual variations in the sum of the differences for B and P are shown together in fig. 1. To get a smooth curve in either case would probably require some 30 years' observations, but the differences between the two curves speak for themselves.

§ 29. Whilst the difference of phase in the two curves of fig. 4 is what most readily catches the eye, another difference seems not less important. In the P curve the afternoon maximum and the morning minimum are respectively the largest and smallest values in the day; but in the B curve it is the morning maximum and afternoon minimum that are the extremes.

Comparing the two last columns in Table XVII. with the day and night falls of P in Table IV. we note again an essential difference. In the case of B the day fall is the larger in every month of the year. The excess, it is true, is most conspicuous in summer (the season when the day fall in P exceeds the night fall), but taking an arithmetic mean from the four winter months, November to February, we have

$$\text{day fall} / \text{night fall} = 1{\cdot}6 \quad \text{in B},$$

$$= 0{\cdot}55 \text{ in P}.$$

§ 30. To disclose more exactly the nature of the differences, the monthly and seasonal diurnal inequalities of barometric pressure were analysed in Fourier series with 24, 12, 8, and 6-hour terms. The results appear in Table XVIII., the notation used corresponding exactly to that of Table V.

TABLE XVIII.—Barometric Pressure, Diurnal Inequality, Amplitudes, and Phase Angles (Unit for Amplitudes, 0·0001 inch).

	c_1.	α_1.	c_2.	α_2.	c_3.	α_3.	c_4.	α_4.
		° ′		° ′		° ′		° ′
January . .	5·1	199 28	99·3	153 59	49·3	345 38	22·5	210 55
February .	8·6	44 37	104·8	150 12	31·4	342 53	9·8	91 42
March . .	40·0	28 18	115·8	150 13	18·1	332 33	13·4	24 25
April . . .	82·2	30 7	117·9	151 26	9·4	170 42	11·7	− 8 46
May . . .	108·9	29 41	103·3	148 39	23·5	160 38	5·4	− 44 46
June . . .	93·0	16 13	91·7	144 6	29·5	160 44	1·1	− 62 1
July . . .	67·0	18 12	94·0	140 20	31·6	151 4	2·6	− 51 31
August . .	94·8	6 45	92·3	140 43	13·7	156 16	15·6	− 50 18
September .	72·5	5 19	122·3	151 32	2·3	352 45	10·7	− 20 42
October . .	13·9	115 23	113·6	158 28	28·6	357 18	5·9	17 16
November .	13·6	317 32	99·7	158 10	38·8	354 51	10·1	189 1
December .	18·1	83 35	98·2	151 57	46·3	351 34	22·7	216 1
Year . . .	47·1	21 12	103·9	150 15	9·1	359 0	2·9	282 27
Winter . .	4·7	44 29	100·3	153 32	41·3	348 55	12·7	199 14
Equinox . .	47·5	24 44	117·2	152 52	9·6	347 17	9·9	2 30
Summer . .	89·9	18 8	95·2	143 35	24·5	156 58	6·1	310 15

Comparing Tables XVIII. and V., we see that in both the amplitude of the 24-hour term varies much with the season; but whereas in the case of P it is conspicuously largest in winter, that is precisely the season when it is least in B. Table XVIII. shows apparently a secondary minimum for c_1 in summer, but the smallest value in summer is 13 times the value in January. The fundamental nature of the difference between the annual variations of c_1 in B and P can in fact be seen at a glance on comparing the heavier and lighter full line curves in fig. 3, which represent the monthly values expressed as fractions of the arithmetic mean.

The phase angles α_1 in Table XVIII. show erratic variations in the winter months, which are very probably fictitious. Judging by the seasonal values, α_1 is larger in winter than in summer, but the difference is small compared to the corresponding difference in Table V. In all the seasons α_1 is much less for B than for P, in other words, the hour of maximum for P is much the earlier.

§ 31. In the case of the 12-hour term the differences between the annual variations in the amplitudes for B and P are comparatively small. These variations are illustrated by the dotted curves in fig. 3.

The phase angles α_2 in Table XVIII. show fairly similar characteristics to those exhibited in Table V. In both cases the seasonal variation is comparatively small. The P phase angle is invariable the larger, *i.e.*, the maxima in the 12-hour curve are again earlier for P than for B; the difference in time is however on the average only slightly over an hour, though greater in summer than in winter.

The 8-hour term in B is unusually large. In winter c_3 is in fact much in excess of c_1.

The annual variation of c_3 is regular and strongly developed, but is of a very unusual character. The winter and summer values of α_3 in Table XVIII. are nearly opposite in phase. There is also a considerable difference between the winter and summer values of α_3 in Table V., but the difference is twice as big for B as for P and is exactly in the opposite direction.

In the case of the 6-hour term the phase angles in B and P vary somewhat similarly with the season, and the difference in the case of the mean diurnal inequalities for the year represents a difference of only some 10 minutes in time. The annual variation of c_4 is somewhat irregular in both elements, and a long series of year's data would be necessary for a satisfactory comparison.

§ 32. When comparing the Kew data with those from the Bureau Central and the Eiffel Tower, we found that the 12-hour term in the diurnal inequality of potential was the only one which presented under all conditions closely similar features as regards times of maxima and minima, and as regards amplitude near the ground. Similarly, it is well known that the 12-hour term in the diurnal inequality of barometric pressure presents at the ground level phenomena of a much more regular character than does the 24-hour term. The latter term seems largely dependent on local conditions, whereas the 12-hour term is usually pretty much the same at places of nearly the same latitude. These phenomena are shown in a striking fashion by comparing the data of Table XVIII. with corresponding data for Jersey* based on observations by DECHEVRENS.

In view of these facts, it is highly significant that the general resemblance that has been noticed between the diurnal inequalities of potential gradient and barometric pressure is now found to proceed almost entirely from the parts that have a 12-hour period. At Kew, at least, so far as the 24-hour terms are concerned, it is a case not of resemblance, but of marked dissimilarity.

During the seven years whose data have been considered, the charge of the electrograph and the taking of the absolute observations have devolved upon Mr. E. G. CONSTABLE, the Senior Assistant engaged in the meteorological work of the Observatory Department, and his Junior Assistant, Mr. E. BOXALL. The selected days were chosen by Mr. CONSTABLE in consultation with myself.

The chief burden of the preliminary work was borne by Mr. CONSTABLE, who drew the free-hand pencil curves and took all the measurements. A good deal of the arithmetical work was done by other members of the staff, especially by Messrs. BADDERLY and FRANCIS. All the reductions and calculations have been carefully checked, mostly by myself, and notwithstanding the multiplicity of details I hope no serious errors remain undetected. It remains to express my thanks to the Meteorological Office—to whom the Electrograph belongs—and to the Director, Dr. SHAW, for permission to publish the results.

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* 'Meteorologische Zeitschrift,' August, 1905, p. 384.