V. *On Periodical Laws discoverable in the mean effects of the larger Magnetic Disturbances. By Lieut.-Colonel* EDWARD SABINE, *R.A., Treas. & V.P.R.S.*

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IN the preface to the first part of the first volume of the "Observations on days of unusual Magnetic Disturbance at the British Colonial Observatories," published in 1843, and in the introductory comments prefixed to the first volume of the "Observations at the Toronto Observatory," published in 1845, I stated the reasons which induced me to believe that the magnetic disturbances of large amount and occasional occurrence, designated in the Report of the Committee of Physics of the Royal Society as the "irregular variations," and perhaps more commonly known by the name of magnetic storms or shocks, would be found, when studied in their *mean* effects on the local magnetic direction and force extending over a sufficient period of time, to have a character of *periodicity,* which if established, would leave no doubt as to the class of magnetic phenomena to which they should be considered to belong. The opinion thus expressed resulted from an examination to which I had subjected the series of two-hourly observations of the Declination in 1841, made simultaneously at Toronto and at Hobarton, and those of 1842 at Toronto; (the corresponding observations for 1842 at Hobarton not having reached England in sufficient time to be included in the examination). Short as this period was, the evidence of the existence of laws of periodical action, connecting the effects of causes operating for the most part simultaneously at distant parts of the globe with the seasons of the year and the hours of the day at particular stations, was sufficiently systematic to induce me to regard this branch of inquiry as a most hopeful one, but as requiring for its prosecution a longer continuance of observations than had been at that time provided for. At Toronto and the other observatories under the Ordnance Department, hourly observations were substituted in 1842 for the two-hourly series previously adopted. It had appeared desirable at the commencement of these establishments not to overcharge them with work; but as it became obvious that whenever a physical theory should be brought forward to explain the phenomena which were the subjects of observation, such as, for example, those of the *diurnal variation,* there would be an immediate demand for the variation observed *at least* at *every* hour, arrangements were made, in the *spirit* of the Royal Society's Instructions, to secure a better provision for the requirements of theory than had been contemplated by the *letter* of those Instructions, and with this view observations at every hour were substituted for observations at every two hours. The series at Hobarton (under the Admiralty) had

been made hourly from its commencement, the personal establishment left by Sir James Clark Ross having been calculated with that view*.

Having lately examined the hourly simultaneous observations of the Declination at Toronto and Hobarton for the years 1843, 1844 and 1845, in the course of their preparation for the press, I have had great satisfaction in finding that they confirm in a remarkable degree the anticipations which I had formed. The general evidence of periodicity, connected with the seasons of the year and the hours of the day in the mean effects at these two distant stations, of causes which yet operate for the most part simultaneously at both, thus furnished by a series of hourly observations continued for three years, is far too systematic, and rests on a basis of too long duration to make it probable that it will be otherwise than confirmed by the continuation of the series in the subsequent years; although the exact periods, and the mean numerical values of the effects produced, or their proportions to each other in the different seasons and at the different hours may, and doubtless will, receive modifications. The term "irregular" can therefore no longer be considered as correctly applied to this remarkable branch of the magnetic phenomena, which studied in their effects must now be regarded as included in the class of "periodical variations." However (apparently) irregular may be the times of their occurrence, as general phenomena affecting contemporaneously parts of the globe most distant from each other, their *effects* at those stations are found to be subject to periodical laws connected with local seasons and local time, indicating a relation directly or indirectly to the sun's place in the ecliptic, and to the earth's diurnal rotation on its axis, and producing a sensible mean effect on the magnetic direction in conformity with their own peculiar laws.

The practical bearing of this conclusion on investigations of a most interesting and valuable character which have recently been brought before the Royal Society, regarding the peculiarities of the diurnal variation in different parts of the globe and their physical explanation, will be evident, when it is considered that we have thus in each day or period of twenty-four hours *two* periodical variations, with laws, as will be seen in the sequel, extremely dissimilar. What commonly has received the name of the "diurnal variation" of the magnetic elements, is their variation at different hours of the twenty-four from a mean value obtained by summing the hourly observations and dividing the sum by their number; or, otherwise expressed, and with reference to the magnetic *direction* only, it is the figure described by either extremity of a free needle in the course of a day, under the influence of *all* causes that may

* The change from two-hourly to hourly observations was accomplished at the Ordnance observatories by adding, with permission of the Master-General of the Ordnance, one non-commissoned officer to the previous strength of the establishment. The extra pay of this artillery soldier for the particular service on which he was employed was fifteen pence a day, or £22 16*s*. 3*d*. a year. This is mentioned because it is not generally known at how small an expense, services of this nature within the competency of the military force stationed in the colonies, can be rendered, whilst the men who are so employed are available for military duty at any moment that may be required.

influence its position, and taken on an average of a sufficient number of days to make the figure a fair mean representation. This is the "diurnal variation," as shown by observation at different seasons and at different parts of the globe, which it has been Mr. FARADAY's object, in papers recently read before the Society, to explain physically. But the variation thus observed is in fact constituted by two variations superimposed upon each other, having different laws, and bearing different proportions to each other in different parts of the globe. At tropical stations the influence of what have been hitherto called the "irregular disturbances" is comparatively feeble, and their periodical effects may be therefore less deserving of attention; but it is otherwise at stations situated as are Toronto and Hobarton, where their influence is both really and proportionally greater, and already amounts to a clearly recognizable part of the whole diurnal variation; and it must be very far otherwise at stations which still more nearly approach those localities on the globe, where disturbances of this class become much greater than either at Hobarton or Toronto. As these localities are approached, the mean diurnal variation must be expected to partake more and more of the law by which the effects of those disturbances are regulated; and if that law be different, as it will be shown to be in the instances adduced in this paper, from another law also shown to exist, and by which another portion of the diurnal variation is governed, it may become necessary, and most probably will become necessary, at such stations, to separate, approximately at least, the effects so regulated by different laws in order to study their respective physical causes.

The Instructions of the Royal Society, which were written before the periodical character of the so-called "irregular" variations was suspected, contemplate that by a sufficiently long continuance of the observations the effects of the "irregular variations" will be self-compensatory. "The observations," it is said, "must be long-continued at the same hours, before we can be assured that the irregularities do not sensibly affect the mean results." But since the true character of the disturbances is now more correctly known, it becomes obvious that no continuance of the observations will render their influence insensible: and the simplification of the problem, in the solution of which Mr. FARADAY is engaged, will require the separation, as far as may be practicable, especially in the higher latitudes, of the two classes of variation which have distinct laws, and therefore probably distinct immediate causes. I venture therefore to hope for the indulgence of the Royal Society in an endeavour to establish the fact of a distinct law of periodical action in the disturbances of occasional occurrence and unusual amount,—to show its general and remarkably analogous character at two stations separated from each other nearly as widely as two stations can be on the surface of the globe, and approximately at least to separate the mean diurnal variations at those two stations into their respective components.

The stations of Toronto and Hobarton are well-situated to furnish observations to be employed in the investigation which forms the subject of this paper. Both stations

are very nearly in the same latitude, but in different hemispheres as respects the equator, and are both extra-tropical; they also differ about fifteen hours of longitude from each other. Simultaneous observations occurring in the winter months of the one station fall therefore into the summer months of the other; and the day observations of the one are for the most part the night observations of the other. The clocks which gave the time for the observations were regulated at both stations to show the mean solar time of the meridian of Göttingen, 9^h 15^m west of Hobarton, and 5^h 55^m east of Toronto. The observations were made at the completion of every hour of mean solar time at Göttingen. By this pre-arrangement the whole body of observations during the three years would have been synchronous in respect to absolute time, but for the circumstance that no observations were made on the Sundays, the Christmas days and the Good Fridays; all which days being regulated, agreeably to the purposes for which they were excepted, by *local* time, it followed that in consequence of the difference of meridians between the two stations, there were fifteen observations in each of fifty-four days of each year at each station which had no corresponding observations at the other station. The proportion of these to the whole body of observations is about one-ninth; consequently about eight-ninths of the whole were as strictly synchronous as such observations can conveniently be made. As it is not the object of this paper to examine the precise degree in which the so-called irregular disturbances are synchronous in different parts of the globe, I do not permit myself to enter into details on this part of the general subject, reserving such details for a more appropriate occasion; I will merely state generally that the evidence of the synchronous character of the disturbances afforded by the observations of these three years is not less remarkable than has been stated on other occasions; and I will proceed at once to their distribution into the months and hours of their respective occurrence, first at Toronto and then at Hobarton, and to the evidence afforded thereby of the periodical influence by which their mean effects appear to be governed.

The disturbances to be examined are those which, occurring only occasionally, and apparently irregularly, are indicated by the wide departure of the magnetic instruments from their mean or normal positions at the same hours and at the same period of the year. It is no doubt probable that the causes in which they originate do also produce smaller disturbances of the same class and apparently irregular occurrence; but no characteristics have yet been established by which the smaller disturbances of this class may be distinguished from irregularities in the action of causes of known periodical character and regular occurrence. That such characteristics may exist and may hereafter be recognized, so as to become the subjects of observation and a means of effecting a complete separation between the two classes of phenomena, is also probable; but it is not necessary to wait till then in order to assure ourselves that the larger disturbances, viz. those which may be separated from the others by their magnitude alone, are, notwithstanding their seeming irregularity, subject in their mean values to periodic laws, which are quite distinct from those of any class of disturb-

ances or variations previously recognized; whilst the very large amount of a great portion of them affords a security that the character of their laws of periodicity, derived by a separation in which magnitude alone is regarded as the distinguishing circumstance, is not likely to undergo any material alteration (although the mean numerical values may be slightly altered), should an improved method of discrimination lead hereafter to a more perfect classification.

The magnitude of a disturbance being thus taken as a characteristic feature of the class to which it should be referred, it became a question where the line of separation should be drawn; it was desirable that on the one hand the proportion of separated observations should be ample for the intended purposes of generalization; and that on the other hand the line should be taken sufficiently distant from the mean or normal position, to exclude from the separated observations the disturbances which as far as could be judged might belong to another class. On examination, however, it soon appeared that it was not necessary to be very particular, either at Toronto or Hobarton, in selecting the distance at which the line of separation should be drawn on either side of the normal; the disturbances of *very* considerable magnitude were so numerous, and so far exceeded in amount any changes of regular occurrence, as to make it a matter of very minor importance whether a few more or a few less were comprehended at the lower end of the separated class; and after one or two trials, in which the number of separated observations was varied, but the conclusions were found to be substantially the same, five scale divisions (or 3'·6 in arc), on either side of the mean or normal position of the declination magnet at the same hour and in the same month, were adopted as a convenient distinctive value for a disturbance of the larger class at Toronto.

The number of observations thus separated amounted in the three years (1843, 1844 and 1845) to 1650. The number of hours at which observations should have been made in the three years, exclusive of Sundays, Christmas days and Good Fridays, is 22,392, and the number of hours at which observations were actually made is 22,376, sixteen observations only in the three years having been either missed or being otherwise imperfect; the proportion which the number of separated observations bears to the whole number observed is therefore one in 13·6; and we are thus furnished with an approximate measure, on the average of the three years, of the frequency with which the declination magnet is liable to be disturbed to a certain amount at Toronto, when we say that if observations are made at regular intervals, one observation in every 13·6 on the average may be expected to differ as much as 3'·6 from the true mean position corresponding to the hour and season. In 1843 there were 472 disturbed observations; in 1844, 612; and in 1845, 566; whence we may infer that 1843 was the least disturbed year of the three, and 1844 the most so: and for the purpose of assigning numerical proportions, if the degree of disturbance in 1845 be taken as unity, that of 1844 will be expressed by 1·08, and that of 1843 by 0·84. It ought to be one of the results of the system of simultaneous observation

so generally adopted in the years referred to, that numerical values of this nature, derived from a sufficiently extensive induction, should be comparable with each other, and should assist in determining the great questions, whether disturbances of the class under consideration are wholly general or only partially so; and whether their greater prevalence in particular years, as shown by the observations of any one of the observatories, is to be regarded as a general, or as a local, phenomenon.

If we refer the 1650 disturbed observations to the respective months in which they occurred, the numbers are severally as follows:—

TABLE I.

January	87	July	173
February	101	August	199
March	123	September	232
April	182	October	146
May	130	November	103
June	87	December	97

There are two minima, January and June; the numbers increase from the minimum in January to a maximum in April, and decrease to the second minimum in June; they then increase again to a second maximum in September, followed by a decrease to the minimum in January. The September maximum is greater than the April maximum. If the year be divided into six months of summer and six months of winter, the six summer months, *i.e.* April to September inclusive, have 1003 disturbed observations; and the winter months, *i. e.* October to March inclusive, 657. If the division be into quarters, solstitial and equinoctial, the two equinoctial quarters have the higher numbers, but the summer solstitial quarter (390) is very little less than the spring equinoctial (406); the principal contrast is between the autumn equinoctial quarter (577), and the winter solstitial (287).

If we divide the 1650 disturbed observations occurring in the three years into two portions, one containing the easterly disturbances, or those of the north end of the magnet towards the east, and the other containing the westerly disturbances, we find the number to be 897 easterly and 753 westerly; the easterly preponderating in the proportion of 1·19 to 1.

If we refer the easterly and westerly disturbances separately to the respective months of their occurrence, we have the numbers as follows:—

TABLE II.

Months.	Easterly.	Westerly.	Months.	Easterly.	Westerly.
January	39	48	July	111	62
February	50	51	August	106	93
March	66	57	September	132	100
April	102	80	October	74	72
May	67	63	November	45	58
June	62	25	December	43	54

Whence we perceive, that whether we regard the separate account of the easterly or of the westerly disturbances, we find the numbers increase from a minimum in January to a maximum in April, and decrease to a second minimum in June; that they then commence afresh to increase to a maximum in September, and thence decrease to the minimum in January. With the exception of a small excess of easterly disturbances in July in comparison with August, the progression, which has been found to take place when the combined easterly and westerly disturbances were under consideration, is found to be the same when the separate portions are examined. The minima of each progression are in January and June; the maxima in April and September.

Distinct from this is the conclusion we may obtain if we make an intercomparison of the numbers in the respective columns of easterly and westerly disturbances. By this intercomparison we are led to perceive that in November, December and January, the number of westerly disturbances exceeds the number of easterly; that in the adjacent months on either side, viz. in October and February, the number of each is nearly equal; and that in all the other months of the year the easterly disturbances predominate; the predominance being greatest in June and July. Thus we observe that the causes which produce large easterly deflections of the north end of the magnet, when compared with those which produce westerly deflections, are most influential in June and July, and least so in December and January. Hence, it happens, that the June minimum of westerly disturbance is less than the January minimum, and is the minimum of the year in that portion of the disturbed observations; whilst the January minimum is less than the June minimum of easterly disturbance, and is the minimum of the year in that portion. We find also in the excess of easterly disturbances in June and July, a probable explanation of the small apparent irregularity already noticed in the progression of the monthly numbers in the easterly disturbances, wherein a small excess appears in the July numbers in comparison with those of August. The excess in the total number of disturbed observations in the summer quarter over the winter quarter, appears also to be due to the excess of easterly disturbances occurring in the summer quarter; for if we regard only the westerly disturbances, we find their numbers to be even somewhat greater in winter than in summer (westerly disturbances, November to February, 160: May to July, 150: easterly disturbances, November to February, 127: May to July, 240).

If we now pass to the distribution of the 1650 disturbed observations into the respective *hours* of their occurrence, and seek in the numerical relations which may be thus manifested the evidence which they may afford of the existence of a *diurnal* affection, we may in the first instance examine the number of disturbed observations occurring in each of the hours, independently of the question of whether they are easterly or westerly disturbances: they are as follows:—

TABLE III.

Hours of Toronto time.	Number of disturbed observations.	Hours of Toronto time.	Number of disturbed observations.	Hours of Toronto time.	Number of disturbed observations.
6 A.M.	81	2 P.M.	37	10 P.M.	96
7 A.M.	72	3 P.M.	45	11 P.M.	72
8 A.M.	58	4 P.M.	44	Midnight ...	89
9 A.M.	66	5 P.M.	35	1 A.M.	83
10 A.M.	71	6 P.M.	46	2 A.M.	78
11 A.M.	69	7 P.M.	62	3 A.M.	80
Noon	61	8 P.M.	77	4 A.M.	78
1 P.M.	55	9 P.M.	101	5 A.M.	90

It is obvious at first sight from this Table that there is a great disparity in the occurrence of disturbed observations during the day and during the night; from 7 A.M. to 6 P.M. inclusive, the average number in each hour is 55, and from 7 P.M. to 6 A.M. inclusive, 82; but the principal contrast is between the hours of the afternoon and those of the night; the average of the five hours, from 2 to 6 P.M., being only 41, or exactly the half of the average of the night hours, 7 P.M. to 6 A.M. But this irregularity of distribution in respect to hours becomes far more striking when the disturbed observations are separated into easterly and westerly disturbances. Commencing with the easterly, we have the following Table:—

TABLE IV.

Hours of Toronto Time.	Number of Easterly disturbances.	Hours of Toronto time.	Number of Easterly disturbances.	Hours of Toronto time.	Number of Easterly disturbances.
6 A.M.	36	2 P.M.	10	10 P.M.	83
7 A.M.	36	3 P.M.	8	11 P.M.	57
8 A.M.	19	4 P.M.	12	Midnight ...	67
9 A.M.	23	5 P.M.	15	1 A.M.	54
10 A.M.	25	6 P.M.	27	2 A.M.	43
11 A.M.	30	7 P.M.	45	3 A.M.	39
Noon	19	8 P.M.	65	4 A.M.	35
1 P.M.	21	9 P.M.	86	5 A.M.	43

Here we perceive that when the easterly disturbed observations alone are considered, the disproportion of the occurrence in the hours of the day and of the night is much increased, the average number in each hour, from 7 A.M. to 6 P.M. inclusive, being only 20·5, whilst from 7 P.M. to 6 A.M. inclusive it is 54·5. But the hours which are contrasted in an especial degree are from 2 to 6 P.M. inclusive, and from 8 P.M. to 1 A.M. inclusive; the average number of easterly disturbances in each of the five hours, from 2 to 6 P.M., being 14, and in each of the six hours, from 8 P.M. to 1 A.M., 69: the minimum number occurring from 2 to 4 P.M. and the maximum at 8 and 9 P.M.

If we now turn to the westerly disturbances, as shown in the next Table, we find —1st, that they have their minima at the hours when the easterly disturbances have their maxima; and 2nd, that they do not appear to have so marked an epoch of maximum occurrence as do the easterly disturbances.

TABLE V.

Hours of Toronto time.	Number of Westerly disturbances.	Hours of Toronto time.	Number of Westerly disturbances.	Hours of Toronto time.	Number of Westerly disturbances.
6 A.M.	45	2 P.M.	27	10 P.M.	13
7 A.M.	36	3 P.M.	37	11 P.M.	15
8 A.M.	39	4 P.M.	32	Midnight ...	22
9 A.M.	43	5 P.M.	20	1 A.M.	29
10 A.M.	46	6 P.M.	19	2 A.M.	35
11 A.M.	39	7 P.M.	17	3 A.M.	41
Noon	42	8 P.M.	12	4 A.M.	43
1 P.M.	34	9 P.M.	15	5 A.M.	47

In the next Table I have placed the excess in the number of westerly over the easterly disturbances, or of easterly over westerly disturbances, at every hour of the day and night.

TABLE VI.

Hours of Toronto time.	Excess in the number of disturbed observations.	Hours of Toronto time.	Excess in the number of disturbed observations.
6 A.M.	9 Westerly.	6 P.M.	8 Easterly.
7 A.M.	0	7 P.M.	28 Easterly.
8 A.M.	20 Westerly.	8 P.M.	53 Easterly.
9 A.M.	20 Westerly.	9 P.M.	71 Easterly.
10 A.M.	21 Westerly.	10 P.M.	70 Easterly.
11 A.M.	9 Westerly.	11 P.M.	42 Easterly.
Noon	23 Westerly.	Midnight ...	45 Easterly.
1 P.M.	13 Westerly.	1 A.M.	25 Easterly.
2 P.M.	17 Westerly.	2 A.M.	8 Easterly.
3 P.M.	29 Westerly.	3 A.M.	2 Westerly.
4 P.M.	20 Westerly.	4 A.M.	8 Westerly.
5 P.M.	5 Westerly.	5 A.M.	4 Westerly.

We have in this Table a striking illustration of the periodical character of the larger disturbances, in the very different proportion of the numbers of easterly or westerly disturbances prevailing at the different hours. During the hours of the day, or notably from 8 A.M. to 4 P.M., westerly disturbances preponderate, whilst during the hours of the night, or notably from 7 P.M. to the early morning, easterly disturbances preponderate. The average excess in the number of *westerly* disturbances is 19 in each of the nine hours, constituting the former period (8 A.M. to 4 P.M.), and of easterly disturbances 48 in each of the seven hours constituting the latter period (7 P.M. to 1 A.M.). The greatest excess of easterly disturbance occurs at 9 and 10 P.M., when about seven-tenths of the whole number of disturbed observations consists of deflections of the north end of the magnet towards the east.

It is obvious from this systematically unequal distribution in the number of easterly and westerly disturbances of large amount at the different hours of the twenty-four, that unless it should be found on examination that the inequality in the proportion of the *numbers* should be counterbalanced by a similar inequality, but in the opposite

direction, of the *values* of the easterly and westerly disturbances, the general result of the disturbances of this class, viz. those of large amount, must be to produce a *mean diurnal variation* of a distinct character from that which is usually known as such; inasmuch as the periodical law indicated by the last Table is very different in the hours of easterly and westerly deflection, and in those of maxima and minima, or the turning-points, from the law of the diurnal variation derived from the whole body of the observations. The correct inference will then be, that the larger disturbances have a periodical law of their own, regulating their mean effects, and influential on the mean direction of the magnet at different hours of the twenty-four; and that this law is not the same as the periodical law derived from the other observations from which they have been separated. For the purpose of examining this question, which, for the reason already stated, requires that the mean numerical values of the larger disturbances at the several hours should be sought out, I have had the mean diurnal variation for the years 1843, 1844 and 1845 at Toronto computed in two different ways, viz.—1st, from the whole body of the hourly observations, no observation whatsoever being omitted; 2nd, from the same observations, omitting the 1650 disturbances of largest amount separated in the manner described in this paper; that is to say, from the 20,726 remaining observations. In the difference between the two we have the mean diurnal variation produced by the larger disturbances, estimated on the average of the whole period of three years: it is shown in the following Table:—

TABLE VII.

Hours of Toronto time.	Mean diurnal variation produced by the larger disturbances.	Hours of Toronto time.	Mean diurnal variation produced by the larger disturbances.
6 A.M.	′ 0·02 West.	6 P.M.	′ 0·16 East.
7 A.M.	0·02 West.	7 P.M.	0·28 East.
8 A.M.	0·10 West.	8 P.M.	0·56 East.
9 A.M.	0·09 West.	9 P.M.	0·79 East.
10 A.M.	0·06 West.	10 P.M.	0·75 East.
11 A.M.	0·01 East.	11 P.M.	0·42 East.
Noon	0·09 West.	Midnight ...	0·36 East.
1 P.M.	0·02 West.	1 A.M.	0·33 East.
2 P.M.	0·04 West.	2 A.M.	0·20 East.
3 P.M.	0·08 West.	3 A.M.	0·14 East.
4 P.M.	0·03 West.	4 A.M.	0·03 East.
5 P.M.	0·05 East.	5 A.M.	0·00

A glance at this Table is sufficient to show that the periodical law which governs the larger disturbances is quite as clearly manifested, and its systematic character as clearly evidenced, when their mean numerical values are substituted for the numbers of easterly or westerly disturbances occurring at the different hours. It will be best to reserve any further comments until the results have been stated of a similar examination of the observations at the Hobarton observatory in the same three years, 1843, 1844 and 1845.

For the purpose of making this examination, it appeared desirable to separate such a number of the larger disturbed observations occurring during the three years at Hobarton (commencing with the largest), as should bear nearly the same proportion to the body of the observations from which they were separated, as had been the case at Toronto. With this view it was necessary to approximate the line of separation at Hobarton more nearly to the mean or normal position of the magnet than at Toronto; or in other words, to take a lower limit than at Toronto for the deflections of the declination magnet, either east or west of its mean position, which should be classed as belonging to the larger disturbances. The reason is twofold: first, the inclination at Hobarton is nearly 5° less than at Toronto (−70° 38′ at Hobarton, and +75° 15′ at Toronto), whilst the total magnetic force acting on the free needle is nearly the same at both stations; an equal disturbing force will therefore produce a greater deflection of the declination magnet at Toronto, from mechanical considerations, than at Hobarton; and second, that experience has fully shown that the disturbing causes themselves act with greater energy, independently of the mechanical considerations referred to, at Toronto than at Hobarton. It was soon found that a value taken at about two-thirds that at Toronto, viz. 3·4 scale divisions (or 2′·4 nearly in arc), would give nearly the same proportion of separated observations at Hobarton, as 5 scale divisions (or 3′·6 in arc) at Toronto, and this value was accordingly taken.

The number of observations thus separated was 1479; the system of observation being hourly, the total number of observations which should have been made in the three years (Sundays, Christmas days and Good Fridays excepted) is 22,392; the actual number was 21,436; the difference, 956, being occasioned partly by an interruption of several days in June and July 1843, owing to the suspension-thread of the magnet breaking, and partly by observations being occasionally missed, as the hourly system was rather heavy for the establishment which had been left to carry it on. The proportion of separated observations is therefore 1479 : 21,436, or 1 : 14·5; the proportion at Toronto being 1 : 13·6.

The 1479 disturbed observations are composed of 415 in 1843, 562 in 1844, and 502 in 1845; showing, as at Toronto, 1843 to have been the least disturbed year of the three, and 1844 the most so. Taking the number in 1845 as unity, we have the numerical proportions as follows:—

Hobarton	1843	0·83	Toronto	1843	0·84
	1844	1·12		1844	1·08
	1845	1·00		1845	1·00

This is quite as near an accordance in the proportion as it would be reasonable to expect, even on the extreme supposition of the disturbances being in all cases common to both stations, as, including the observations missed at Hobarton, between one-sixth and one-seventh of the hourly observations at Toronto were without corresponding simultaneous observations at Hobarton:—

If we now refer the 1479 disturbed observations to the respective months of their occurrence, we have the numbers severally as follows :—

Table VIII.

January	208	July	56
February	161	August	102
March	159	September	125
April	148	October	138
May	48	November	123
June	19	December	192

We have here plainly a law of numbers dependent upon the season of the year; but which with some points of resemblance has also some marked points of difference from the law found at Toronto. The number of disturbed observations arrange themselves at Hobarton in a single progression instead of a double progression as at Toronto. The maximum number occurs in December and January, the two mid-summer months, and the minimum in May, June and July, the midwinter months. The six summer months, October to March inclusive, have 981 disturbed observations, and the six winter months, April to September inclusive, 498; or on the average nearly twice as many in each of the summer months as in the winter months; whilst at Toronto the proportion is more nearly 1·5 in the summer months to 1 in the winter months. If the year be divided into quarters, the summer solstitial quarter has the greatest number (523); then the two equinoctial quarters (respectively 468 and 365, the numbers at the autumnal equinox preponderating as at Toronto, but the autumn being in this case, February, March and April, instead of August, September and October as at Toronto); and finally, the winter solstitial quarter (123) having here, as at Toronto, a much less number of disturbed observations than the other three.

If we divide the 1479 larger disturbances into easterly and westerly portions (Table IX.), we have 613 deflections of the north end of the magnet towards the east, and 866 towards the west. The predominance is here of westerly disturbances as it was at Toronto of easterly, and as analogy would require, since the stations are in different hemispheres and the deflections are of the same end of the magnet at both. The proportion in which the westerly deflections preponderate is greater than that of the easterly predominance at Toronto, being about 1·4 : 1 at Hobarton and but 1·2 : 1 at Toronto. The westerly disturbances are in excess in every month of the year at Hobarton, whereas the excess of easterly disturbances at Toronto prevails only during seven months of the year, the westerly being in excess during the winter solstitial quarter. But with this difference there is still a considerable analogy preserved; the proportion of easterly disturbances to westerly is greatest in the summer quarter and least in the winter quarter at Toronto, whilst at Hobarton the converse proportion holds good, the proportion of westerly to easterly disturbances being greatest in the summer quarter and least in the winter quarter at Hobarton.

TABLE IX.

Months.	Easterly.	Westerly.	Excess of Westerly.	Months.	Easterly.	Westerly.	Excess of Westerly.
January	80	128	48	July	22	34	12
February......	73	88	15	August	47	55	8
March.........	70	89	19	September ...	50	75	25
April	69	79	10	October	58	80	22
May	16	32	16	November ...	42	81	39
June	5	14	9	December ...	81	111	30

In this comparison of the laws which appear to regulate the distribution of the larger disturbances in the several months of the year at Toronto and Hobarton, I have been desirous of giving quite as much prominency to the points of difference at the two stations as to those of resemblance; believing the one to be quite as likely to conduct to a recognition of the physical causes of these remarkable phenomena as the other. But it must be remembered that three years scarcely form a sufficient basis of observation for secure and correct deduction of the minor details of an *annual* variation, though they may be sufficient in the case of *diurnal* variation. A continuation of the comparison by a similar examination of the hourly observations at Toronto and Hobarton in the three following years, 1846, 1847 and 1848, may be expected to elucidate what may appear obscure or uncertain on the present occasion, and will enable the differences as well as the analogies of the annual laws at the two stations to be discussed on more secure grounds. I will therefore proceed to the distribution of the 1479 disturbed observations at Hobarton into their respective hours of occurrence, for the purpose of examining the evidence they may afford of a diurnal law, for the deduction of which in its main features at least three years' continuance of observation ought to be a sufficient time.

Table X. shows the number of disturbed observations occurring at each hour of the twenty-four, separating them also into easterly and westerly disturbances.

TABLE X.

Hours of Hobarton time.	Easterly disturbances.	Westerly disturbances.	Total.	Hours of Hobarton time.	Easterly disturbances.	Westerly disturbances.	Total.
6 A.M.	27	21	48	6 P.M.	22	20	42
7 A.M.	38	25	63	7 P.M.	11	33	44
8 A.M.	32	36	68	8 P.M.	10	50	60
9 A.M.	34	24	58	9 P.M.	9	68	77
10 A.M.	36	18	54	10 P.M.	5	66	71
11 A.M.	37	28	65	11 P.M.	7	70	77
Noon	40	33	73	Midnight ...	17	66	83
1 P.M.	41	31	72	1 A.M.	17	67	84
2 P.M.	36	22	58	2 A.M.	16	44	60
3 P.M.	36	22	58	3 A.M.	29	40	69
4 P.M.	37	17	54	4 A.M.	28	27	55
5 P.M.	25	21	46	5 A.M.	23	17	40

If we regard, first, the *westerly* disturbances, we perceive a scarcely less striking disparity in their relative numbers during the hours of the day and of the night than was found to be the case with the *easterly* disturbances at Toronto. From the early

hours of the morning to 6 and 7 P.M., the average number of westerly disturbed observations is considerably less than half the average number during the hours of the night (8 P.M. to 3 A.M. inclusive); whilst the contrast is still greater (as in the case of the easterly disturbed observations at Toronto) between the hours of the afternoon (2 to 6 P.M.) and the early hours of the night (8 P.M. to 1 A.M.).

The hours of the maximum occurrence of the westerly disturbances are also those of the minimum occurrence of easterly disturbances, and the latter do not appear to have any marked epoch of maximum occurrence at other hours.

Referring back to the comments on Tables III., IV., V. and VI., the analogy between the two stations will be seen to be most striking. Laws derived directly from the phenomena, and having so much in common at stations so widely remote from each other, cannot be regarded as accidental, and claim to be viewed as a step gained in the analytical examination of the magnetic phenomena and in their classification; in the path therefore which, according to the principles of the inductive philosophy, conducts from a knowledge of effects to the perception of their cause or causes. We have traced in the largest and most influential portion of the disturbances, belonging to the class which has hitherto borne the name of "irregular," the existence of a law connecting them with the local hours of the station at which they were observed; and in the accordance of this law, as severally deduced at Toronto and Hobarton, we see reason to attribute to it a more general character than that of a mere dependence on the peculiarities of particular stations. In order that this may be more clearly seen, I have placed in the next Table a comparative view of the diurnal variation derived from the larger disturbances at Toronto and Hobarton, on the average of the three years under discussion. The phenomena at Toronto are reproduced from Table VII., and those at Hobarton have been obtained in the same manner as at Toronto, and as is described in the paragraph which immediately precedes Table VII.

TABLE XI.

Local time.	Hobarton.	Toronto.	Local time.	Hobarton.	Toronto.
6 A.M.	′ 0·03 East.	′ 0·02 West.	6 P.M.	′ 0·04 West.	′ 0·16 East.
7 A.M.	0·06 East.	0·02 West.	7 P.M.	0·16 West.	0·28 East.
8 A.M.	0·02 East.	0·10 West.	8 P.M.	0·27 West.	0·56 East.
9 A.M.	0·04 East.	0·09 West.	9 P.M.	0·39 West.	0·79 East.
10 A.M.	0·03 East.	0·06 West.	10 P.M.	0·42 West.	0·75 East.
11 A.M.	0·03 East.	0·01 East.	11 P.M.	0·41 West.	0·42 East.
Noon	0·02 East.	0·09 West.	Midnight ...	0·38 West.	0·36 East.
1 P.M.	0·04 East.	0·02 West.	1 A.M.	0·34 West.	0·33 East.
2 P.M.	0·05 East.	0·04 West.	2 A.M.	0·24 West.	0·20 East.
3 P.M.	0·06 East.	0·08 West.	3 A.M.	0·12 West.	0·14 East.
4 P.M.	0·05 East.	0·03 West.	4 A.M.	0·02 West.	0·03 East.
5 P.M.	0·01 East.	0·05 East.	5 A.M.	0·03 East.	0·00

The general character at the two stations (easterly deflections at the one being equivalent, as already stated, to westerly at the other) is strikingly accordant: the principal difference appears to consist in the mean easterly deflection at Toronto

being greater in amount from 6 P.M. to 10 P.M. than the westerly deflection at Hobarton at the same hours.

The absolute quantities shown in this Table are small, but it must be remembered that they represent the *mean daily* effect of the disturbances, during the whole period of three years under discussion; while the disturbances themselves are by no means of daily occurrence. Small as the numbers are, however, they make a very important change in the character of the residual diurnal variation, both at Toronto and Hobarton, from that which is derived from the mean of all the observations including the disturbed ones. In order that this may be distinctly seen, I have placed in the following Table (XII.) the mean diurnal variation as it would be shown at each hour with and without the disturbances, and have added columns containing the amount of the change in the mean direction in the intervals from hour to hour: the extreme westerly position at Toronto and the extreme easterly position at Hobarton are taken as the respective zeros, from which the diurnal variation at the several hours is counted. The sign + in the column of differences signifies, therefore, that the north end of the magnet has moved during the interval to the east at Toronto and to the west at Hobarton, and the sign − has the contrary signification.

TABLE XII.—Diurnal variation at Toronto and Hobarton, with the disturbed observations retained, and with the same omitted; derived from hourly observations during the years 1843, 1844 and 1845.

Toronto.					Hobarton.				
Toronto mean time.	Retaining the disturbed observations.		Omitting the disturbed observations.		Hobarton mean time.	Retaining the disturbed observations.		Omitting the disturbed observations.	
Hours.	Diurnal variation.	Differences.	Diurnal variation.	Differences.	Hours.	Diurnal variation.	Differences.	Diurnal variation.	Differences.
6 A.M. ...	′ 7·52	′ +0·91	′ 7·52	′ +0·91	6 A.M. ...	′ 5·29	′ +0·76	′ 5·26	′ +0·80
7 A.M. ...	8·43	+0·24	8·43	+0·33	7 A.M. ...	6·05	+0·98	6·06	+0·93
8 A.M. ...	8·67	−0·93	8·76	−0·95	8 A.M. ...	7·03	+0·52	6·99	+0·54
9 A.M. ...	7·74	−2·25	7·81	−2·28	9 A.M. ...	7·55	−0·61	7·53	−0·62
10 A.M. ...	5·49	−2·63	5·53	−2·70	10 A.M. ...	6·94	−1·77	6·91	−1·77
11 A.M. ...	2·86	−2·08	2·83	−1·98	11 A.M. ...	5·17	−2·30	5·14	−2·31
Noon	0·78	−0·78	0·85	−0·85	Noon	2·87	−2·06	2·83	2·04
1 P.M. ...	0·00	+0·30	0·00	+0·32	1 P.M. ...	0·81	−0·70	0·79	−0·69
2 P.M. ...	0·30	+1·07	0·32	+1·11	2 P.M. ...	0·11	−0·11	0·10	−0·10
3 P.M. ...	1·37	+1·32	1·43	+1·27	3 P.M. ...	0·00	+0·90	0·00	+0·89
4 P.M. ...	2·69	+1·20	2·70	+1·11	4 P.M. ...	0·90	+1·25	0·89	+1·21
5 P.M. ...	3·89	+0·83	3·81	+0·73	5 P.M. ...	2·15	+0·95	2·10	+0·90
6 P.M. ...	4·72	+0·48	4·54	+0·36	6 P.M. ...	3·10	+0·70	3·00	+0·58
7 P.M. ...	5·20	+0·37	4·90	+0·24	7 P.M. ...	3·80	+0·69	3·58	+0·58
8 P.M. ...	5·57	+0·50	5·00	+0·26	8 P.M. ...	4·49	+0·56	4·16	+0·43
9 P.M. ...	6·07	+0·08	5·26	+0·11	9 P.M. ...	5·05	+0·35	4·59	+0·32
10 P.M. ...	6·15	−0·29	5·37	+0·05	10 P.M. ...	5·40	+0·17	4·91	+0·19
11 P.M. ...	5·86	−0·20	5·42	−0·17	11 P.M. ...	5·57	−0·05	5·10	−0·03
Midnight...	5·66	−0·12	5·25	−0·07	Midnight...	5·52	−0·29	5·07	−0·24
1 A.M. ...	5·54	−0·14	5·18	0·00	1 A.M. ...	5·23	−0·31	4·83	−0·22
2 A.M. ...	5·40	+0·17	5·18	+0·23	2 A.M. ...	4·92	−0·31	4·61	−0·19
3 A.M. ...	5·57	+0·46	5·41	+0·57	3 A.M. ...	4·61	−0·06	4·42	+0·05
4 A.M. ...	6·03	+0·55	5·98	+0·58	4 A.M. ...	4·55	+0·23	4·47	+0·29
5 A.M. ...	6·58		6·56		5 A.M. ...	4·78		4·76	

Considering Toronto in the first instance, it is obvious from this Table that the westerly retrogression, which is found to take place from 10 P.M. to 2 A.M. in the diurnal march of the magnetic declination when the whole of the observations are retained, is certainly chiefly, and probably entirely, occasioned by a return of the magnet from the disturbed position to which it had been carried by the great excess of easterly disturbances between the hours of 7 and 10 P.M.; which easterly excess rapidly diminishes after 10 P.M. When the disturbed observations are omitted, the movement of the north end of the needle towards the east after 6 P.M. is seen to be slower, and never reaches so great an easterly extreme as takes place when the disturbed observations (which it must be remembered are only of occasional occurrence) are retained and allowed to influence the daily mean. By the separation of the disturbances of principal magnitude in the manner described in this paper, the westerly retrogression at the hours referred to is in fact almost eliminated, and we can scarcely doubt that it would be entirely so, if we possessed the means of more completely separating the whole of the disturbances which belong to the same class and cause as the larger ones; and that by such separation the character of the residual diurnal variation would be entirely changed (as it is now almost entirely changed) from a double progression having two maxima and two minima, to a single progression with one easterly extreme at 8 A.M., and one westerly extreme at 1 P.M. The change in the character of the diurnal variation at Hobarton, caused by the omission of the disturbed observations, is similar in kind to that at Toronto, though not quite so strongly marked.

The change of character which thus appears to be indicated (at both stations, but particularly at Toronto) is a very important one, as will be readily admitted by those who are engaged in searching out the physical causes of these phenomena. The *nocturnal episode*, as it has been termed by Mr. FARADAY, or the retrogression of the declination during the hours of the night, would be done away as a part of the regular diurnal variation; and the physical explanation which we should have to seek would be that of a different phenomenon, namely, of an *increased* movement, *not* in the *retrograde* direction, but in the *same* direction as that of the regular diurnal variation, occurring at earlier hours of the night than those of the retrogression; being moreover of occasional and apparently fitful (as opposed to regular) occurrence,—although when the average is taken of a sufficient number of days it is found to be strictly periodical in its mean effects, and influential therefore on the mean diurnal variation of the magnet. I wish however to guard myself from being understood to oppose, by these remarks, the supposition that has been made of the existence of physical causes acting during the night antagonistic to those of the day: there may still be room for a supposition of this nature; for admitting the apparent retrogression to be greatly lessened if not entirely eliminated by the withdrawal of the influence of disturbances of occasional occurrence, still it continues to be true that the progression of the residual diurnal variation which commences at an early hour of the afternoon is *checked* during the hours of the night, even if it be not at any moment actually reversed.

Although conclusions which are drawn from hourly observations, continued during three years at two stations, scarcely seem to require the support they may receive from their agreement with inferences previously drawn resting on a much narrower basis, yet it may not be unimportant to recall those, derived from a similar investigation to the present into the two-hourly observations at Toronto in the years 1841 and 1842, which were published by me in 1845 in the Comments on the Observations of those years contained in the first volume of the Toronto Observatory. After remarking that the deflections produced by the disturbances are of sufficient magnitude and regularity of occurrence to constitute a recognizable and systematic component part of the mean diurnal variation obtained from observations of a month's continuance or more, I stated as follows: "By their easterly maximum at 10 P.M. (together with the increasing prevalence of easterly deflections at the previous hours of 6 and 8), there is superinduced an excess of easterly direction at those hours, which appears to be in great measure the cause of the westerly retrogression of the magnet at the succeeding hours of midnight and 2 A.M.; and we are thus led to infer the probability, that if the whole effect of the disturbing cause, or causes, could be eliminated, the residual portion of the diurnal variation might appear as a single progression with but one maximum and one minimum in the twenty-four hours.

"The connection which thus appears between the systematic operation of the disturbances and the occurrence of a double progression in the diurnal variation, would lead to an important inference in regard to the disturbances themselves, to which it may be well to advert, in order that the subject may receive further examination by the observations of other observatories. The hours of the night at which the otherwise continuous easterly march of the diurnal variation is interrupted, appear to be the same, or very nearly the same, at all the observatories at which results have yet been published. If this interruption be either wholly, or in great measure, occasioned by the influence of the disturbances, operating in a systematic manner, as they are found to do at Toronto, the deflections which they produce at other stations must also have a similar systematic character, and be connected, as those of Toronto are, with the hour of the day at the particular station.

"We should in such case arrive at the important conclusion, that whilst the disturbances must be attributed to general causes, inasmuch as they are found to prevail on the same days in different and very remote parts of the globe—it must also be recognized, that their operation, in every particular locality, is regulated by a law which respects the hours of the place."

The investigation, which has been the object of this paper, is obviously incomplete until a similar examination shall have been made of the influence of the larger disturbances on the mean diurnal variation of the Inclination and of the total Force. I may perhaps hope to make such an investigation the subject of a future communication.