XXII. *On the Great Magnetic Disturbance which extended from August 28 to September 7, 1859, as recorded by Photography at the Kew Observatory.* *By* BALFOUR STEWART, *A.M.*

Received June 28,—Read November 21, 1861.

DURING the latter part of August, and the beginning of September, 1859, auroral displays of almost unprecedented magnificence were observed very widely throughout our globe, accompanied (as is invariably the case) with excessive disturbances of the magnetic needle.

The interest attached to these appearances is, if possible, enhanced by the fact, that at the time of their occurrence a very large spot might have been observed on the disc of our luminary—a celestial phenomenon which we have grounds for supposing to be intimately connected with auroral exhibitions and magnetic storms.

The auroral displays above mentioned were very attentively observed throughout Europe, America, and Australia. In many places these were of the most gorgeous character, while other places were visited by this meteor where its appearance was an event of very rare occurrence. Even from as low a latitude as Cuba we have a description of it by the Director of the Havannah Observatory, accompanied with the remark that only four previous displays had been recorded in the traditions of the island. In not a few instances telegraphic communication was interrupted, owing to the current produced in the wires; and in some cases this proved so powerful that it was used instead of the ordinary current, the batteries being cut off and the wires simply connected with the earth.

It is unnecessary to enter into further particulars regarding this meteor, as the descriptions of it given by observers at places widely apart have been collected together by Professor E. LOOMIS, and published in a series of papers communicated to the American Journal of Science and Arts. I shall only add that, both from the European, the American, and the Australian accounts, there appear to have been two great displays, each commencing at nearly the same absolute time, throughout the globe,—the first on the evening of the 28th of August, and the second on the early morning of the 2nd of September, Greenwich time.

Magnetic disturbances of unusual violence and very wide extent were observed simultaneously with these displays. These were recorded more or less frequently at the various observatories; but at Kew there is the advantage of a set of self-recording magnetographs (the property of the Royal Society), which are in constant operation.

As a description of these instruments has already been published in the volume of Reports of the British Association for 1859, it is only necessary here to mention that

they afford the means of obtaining a continuous photographic register of the state of the three elements of the earth's magnetic force—namely, the declination, and the horizontal and vertical intensity. Reduced representations of the traces furnished by these instruments during the great disturbance under discussion accompany this paper; and it will now be necessary to give a short description of these.

In the originals we have for each element, for each day, a straight line and a curved one. The straight or zero-line serves as a line of abscissæ, along which the time is reckoned; and if from any point of this line denoting a certain time an ordinate be drawn to the corresponding point of the curved line, the length of this ordinate will represent the state of the magnetic element at this time.

The register is taken from 10 A.M. of one day to the same hour of the next, and the curve proceeds (in point of time) from the left to the right of the paper. In full size, the length of the zero-line is about 18 inches for twenty-four hours, so that three-quarters of an inch denote one hour; but on the reduced scale appended to this paper, three-tenths of an inch denote one hour. The exact Kew mean time corresponding to the commencement and end of each curve is stated at the conclusion of this paper. Increasing ordinates denote decreasing westerly declination, decreasing horizontal, and decreasing vertical force. In the reduced scale which accompanies this paper, a change of one inch in the ordinate represents a change of 55′ in the declination, while for the horizontal force it denotes a change equal to ·0237 of the whole, and for the vertical force a change equal to ·006 of the whole.

Referring to the curves, it will be seen that the first disturbance commenced about half-past ten on the evening of the 28th of August, affecting all the elements simultaneously. It will also be observed that for the early part of this day, before the disturbance commenced, the curves present a peculiar serrated appearance. This is a phenomenon which often precedes and follows large disturbances.

At about $7\frac{1}{2}$ P.M., August 29, the violence of the disturbance had somewhat abated, and things remained nearly in this state until 5 A.M., September 2, about which time another very abrupt disturbance simultaneously affected all the elements, continuing with great violence until about 4 P.M. of the same day, when it became somewhat less. The elements, notwithstanding, remained in a state of considerable disturbance until September 5, and scarcely attained their normal state even on September 7 or 8.

A graphical representation of the amount of disturbance is furnished by the dotted line, or line of normals, which accompanies each curve.

These normals have been furnished through the kindness of General SABINE, by whom they were calculated. They denote the probable position which the curve corresponding to each element would have occupied, had not disturbance supervened.

The normal for the declination for any hour is a mean of the daily observations at that hour during August and September, after the omission of all disturbed observations which differ from the final normal by an amount equal to or exceeding 3′·3.

The normals for the horizontal and vertical force have been obtained in a somewhat

similar manner, the separating values (corresponding to 3′·3 for the declination) being for the horizontal force ·0014 of its whole amount, and for the vertical force ·000478 of the whole.

I now proceed to notice some of the peculiarities of this magnetic storm.

It appears that we have two distinct well-marked disturbances, each commencing abruptly and ending gradually, the first of which began on the evening of August 28, and the second on the early morning of September 2. These two great disturbances correspond therefore in point of time to the two great auroral displays already alluded to.

The average effect of the disturbance of August 28 was to increase the declination, and to diminish the horizontal and vertical components of the earth's magnetic force. The appearance of the curves indicates very well the *modus operandi* of the disturbing force on this occasion. From their serrated appearance, it will be seen that a force tending to increase one of the elements was generally followed after a short interval by one of the opposite description, and *vice versâ*. The exertion of the disturbing force was thus of a throbbing or pulsatory character. The interval of time between two of these minute pulsations may be said to have varied from half a minute, or the smallest observable portion of time, up to four or five minutes.

This pulsatory character of the disturbing force agrees well with the nature of its action on telegraphic wires, in which observers have noticed that the polarity of the current changes very frequently.

Apart from these comparatively rapid and minute changes, the curves referring to this great disturbance indicate, for all the elements, pulsations in the disturbing force which have a period of from forty to fifty minutes. These pulsations are of a very violent character in the case of the declination, where the ebb and flow of the force alternately carries the needle above and below its normal position.

We have thus, as it were, two sets of waves, the first or smaller of which is superimposed upon the second or larger, just as in the ocean we sometimes see ripples caused by the wind traversing the surface of a great wave. But in addition to these there is a still more remarkable period which this great disturbance seems to have accomplished for all the elements in about six hours from its commencement, after which it started anew in the same direction as at first, to accomplish another period or grand wave, which lasted about the same time. The violence of the disturbance seems to have exhausted itself in the accomplishment of these two grand waves; for after this, although the needle was far from tranquil, yet its evagations were of a more moderate description.

Three periods are thus observable,—

1. That extending from half a minute up to four or five minutes.
2. A period of from forty to fifty minutes.
3. A period of about six hours.

It is impossible to state with accuracy what were the greatest departures from the mean values caused by this disturbance, as the curves for all the elements went beyond the sensitive paper; very approximately, however, we may estimate these as follows:—

For the declination a departure of about . . . +2° 20′
For the horizontal force . . . . . —·04 of the whole.
For the vertical force . . . . . —·01 of the whole.

The second great disturbance commenced very abruptly on September 2, at 5 A.M. In character it was similar to that of August 28, its mean tendency being to increase the declination, and to diminish the horizontal and vertical components of the earth's magnetic force.

It is impossible to state the greatest departures from the mean caused by this disturbance; but in all probability they equalled or even exceeded those of the first. In appearance, also, the second disturbance was similar to the first, and it lost its excessive character for all the elements simultaneously about $3^h\ 40^m$ P.M. of the 2nd of September; but, as has been already mentioned, and as may be seen from the lines of normals, it did not finally subside until September 7.

After it had somewhat abated, its nature was exhibited by that peculiar serrated appearance of the curves which has already been alluded to, and which is very prominent in those of September 3rd and 4th. This appearance, however, had ceased some time before the elements finally resumed their normal values.

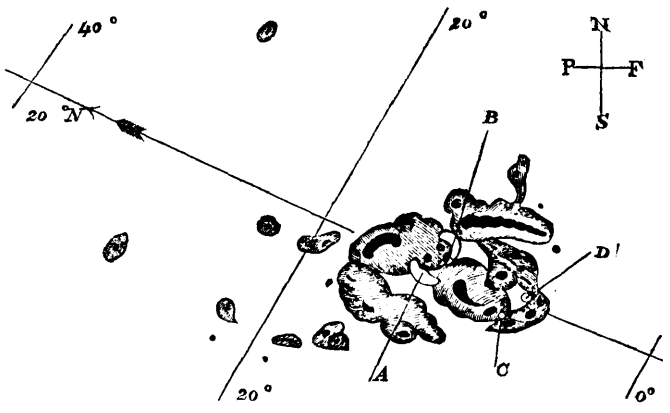
Such is a brief and very imperfect description of the leading features of this great magnetic storm, which for excessive violence of character and length of duration, I have been assured by General SABINE, has never been surpassed by any similar phenomenon which has occurred in his long and varied experience.

But, besides these two remarkable disturbances into which it divides itself, this great storm comprehends a minor disturbance, not approaching these two in extent, but yet possessing an interest peculiar to itself, which entitles it to be mentioned.

On September 1, a little before noon, Mr. R. C. CARRINGTON happened to be observing, by means of a telescope, a large spot which might then be seen on the surface of our luminary, when a remarkable appearance presented itself, which he thus describes in a communication to the Royal Astronomical Society.

"While engaged in the forenoon of Thursday, September 1, 1859, in taking my customary observation of the forms and positions of the solar spots, an appearance was witnessed which I believe to be exceedingly rare. The image of the sun's disc was, as usual with me, projected on to a plate of glass coated with distemper of a pale straw colour, and at a distance and under a power which presented a picture of about 11 inches diameter. I had secured diagrams of all the groups and detached spots, and was engaged at the time in counting from a chronometer and recording the contacts of the spots with the cross-wires used in the observation, when within the area of the great north group (the size of which had previously excited general remark), two patches of intensely bright and white light broke out, in the positions indicated in the appended diagram by the letters A and B, and of the forms of the spaces left white. My first impression was, that by some chance a ray of light had penetrated a hole in the screen

attached to the object-glass, by which the general image is thrown into shade, for the brilliancy was fully equal to that of direct sunlight; but, by at once interrupting the



current observation, and causing the image to move by turning the R.A. handle, I saw I was an unprepared witness of a very different affair. I thereupon noted down the time by the chronometer, and, seeing the outburst to be very rapidly on the increase, and being somewhat flurried by the surprise, I hastily ran to call some one to witness the exhibition with me, and on returning within 60 seconds, was mortified to find that it was already much changed and enfeebled. Very shortly afterwards the last trace was gone; and although I maintained a strict watch for nearly an hour, no recurrence took place. The last traces were at C and D, the patches having travelled considerably from their first position, and vanishing as two rapidly fading dots of white light. The instant of the first outburst was not 15 seconds different from $11^h\ 18^m$ Greenwich mean time, and $11^h\ 23^m$ was taken for the time of disappearance. In this lapse of five minutes, the two patches of light traversed a space of about 35,000 miles, as may be seen by the diagram, which is given exactly on a scale of 12 inches to the sun's diameter. On this scale the section of the earth will be very nearly equal in area to that of the detached spot situated most to the north in the diagram, and the section of Jupiter would about cover the area of the larger group, without including the outlying portions. It was impossible, on first witnessing an appearance so similar to a sudden conflagration, not to expect a considerable result in the way of alteration of the details of the group in which it occurred; and I was certainly surprised, on referring to the sketch which I had carefully and satisfactorily (and I may add fortunately) finished before the occurrence, at finding myself unable to recognize any change whatever as having taken place. The impression left upon me is, that the phenomenon took place at an elevation considerably above the general surface of the sun, and, accordingly, altogether above and over the great group in which it was seen projected. Both in figure and position the patches of light seemed entirely independent of the configuration of the great spot, and of its parts, whether nucleus or umbra. The customary observation was shortly resumed; and the diagram engraved,

as well as the larger drawing exhibited at the Meeting on November 11, was deduced from an exact reduction of the recorded times.

"It has been very gratifying to me to learn that our friend Mr. HODGSON chanced to be observing the sun at his house at Holloway on the same day, and to hear that he was a witness of what he also considered a very remarkable phenomenon. I have carefully avoided exchanging any information with that gentleman, that any value which the accounts may possess may be increased by their entire independence."

On calling at Kew Observatory a day or two afterwards, Mr. CARRINGTON learned that at the very moment when he had observed this phenomenon the three magnetic elements at Kew were simultaneously disturbed. If no connexion had been known to subsist between these two classes of phenomena, it would, perhaps, be wrong to consider this in any other light than a casual coincidence; but since General SABINE has proved that a relation subsists between magnetic disturbances and sun spots, it is not impossible to suppose that in this case our luminary was taken *in the act*.

This disturbance occurred as nearly as possible at $11^h\,15^m$ A.M. Greenwich mean time, on September 1, 1859, affecting all the elements simultaneously, and commencing quite abruptly.

The first or most abrupt portion of the disturbance lasted only about three minutes for all the elements; but after that there was a more gradual change in the same direction before the curve turned. This more gradual continuation of the first sudden movement lasted about seven minutes for all the elements.

The westerly declination was increased—

By the first, or three-minute movement, about . .	6′·6
By the last, or seven-minute movement, about . .	6·6
In all, the disturbance increased the westerly declination	13′·2

The horizontal force was diminished—

By the first movement	·005 of the whole.
By the last movement	·0025 of the whole.
In all, it was diminished by	·0075 of the whole force.

The vertical force was also diminished—

By the first movement	·0008 of the whole.
By the last movement	·0005 of the whole.
In all, it was diminished by	·0013 of the whole force.

It thus appears that the direction of this disturbance was the same for all the elements as that of the two great disturbances, the latter of which took place not many hours afterwards.

The leading features of this great storm appear to suggest something regarding the

nature of that relationship which manifestly exists between auroral displays, earth-currents, and magnetic disturbances.

I cannot think that the latter are caused directly and mainly by the two former, but rather that the three are simultaneous effects produced by the same cause. I believe that this is the opinion entertained by General SABINE, who has investigated the subject from another point of view.

A very remarkable feature of this disturbance was its period of about six hours, which is most distinctly shown in the curves of the horizontal and vertical forces. For about three hours the two components of the earth's force at Kew were diminishing, and for the next three hours these were increasing, until, after the lapse of about six hours, they had again attained their normal values. Were this due to the direct action of an electric current, it would require that this current should have flowed in the same direction for six hours; or at least that it should have been so limited in direction as to influence the earth's magnetism at Kew in the same manner for about six hours.

Referring now to the accounts collected by Professor LOOMIS of the influence of this great storm upon telegraphic wires, and also to a paper on magnetic storms and earth-currents, communicated by Mr. C. V. WALKER to the Royal Society on January 31, 1861, we find that the duration of the currents produced in the telegraphic wires is for the most part exceedingly small. The 1-minute currents (says this last author) are most in number; then, in order, the 2-minute, 3-minute, 4-minute, $\frac{1}{2}$-minute, and 5-minute. Now it seems impossible that any combination of such currents of short period and rapid reversal can account for the six hours' march of the earth's force at Kew, and equally impossible not to associate these currents of small period with the rapid and minute changes which give a pulsatory character to the disturbing force, and a serrated appearance to the curves.

It is not difficult to conceive a mode of action of the primary force which would produce these effects.

We have grounds for supposing this primary disturbing force to reside in our luminary.

The earth may be viewed as the iron core of a RUHMKORFF'S machine, separated by an insulating medium (that is to say, the lower strata of the atmosphere) from a conducting medium (that is to say, the upper and rarer strata of the atmosphere).

Suppose the primary current in the sun suddenly to become increased or diminished a little. This will not produce a reversal in the magnetic state which this current has communicated to the earth, but merely a small change in its amount; or, in other words, the magnetic disturbance produced by the current will merely be somewhat increased or diminished.

The change in the primary current, heightened by the change of the iron core, will, on the other hand, produce a secondary current:

1st. Along the surface of the earth, which is sufficiently conducting for the purpose;

2nd. Along the upper strata of the atmosphere;

and this discharge will be in one direction for an increase, and in the opposite direction for a diminution of the primary current.

Disturbances would thus seem to be due to the absolute amount of the primary current, and auroras and earth-currents to the rapidity with which this current changes. Let me remark, in conclusion, that if it be true that the spots on the surface of our luminary (or action connected with these spots) are the primary cause of magnetic disturbances, it is to be hoped, since the study of the sun's disc is at present a favourite subject with observers, that ere long something more definite may be known with regard to the exact relation that subsists between these two great phenomena.

Explanation of the Plates.

Plate IX. contains reduced tracings of the declination curves.

Plates X. and XI. those of the horizontal and vertical force curves.

The curves run in order of time from the top to the bottom of the Plate, also from left to right.

The precise Kew mean time of the commencement and end of each curve is as follows:—

	d	h	m		d	h	m
No. I. Aug.	27	22	21½	to Aug.	28	22	9½
II.	28	23	27	„	29	22	9½
III.	29	22	13	„	30	22	10
IV.	30	22	20½	„	31	22	9½
V. Sept.	0	22	12½	„	1	22	9½
VI.	1	22	19½	„	2	22	9½
VII.	2	22	18	„	3	22	9½
VIII.	3	22	12	„	4	22	11
IX.	5	0	17	„	5	22	1
X.	5	22	21	„	6	22	14
XI.	6	22	25	„	7	22	9
XII.	7	22	12	„	8	22	9

declination Aug. 29 0 27 to Aug. 29 22 9½