VII. *On Magnetic Storms and Earth-Currents.*

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Received January 31,—Read February 14, 1861.

Disturbances of the needles of the electric telegraph were noticed very soon after the completion of the first working lines. They were at once seen to be due to causes exterior to the apparatus itself.

On Saturday, May 8, 1847, I find the following entry in my diary:—"At Tonbridge. Through instrument needles stood at 'wait' from 5.6 to 5.10, and hung when turned to Dover; all right when turned to London. From 6.4 to 6.19 they hung to 'go on' on the down side. The Maidstone needles also hung."

On Friday, September 24:—"Singular atmospheric day. All over the line, and in all the groups, needles were strongly affected between noon and midnight. Signals could hardly be made. Bells rang. The deflections varied. Sometimes the up-side deflections differed from the down. Memorandum for Tonbridge.—12.50 turned down, needles at E.N.; 1 P.M., vertical; 1.5, at E.N.; 1.11, +H; 1.14, vertical; 1.15, E.N. hard up; 1.17, vertical; 1.18, E.N.; 1.23, vertical. During some parts of day through-bells rang. At night evidently an extensive aurora; but being full harvest moon and clear, not very conspicuous."

On Saturday, October 23:—"Needles hung. Wind S.W. gale; driving rain; low heavy clouds; continued unfair; signals much retarded. This continued more or less during day and night, of which I have a series of notes made at Tonbridge. The needles were occasionally affected during Sunday; and at night there was a splendid aurora visible, in spite of the full moon. The sudden transitions from right to left were remarkable."

On Monday, October 25:—"The needles affected a little this morning. At 10.1 A.M. the needles went over suddenly to W.; and in the next minute changed as suddenly to R."

I copy these notes just as they stand recorded. They are expressed in the technical language of telegraphy. I shall have no occasion to refer back to them for illustration, as we have observations of recent date, carried on for long periods and under regulation, so that it is not necessary to occupy time in putting the above into common language, further than to say that when the telegraph needles are deflected to the right hand they make E.N. or R, or "wait;" and when deflected to the left, they make +H or W, or "go on;" and that a positive current passing in the telegraph wires from Dover to London causes a right-hand deflection, and one from London to Dover a left hand.

The above are specimens of disturbances that made themselves, at that period, very conspicuous. On the one hand, they were inconvenient to the good working of the telegraph; on the other, they opened out a new field of inquiry. I therefore issued the following circular to all the telegraph stations under my control, viz. those on the South-Eastern Railway:—

"General Order, No. 54. October 25, 1847. To all Telegraph Clerks.

"The needles are occasionally deflected by atmospheric causes. Whenever this occurs make accurate notes of the time, the direction, and all changes; continue these notes as long as the phenomena endure; and notice the different effects on the different instruments and on the bells. Send the notes to this office on the following morning. Those on night duty at such times are to look out for the aurora borealis, and if possible to describe it.

(Signed) "CHARLES V. WALKER,
"*Superintendent of Telegraphs.*

"Send all the notes you made on Saturday and yesterday immediately."

The instruments on which the above observations, and all that form the subject of this communication, were made, are COOKE and WHEATSTONE'S well-known double-needle and single-needle telegraphs. A magnetized needle is suspended vertically in a vertical galvanometer coil; an outer needle on the same axis as the other serves as an index; its motion is limited by a pair of ivory studs, permanently fixed about an inch apart in the metal face of the instrument.

That these disturbances were connected with the appearance of aurora borealis and magnetic storms was soon recognized, as may be gathered from the extracts that have been given, as well as from the following taken from my 'Electric Telegraph Manipulation,' published March 1, 1850:—

"85. *Magnetic storms.*—Did any doubt remain of the electrical character of the *Aurora Borealis*, it would be removed by the phenomena presented by the needles of the telegraph, and often by the bells, during the prevalence of this meteor. At such times the needles move just as if a good working current were pursuing its ordinary course along the wires: they are deflected this way or that, at times with a quick motion and changing rapidly from side to side many times in a few seconds, and at other times moving more slowly and remaining deflected for many minutes with greater or less intensity, their motions being inconstant and uncertain. These phenomena have occurred less frequently on the part of the line between Reigate and Dover, which runs nearly E. and W., and on the part between London and Reigate, which is nearly N. and S. When, however, they do make their appearance on the telegraphs in those parts, we are prepared to expect auroral manifestations when night arrives; and we are rarely disappointed. The deflections, in their variations, appear to coincide with the various phases of the aurora. On the branch line running from Ashford to Ramsgate, these deflections have been a much more common occurrence, even when the other parts of the line were unaffected, and when no auroral phenomena were noticed."—P. 66.

From the record of 'The Daily Observations of Magnetometers at the Royal Observatory, Greenwich, in the year 1847,' I make extracts, as far as they apply to the notes of disturbances quoted above.

May 8. *Declination magnet.*—" Between 4^h and 6^h the change was considerable for the time of day."

Vertical-force magnet.—" Between 0^h and 1^h 50^m and between 6^h and 8^h considerable changes occurred."

Sept. 24. *Declination magnet.*—" From 0^h to 16^h . . . . the changes were very considerable."

Horizontal-force magnet.—" The changes were very frequent and of large amount."

Vertical-force magnet.—" Between 0^h and 10^h . . . . considerable changes occurred."

Oct. 23. *Declination magnet.*—" The changes were frequent and of large amount."

Horizontal-force magnet.—" The changes were frequent and of large amount."

Vertical-force magnet.—" Between 0^h and 12^h the changes were frequent and of large amount."

October 24.—" October 23^d 22^h (*i. e.* 10 A.M. October 24). Remarkable changes having taken place in the positions of the declination and horizontal-force magnets, extra observations were commenced " [they were continued till 23^h 57^m 30^s, *i. e.* till 11^h $57\frac{1}{2}^m$ A.M. October 25].

Oct. 25. *Declination magnet.*—" The changes were frequent and of large amount."

Horizontal-force magnet.—" The changes were frequent and of large amount."

Vertical-force magnet.—" The changes were frequent and of large amount."

In the 'Extraordinary Meteorological Observations' at the same place for the same year, an aurora is noted on September 24 from $9.39\frac{1}{2}$ to $10.40\frac{1}{2}$ P.M.

Seven pages are also occupied with an ample description of the magnificent aurora of Sunday, October 24. An account of this aurora, with a series of coloured engravings, was also published at Cambridge by Mr. JOHN MORGAN and Mr. T. BARBER.

The period to which I have been referring was, as is well known, a period of great magnetic disturbance. The extent to which these disturbances were manifested in the form of current electricity traversing our telegraph wires, may be gathered from the following further extract from 'Electric Telegraph Manipulation:'—

" 87. *Movable studs.*—So much were we inconvenienced during 1848, that I was compelled to provide a remedy. On the face of the instruments are seen a pair of small studs, which are of ivory, and which give a limit to the deflection of the needle; and if by any extraneous cause, and without any act of ours, the needle should be driven hard up against one of the studs, our attempt to deflect it in that direction by an ordinary signal would not be manifest; for it is there already. But if under such circumstances the studs were removed, and the needle allowed to go as far as the natural force could deflect it, we could *increase* that deflection by sending our usual currents in the proper direction; so that if the studs are made to follow the needle into its new position, and are so placed that the needle shall be half-way between them, we can still get each kind of deflection," &c.—P. 67.

I then go on to describe how I mounted the studs and made them movable. Immediate steps were taken to apply this adjustment to the existing instruments. Matters looked so serious at the time that further steps were taken. I made the coils of the galvanometers movable round their centre; and, when the needles were disturbed, moved the coils after them, as when using a sine-galvanometer, until the needle was midway between the studs and in the centre of the coil, although of course no longer vertical.

We were soon, however, as much surprised by the disappearance of these disturbances, as we had originally been by their appearance. Our arrangements for adjusting the needles were scarcely carried out when the necessity for the alterations began to disappear. Again quoting the words which conveyed our then impressions:—"86. It is most remarkable that during the year 1849 these deflections were rare and trivial, whereas in 1847 and 1848 they occurred many times on the main line, and were of almost daily occurrence on the Ramsgate branch, and to such an extent that the instruments required unusual precautions to enable them to give signals."—*Electric Telegraph Manipulation*, p. 67.

This state of things still continued to March 1, 1850, when the remarks just quoted were published; and a considerable period subsequently elapsed before any change for the worse (speaking technically) occurred; and this will account, in great measure, for the question having so long lain dormant. We did not then know, as we now do, that these disturbances have a cycle of about eleven years from the maximum period of activity to the next maximum, and that they go with the magnetic disturbances. It seemed at the time as if we had passed out of an abnormal state, which had left no evidence behind of its probable return at some distant period.

The "unusual precautions" referred to in the last extract, over and above the adjustments applied to the instruments themselves, were:—detaching the earth-wire at the respective termini of the Ramsgate branch line of telegraphs; converting the double needle into a single needle communication; employing the wire released from one needle as the return wire for the circuit of the needle retained. When the telegraph was thus cut off from all communication with the earth the disturbances ceased.

In the 'Philosophical Transactions' for the year 1849, is a paper by W. H. BARLOW, Esq., "On the Spontaneous Electrical Currents observed in the Wires of the Electric Telegraph," which was read on May 25, 1848. The author not only records the simultaneous disturbances observed by him of the magnets, and of the telegraph galvanometers on September 24 and 25, and October 23, 24, and 25, 1847, but he describes also an original and very interesting set of experiments made by him at Derby upon various telegraph routes centring in that station. He regarded the stations in their absolute bearing each on the other, and without reference to the route pursued by the telegraph wire itself in its course from station to station; and deduced from his observations that "the direction in which the currents travel..... will be between S. 28° W. and S. 75° W.; and apparently strongest when the earth-connexions are N.E. and S.W." The great interest attached to the fact that the direction of the current depends on the relative positions of the earth-connexions, and not on the direction of the wire itself, induced him to make further observations, which confirmed that view. They were made on May 1, 2, 3, and 8, 1848. It was further ascertained that disturbances had been noticed on the short line of telegraph that was led entirely under ground from the Strand to Nine Elms. Taking this in connexion with the influence of the relative position of the earth-connexions, he continues, "The most probable explanation appears to be that the currents are terrestrial, of which a portion is conveyed along the wire, and rendered visible by the multiplying action of the coil of the galvanometer." I refer particularly to this communication, because the two facts with which we have to deal—that currents are found travelling in the earth, and that a portion of such currents comes under our notice in the form of a derived current—are at the basis of all further inquiries into their nature.

I have mentioned that the disturbances ceased to attract our notice after the close of the year 1848. Feeble deflections, it is true, were occasionally observed, but they were practically disregarded, as they were not of sufficient magnitude to interfere with telegraphic operations. Our attention began again to be called forcibly to them about the close of the year 1856; and instructions were again issued to take notes and make a weekly return to me. The result is that I have a large accumulation of observations, commencing in April 1857 and continuing to the present date. It is not my intention to discuss these returns, nor to extract from them the dates of great disturbances. The fact that earth-currents, disturbed magnetometers, and auroræ are part of the same phenomenon, is too well established to require cases in point.

The most remarkable magnetic storm on record, at least since lines of telegraph have existed, is that which occurred in the autumn of 1859, commencing on August 27, and continuing until September 6. All the concurrent phenomena were manifested in a very exalted degree, and attracted the attention of observers in both hemispheres. Disturbances were conspicuous in Australia, as they were in Europe and America. Auroral light was seen in latitudes as low as 20°, 18°, and 13° 18′. A series of five articles will be found in 'The American Journal of Science and Arts' (vol. xxviii. pp. 385 to 408; vol. xxix. pp. 92 to 97, 249 to 266, 386 to 399; and vol. xxx. pp. 79 to 89, being the numbers issued in November 1859, and in January, March, May, and July 1860). To the last of these the name of Professor Elias Loomis is attached; and the other four*, I believe, passed through his hands.

The ninety-three pages referred to are enriched with a large collection of reports from

* Since the above was written, the November Number (1860) of Silliman's Journal has appeared, with a sixth article of twenty-two pages (pp. 3 to 25); and the July Number (1861) with a seventh of fourteen pages (pp. 1 to 14).

various quarters of the globe, of auroral manifestations, disturbed magnetometers, and earth-currents in telegraph wires, of which latter more than one case is mentioned in which the ordinary telegrams were transmitted by aid of the electricity thus presented to the wires.

In his 'Archives des Sciences Physiques,' are two articles by Professor A. De la Rive on this same disturbance (tom. vi. Nouvelle période, pp. 49 to 59, and 275 to 288, being in the Numbers 21 and 23, issued respectively on September 20 and November 20, 1859). M. De la Rive has availed himself of the phenomena recorded on these days in further illustration of his electrical theory of the Aurora, which will be found in detail in the third volume of his 'Treatise on Electricity,' p. 283, English Translation.

In looking over the records collected by Professor Loomis, and those which had been supplied to M. De la Rive, it was plain that we, who have the direction of systems of electric telegraph, had, to a certain extent, failed in our duty. For myself, I had, it is true, received week by week certain returns from a few places in the district under my charge; but they had neither been discussed nor published; so that when M. De la Rive stated in reference to certain Paris observations, "Malheureusement le sens des courants transmis par les fils télégraphiques n'a pas pu être indiqué exactement" (*op. cit.* p. 57), I took the matter up more actively, the more so as he was under a misapprehension (to which I shall refer presently) for lack of information.

The net of telegraph wires upon which my observations have been made, occupies the south-eastern portion of England. The wires are spread over the counties of Kent, Surrey, Sussex, and Berkshire. In a general way, the district may be regarded as bounded on the N. by the river Thames, and on the E. and S. by the British Channel, the other southern counties of England being on the western side. A map of this portion of England is given (Plate II.). The district includes a large number of telegraph stations and other groups of telegraphs, in addition to those which are set out on the map. I have selected various telegraph terminal stations, and taken them in pairs, not giving, as they are not necessary to our purpose, any of the intermediate stations; and have regarded the two stations of each pair as connected by a direct line. It will be evident at a glance that I am in possession of lines in various azimuths. There are eighteen selected lines in all, and each is in a different azimuth. A few more could have been found; but as they occupy only intermediate places, and connect stations where observations cannot conveniently be made, they are rejected. It will be seen that the railway routes between any two stations (and they are also the routes of the telegraph wires) are often devious, while the lines which are to form the basis of this inquiry are direct. In approaching the subject, I take it that a current or drift or flood of electricity is passing at a given time and in a given direction through the mass of the earth. Our telegraph wires penetrate the earth at their respective terminations, probing or sounding, as it were, into this then pervading stream of electricity. They penetrate by the aid of the gas-pipes and water-pipes in towns, by pumps and wells in country places, occasionally by a plate of copper sunk deep in the wet soil, and very frequently by the metals themselves of the railway, the latter method having been more available since the custom of *fishing* or connecting the consecutive rails together with a plate of iron has prevailed. The electricity collected from the earth by these probes or earth-plates appears in our wires as a *derived current*. It enters a wire at the station nearest to the point of the horizon *from* which the current is flowing, and leaves it at the station nearest to the point of the horizon *toward* which it is flowing. In Table XI. the direct distances between the respective terminal stations are given in the fourth column, and the telegraph distances in the fifth. A few cases occur in which the difference is considerable, which is when the railway route is circuitous. I may state here that the reason why the Margate—Ashford telegraph route is nearly double that of the direct route, is because the wires make a loop to Deal, and thence *viâ* Ramsgate to Margate. The effect of this extra length of wire being between the respective earth-plates is, of course, from the increase of resistance, to diminish the value of the derived current. The Margate—Ashford is, as we shall see hereafter, our most active circuit; it would show values still higher were the connecting wire in a direct line.

I regretted to find that the returns which reached me of the telegraph disturbances of August—September 1859 were unusually meagre. The fact appears to have been that the disturbance was of such magnitude and of so long continuance, and this at the busy season when the telegraph is more than usually required, that our clerks were at their wit's end to clear off the telegrams (which accumulated in their hands) by other less affected but less direct routes. At a time when observations would have been very highly acceptable, they were too much occupied with their ordinary duties to make notes of the deflection of the needles and the changes. And I may here advert to the circumstances with which we are surrounded, and the conditions under which our observations are made. The wires and telegraph instruments are erected for commercial purposes; they are, as a rule, very fully occupied. The clerks or employés in charge of the instruments have their various duties to discharge, and have not much time at their command. I am on this account the more indebted to them for the interest they have evinced in these observations, and the unusual diligence with which some of them have made notes of what they have seen. And I may especially refer to J. Dyke at Ashford, D. Malpas at Ramsgate and T. Pulley at Ramsgate, and then at Canterbury. They have proved themselves able volunteers in the cause of science.

The Astronomer Royal, in his "Report to the Board of Visitors," on June 2, 1860, says "it is extremely difficult to extract from the accounts, even the careful ones, of telegraph clerks, such an idea of the phases of the currents as will make them comparable with the phases of magnetic storms." I can well enter into Mr. Airy's views; and if I plead guilty to having not furnished him with observations made on my district, to compare with the other observations that have reached him, it is because I have not heretofore had the opportunity of fairly discussing the crude facts that have accumulated in my hands. He further adds that "it may be worth considering whether it would ever be desirable to establish in two directions at right angles to each other (for instance, along the Brighton Railway, and along the North Kent Railway) wires which would photographically register in the Royal Observatory the currents that pass in these directions, exhibiting their indications by photographic curves in close juxtaposition with the registers of the magnetic elements*." I think it would be very desirable, because it is not practicable on wires erected for other purposes, and with observers whose duties with these wires are of an urgent nature, to secure an undisturbed series of consecutive observations,—and the more so as the abnormal state comes on without forewarning. Nor would it be necessary for this purpose to incur the cost of erecting a long line of wire; for it will be seen, as we proceed, that one of the most active circuits with which we have to deal is only three miles long. I have also two stations at Ashford which are only 972 yards apart, between which derived currents of small value have more than once passed, although the galvanometers by which they were indicated are not of the most sensitive character. This was the case, 1859, November 30, 4.48 to 5.6 P.M., and 1860, August 11, 10.6 to 10.8 P.M. The most favourable direction for wires, or the best bearing for earth-plates, may be gathered from the results to which the following observations will lead.

To return to August—September 1859. The Dover clerk writes on September 2, "This morning, on opening the office, I found the needles of both instruments firmly blocked over to the left, and although the handles were firmly held over to the right to counteract the current, to my surprise I found that our battery power had not the slightest effect.... I am sorry to say there is not the slightest possibility of our working the instrument; needles continuing firmly fixed over, and which has continued for upwards of half an hour." The clerk at Ashford, who generally makes a good series of continuous observations, in this instance, for reasons already named, reports in very few words: "September 1. From 4 A.M. to 9 A.M. very strong on all instruments, first one side and then the other, which prevented any messages to or from; and deflections very strong through the day, which caused great delay to the work.

"September 2. Very strong from 4 A.M. to 10 A.M. and throughout the day. Great delay to messages in consequence."

Deal reports for each of the three days, September 1, 2, and 3, very briefly:—"Hard on, right and left the whole day."

The Ramsgate observations were more in detail, and are given in full in Table I. At this station are three telegraph instruments; the most sensitive is on the group which terminates at Ashford and Margate; the next in character is on the group termi-

* Since this paper was read, Mr. AIRY's Report to Visitors, 1861, June 1, has been printed. Referring to the suggestion in his previous Report, he says, "I conceive that this may be justly regarded as an important physical experiment; and I hope to be able shortly to lay before the Visitors some details of plan, and to ask their opinion in a more precise form." The proposition has come before me officially; I have reported upon it to the Astronomer Royal, and have furnished him with an estimate of the cost of erecting a wire from Greenwich to near Croydon, and another from Greenwich to near Dartford (*vide* Map, Plate II.). The proposition has met with the approval of the Visitors; and I have, to a certain small extent, made progress in anticipation.—C. V. W., July 1861.

nating at Ashford and Ramsgate; the third, on the short group from Ramsgate to Margate, is less delicate. I may mention that arrangements of this kind are general, the long circuits being furnished with the best instruments. This Table is a good specimen of the notes that are usually taken, and of the manner in which the returns are sent in. In the column headed "Direction," the observers insert the letter to which the telegraph needles point; I have substituted for this the direction in which a derived current of positive electricity would be travelling when that letter was made. By N., I mean a positive current passing from the station that is more northerly to the one that is more southerly, and by S. *vice versâ*. And in all cases, as well in this as in the Tables and diagrams that follow, the magnetic north is referred to. The value of the deflections observed on the needles are in this Table expressed in very general terms. The word "hard over" means 45°, or thereabouts; "horizontal," 80° or more, in fact as far over as it can well go. I have placed a copy of this Table in the hands of Professor ELIAS LOOMIS, as he had no continuous series like this in the collection of observations that he had published. It contains some of the details for which M. DE LA RIVE inquired. This Table may be taken as correct as far as it goes. It contains many blank spaces, the observations having necessarily been discontinued from time to time. The changes of the needles from right-hand to left-hand deflections are gradual. One of my best observers says, "I have not at any time known the needles to return suddenly from their deflected position. I have frequently observed them to pass very quickly from one side to the other in a gradual manner, as though worked round by some slow-moving machinery, but never to drop suddenly. I have also observed the needles to partially right themselves, and then to be brought back again to quite as strong, and frequently much stronger deflected position." The manner in which the change from a north to a south current is brought about is very remarkable; it is evidently no drift of a "circular magnetic storm," so to speak, nor is it any kind of axial rotation. To all appearance the north current gradually fades away, and the south as gradually rises and increases in value. When a series of lines converge from various points of the horizon, the change of deflection on one instrument is accompanied by a change on all the others; and this is the case throughout the district. And it has been observed that needles of the most active groups are a little less sluggish in these changes than are the needles of the less active groups. In the midst of storms the needles very frequently have periods of entire tranquility; so, on the other hand, in the midst of calm the needles have periods of activity, sometimes of a few minutes' duration only, and then all is again still. The following are a few cases taken at random from many such:—

1859, November 13, four slight deflections during the day.
14, two slight deflections during the day.
18, one slight deflection from 7.35 to 8 A.M.
1860, January 15, one slight deflection from 9.10 to 9.23 P.M.
30, one slight deflection.
February 27, one slight deflection.
April 21, one slight deflection.

We have repeatedly doubled the size of the conducting wire in a given group, and in all instances have by the change increased, and to all appearance doubled the deflection. This was to be expected with a derived current under like conditions. It was done by Mr. BARLOW, and with similar results, in 1847*.

The frequent occurrence of the words "hard over" and "horizontal" in Table I., convey a good general idea of the violence of the storm and of the times when the greatest activity prevailed. I refrain from discussing this Table, because arrangements were subsequently made by which observations of a more definite character were made, and which have furnished data of greater value. To the examination of these data we now proceed.

In order to form some general idea of the comparative value of the currents that present themselves, I selected a telegraph station (Ramsgate) where there was a good observer, and where deflections occur at all times of disturbance, even when the currents are too feeble to attract attention elsewhere; and I placed there in the telegraph circuit of the Ashford—Margate group a graduated galvanometer. Certain preliminary experiments were made with this galvanometer, in order to have some values of its deflections with which to make comparison. The results are given in Table II. I first took six cells of a battery of amalgamated zinc and platinized graphite, charged with 1 sulph. acid +10 water, and obtained the deflections with one or more cells when the galvanometer and battery were alone in the circuit. The mean results are given in the fourth column.

The galvanometer was then permanently connected at Ramsgate in the Margate—Ashford circuit, the telegraph length of which is $51\frac{1}{4}$ miles; and ordinary currents were sent through the circuit from cells of the common telegraph battery, the number of cells in use being varied. The results are given in the Table; three cells gave a deflection of 5°, and forty-eight a deflection of 62°; intermediate numbers intermediate amounts. It was further noted that good telegraph signals produced a deflection of 60°; middling, one of 54°; and weak, one of 40°. Having thus a tolerable standard for reference, we could observe to better purpose.

Favourable opportunities occurred very soon after these arrangements were made, and of which we were able to avail ourselves, namely, on August 8, 9, 10, 11, and 12, and on September 7, 1860. The results are contained in Tables III. to VIII. inclusive. These Tables do not contain the whole of the observations made on the respective days; there were other detached or interrupted observations before the commencement or after the completion of those tabulated. I have selected a portion of each day during which there was the least possible break of continuity in observing. For instance, on August 8, out of $6^h 44^m$, only 37^m are blank; on August 12, only 21^m out of $10^h 31^m$, and so on (see Table IX. *b*). The "time" column is accurate. All the observing stations receive time signals direct from the Royal Observatory, Greenwich, at least once a day. The "duration" column is subdivided into two parts, marked N. and S., which contain the time in minutes during which a positive current was flowing from the N. to the S.

* Philosophical Transactions for 1849, p. 63.

station, or from the S. to the N. station respectively. The "values" are given in degrees of the galvanometer already described; those under the Margate—Ashford heading are read off direct on the galvanometer; those under the Margate—Ramsgate heading are approximate values on the same galvanometer, obtained by observation on another instrument, which had previously been compared with the standard galvanometer. The majority of the observations contained in the six Tables were made at Ramsgate; in some cases, where an interruption occurred at that station, the blank has been supplied from the notes made at other stations; in such cases the approximate value has been estimated and a query (?) placed beside it. The series would be complete without the Margate—Ramsgate values; but I have collected and tabulated these for the special purpose of pointing out the very large amount of action, the great value to which a derived current will attain on so short a circuit as one of three miles only when well placed. It is very striking to read such values as 76°, 71°, 70°, 73°, 86° under such circumstances. They equal the effect of four or five cells in short circuit; they exceed the effect from a good telegraph battery of forty-eight cells in an ordinary circuit. They greatly exceed what are considered good telegraph signals; and hence we are not surprised to find that the ordinary battery current, as stated in the report from Dover already quoted, has not power enough in many instances to neutralize them. It is evident from these figures that wires of moderate length will suffice, especially when galvanometers of a more highly sensitive character than those before us are employed, for all the purposes of a magnetic observatory.

I have on each day of observation calculated the mean value of the N. and the S. currents in time and in degrees of deflection. The most complete series of observations are those made on September 7. They embrace a period of $9^h\ 28^m$, with blank periods amounting to only $40\frac{1}{2}$ minutes. It is very instructive to go through such a Table as this, and notice the frequent transitions, not merely from N. to S. currents, but from a N. current of high value to a S. current also of high value, and this in the course of a very few minutes. For instance, between $7^h\ 19\frac{1}{2}^m$ and $7^h\ 29^m$, that is to say in the course of only ten minutes, four high and alternate values are registered, 64°, 44°, 34°, and 38°. Many other like cases may be selected from the Tables before us.

These six groups of selected observations are analysed in Table IX. The total number of currents recorded on the six days are arranged according to their values in time. The number of currents on each day that had a duration of $\frac{1}{4}$, $\frac{1}{2}$, and $\frac{3}{4}$ min. are first given; then those of various lengths between one and five minutes; and finally those for each interval of five minutes, beginning with those from six to ten minutes, and terminating with those between 61 and 120 minutes, which is the limit. The results of each day are given under the respective columns in the division of the Table marked *a*; and the sum for each time-value is given in the last column. Only 19 out of 389 currents, or 1 in 20, had a duration of less than a minute. The proportion between those currents which exceeded, and those which did not exceed five minutes in duration, was as 117 : 272, or as 1 : 2·32. Of those which exceeded twenty minutes and those which fell between six minutes and twenty minutes, the proportion was 26 : 91, or

1 : 3·5. Three currents are recorded as having continued for more than one hour; sixteen as having continued more than half an hour. The 1-minute currents are most in number, namely, eighty, or nearly one-fifth of the whole; the next in number are the 2-minute currents, seventy-five. Then follow the 3-minute and the 4-minute, the ½-minute and the 5-minute.

The division *b* of the Table shows at a glance the total period of observation on each day, the total number of minutes during which N. currents were collected, and those during which S. currents were collected, and the sum of the whole. On August 8 the S. currents exceeded the N. by 49 min.; on August 9 the N. exceeded the S. by 1·5 min.; on August 10 the S. exceeded the N. by 28 min.; August 11, N. exceeded S. by 57 min.; August 12, S. exceeded N. by 24 min.; September 7, N. exceeded S. by 21·5 min. During the whole series the S. currents exceeded the N. by 21 minutes. The division *c* of Table IX. shows the mean duration of the N. and S. currents on each day, and the mean of the whole series. On some days the mean duration of the N. currents exceeded that of the S. currents; and on other days the reverse was the case. But taking the mean of all the observations and all the days, as given in the last column, the values of each are nearly the same. We have 9·51 min. as the mean for the N. currents and 9·42 for the S.

In Table X. the total number of currents are arranged according to their values in degrees; that is, according to their action on the galvanometer. In division *a* of the Table, the first column contains the galvanometric degrees, in divisions of 5° each, 1° to 5° being the first in the list, and 81° to 85° being the last. The column under each date is subdivided, the N. currents being entered under the first division, and the S. under the second. The sums of N. and of S. currents for each value are then given; and these are added to give the total of currents for each value. It will be seen, by referring back to Table II., that a deflection of 5° is equal to that produced by three cells of an ordinary telegraph battery in a circuit of 51¼ miles. One cell will give about 2°. The greatest number of currents are found with a value varying between 15° and 20°; they are 91. The next in number, 84, range between 5° and 10°; then follow 56 ranging between 10° and 15°. The proportion of currents which exceed 40° to those which do not, is as 59 : 383, or as 1 : 6·49. The similar proportion of N. currents is 32 : 193, or 1 : 6·03; of S. currents 27 : 190, or 1 : 7·03. Two N. as well as two S. currents were obtained ranging from 71° to 75°, and one N. current exceeding 80°; it was 82°. There is no very marked difference between the numbers of N. and S. for the different values on each day; sometimes the N., at other times the S. are in the ascendent. Above 45°, 26 N. currents are recorded against 22 S.

The *b* division of Table X. gives the mean value of the N. and the S. currents for each day, and the general mean of the whole. The N. on some days and the S. on other days have the higher mean value. The general mean gives 28°·01 for the N. and 26°·87 for the S. currents. Taking the mean of all the currents, the values are 9·46 minutes of time (Table IX. *c*), and 27°·44 of deflection (Table X. *b*).

The Tables we have now been discussing may be taken as good specimens of the general character of earth-currents; and of these I should be somewhat disposed to think that the observations made on September 7 are the most characteristic. Be this as it may, it comes out, from what we have recorded, that there is little difference of behaviour between the two kinds of currents. The S. currents, for instance, differ but little either in degree or in duration from the N. currents.

It is not my purpose in this communication to set forth any theory as to the origin of the currents in question; neither is it my object to discuss the auroral theories. But there is a certain feature in M. De la Rive's theory which fails in the presence of the facts before us, and which requires notice here from the confidence with which it is put forth. On the faith of a few observations made on the Berne—Zurich telegraph line between 8^h and 9^h A.M. on September 2, 1859, this philosopher arrives at the conclusion that the N. currents have a longer duration and are more powerful than the S. currents, and that the latter are merely due to the secondary polarities acquired by the earth-plates when they have transmitted a derived N. current. He calls the N. the direct current; and he says, "Nous pouvons donc conclure de là, d'abord que le courant qui à la fois est le plus fort et dure le plus longtemps, est bien le courant direct perçu par le fil télégraphique, dont une des extrémités plonge à Zurich dans le sol, et l'autre à Berne, et qu'il chemine bien du nord au midi, c'est à dire du pôle nord à l'équateur; nous sommes également conduits à regarder le courant inverse de moindre intensité et de moindre durée, comme provenant des polarités sécondaires qu'acquièrent les deux lames de cuivre plongées dans le sol, quand elles ont transmis dans un circuit fermé, pendant quelques instants, une dérivation du courant terrestre. Ces deux conclusions . . . . sont, comme on le comprend, très précieuses pour la théorie, et elles confirment pleinement celle que j'ai donnée dans ma première notice." Further on he adds, "En effet il n'y a véritablement dans le sol, lors de l'apparition de l'aurore, que des courants dirigés du nord au sud; ces courants sont seulement d'une intensité variable d'un instant à l'autre. Quant aux courants inverses plus faibles, et d'une durée moindre, qu'indiquent les appareils, ils ne sont que l'effet de la manière dont on perçoit les premiers; les plaques de cuivre qui terminent les fils télégraphiques, et qui, plongées dans le sol servent de sondes pour dériver une portion des courants terrestres dirigés du nord au sud, se polarisent bien vite, et donnent ainsi naissance à des courants inverses par l'effet des polarités sécondaires qu'elles ontacquises*."

But from the figures before us it would be hard to say that either the N. or the S. current exceeds the other, either in value or in duration. Take for instance the high values, those exceeding 60°: if we have two N. currents between 61° and 65°, we have also two S.; the same is the case between 66° and 70°, and 71° and 75°. And with respect to duration, the N. currents on some days, and the S. currents on others, have a total excess in time; and if, on the one hand, the mean duration of each S. current is 0·09 minute less than that of the N. currents, the total flow of S. currents is 21 minutes greater. Were it otherwise, it would still be impossible to admit a polarization of elec-

* Arch. des Sc. Phys., Nouvelle période, tom. vi. pp. 281, 282, 286. 1859, Nov. 20.

trodes that would continue active, and highly active too, not for minutes merely, but often for quarter and half hours. We have no approach to such polarization in the ordinary use of the telegraph. Besides, it could with equal propriety be attributed to the S. currents as to the N.; for all our experience thus far leads to the conclusion that no one thing can be said of the one class of current that cannot with equal truth and equal force be said of the other.

Had results such as those before us been made more public heretofore, the learned Professor of Geneva could not but have modified his views; for with the proved existence of so large a quantity of S. current, he could scarcely have presented the auroral theory in its present form, because the N. currents entering at the polar regions and flowing southward is the essential feature of his theory.

While investigating the value and duration of earth-currents, our attention has heretofore been almost confined to a solitary telegraph group, namely, to the Margate—Ashford line; and the currents of positive electricity found moving from Margate, the more northerly station, to Ashford, have in a general way been termed N. currents, and *vice versâ*. It is obvious, however, that the electric flood, in its course through the mass of the earth, might vary greatly in azimuth and still give the same apparent result. Fig. 2, Plate III. will explain this. If the line marked 13 represents the bearing of the Margate—Ashford group in respect to the magnetic meridian N.S., Margate being at the circumference of the circle, an earth-current from any azimuth, not exceeding 90° to the north or south, right or left of the line 13, would enter the telegraph wire at Margate and leave it at Ashford. The shaded portion of the circle shows this limit in either direction. The azimuth of the line in question is 72° E. of N.; so that the limit in one direction is 18° W. of N., and in the other 18° E. of S.; and therefore what we have in general terms called a N. current, might be the result of an actual S.S.E. current, just as it might equally be of a N.N.W. current. The real direction of the currents in the earth cannot be determined from observations made on a single telegraph group; neither can it be determined by simultaneous observations made on different telegraph groups, unless there be some among the groups that have widely different azimuths.

The Map (Plate II.) that accompanies this communication shows the district of England over which these observations extend. I have omitted all intermediate stations, and have inserted, with here and there an exception, only the name of the telegraph stations that are concerned in this investigation. The magnetic meridian makes an angle of $21\frac{1}{4}$° W. with a vertical passing through the Map. It is necessary to bear this in mind when referring from Tables XI. and XII. to the Map. The fine lines drawn on the Map represent the railway routes, and at the same time the routes along which the telegraph wires are led. Direct lines drawn from station to station are used with the magnetic meridian in obtaining the bearings given in Table XI., and the values shown in the first column of distances in the same Table.

I have selected eighteen pairs of telegraph terminal stations, each one differing from the other in azimuth, and have referred them to the magnetic in preference to the astronomical meridian, in order the more readily hereafter to compare the determined direction of earth-currents with the behaviour of the declination-needle during their existence. The mean westerly magnetic declinations at Greenwich have been—

	°	′	″
For 1857	21	34	30
For 1858	21	29	30
For 1859	21	23	30

I have therefore taken $21\frac{1}{4}°$ as an approximate value for 1860 sufficiently near for the present purpose*. Whitstable and Canterbury are as nearly as may be on this meridian, the former being to the north of the latter. Table XI. contains these eighteen groups arranged in order, and in three divisions: 1st, those on the magnetic meridian; 2nd, those bearing East of it; 3rd, those bearing West of it. The numbers in the left-hand column apply to the stations in order; and in using them for reference, 1—2, or more briefly 1, means *from* Red Hill *to* Brighton; 2—1, or more briefly 2, means *from* Brighton *to* Red Hill; and so of the rest. The odd numbers are all made to fall to the north of a line drawn at right angles to the magnetic meridian; and the even numbers to the south of the same line. The figures in the column headed "Bearings" are approximate, fractions of degrees being neglected. They extend from the 82nd degree West of North to the 80th degree East, embracing in all 162°, or only 18° short of the half of a great circle,—giving, therefore, a very wide field for observation. The Table also contains the distances measured in direct line from point to point, and also the distances along the route pursued by the telegraph wire which connects each two points respectively.

Fig. 1, Plate III. is a graphic representation of Table XI. The numbers 1—2, 3—4, &c. correspond with those in the Table; and the lines are laid down at the angles gathered from the Map and given in the Table.

From time to time I have secured simultaneous observations from more groups than one, frequently from several groups. It is not necessary to encumber this communication with specimens of all combinations. I have selected four, beginning at fig. 2 (already referred to, and which is the most simple but least instructive case), and concluding with fig. 5 (which is the most full and conclusive).

Fig. 2 represents the most common of all cases, a current collected by the Margate—Ashford wire No. 13. In this wire, as well as in its near neighbour No. 15, the Ramsgate—Ashford wire, a current may always be found, if detected elsewhere. The effects are similar and simultaneous on all the instruments of this circuitous telegraph group, namely, at Margate, Ramsgate, Deal, and Ashford.

Fig. 3 represents a case almost equally common. No. 13, as before, is the Margate—Ashford group, and No. 17 the Margate—Ramsgate. By setting-off 90° from each line in the direction of the other line, we define the limits within which an earth-current

* Mr. AIRY's Report, published since this paper was read, gives it 21° 14′ 20″.—C. V. W.

must flow in order to be collected in the two wires in question, and in the direction given, as follows:—

No. 13 . . .	$90^{\circ}-72^{\circ}=18^{\circ}$ W. of N.;	the northern limit.
No. 17 . . .	$90-2=88$ E. of N.;	the southern limit.
	$\overline{106}$;	the total range.

This range is shown by the shaded part of fig. 3; and is 74° less than that of fig. 2.

In times of greater activity (and these are very frequent) we have the case shown in fig. 4. Besides No. 13, which, as I have said, is always present, we have, as before, on the one hand No. 17, the Margate—Ramsgate group, and on the other No. 26, the Dover—London group. The azimuths here are far wider apart. By treating them as before, setting off 90° from either toward the other, we have

No. 26 . . .	$90^{\circ}-44^{\circ}=46^{\circ}$ E. of N.;	the northern limit.
No. 17 . . .	$90-2=88$ E. of N.;	the southern limit.
	$\overline{42}$;	the total range.

We get here within a comparatively narrow range, and begin to discover the approximate parts of the horizon whence the currents come. The shaded parts of fig. 4 show this graphically. I have not thought it necessary to give these figures in duplicate in order to show the cases in which all the currents are reversed; it will be readily gathered that, *mutatis mutandis*, the results would be shown by a shaded part in the opposite quadrant.

Table XII. contains, in sections 1 and 2, a selection of a few out of the multitude of simultaneous observations that have been made, and which give the results shown in fig. 4. The years 1857, 1859, and 1860 have contributed samples. I might extend this Table at pleasure. It will be remarked that not only have we here the direction in which the derived currents were moving in the telegraph lines No. 17 and No. 26, or their converse, Nos. 18 and 25; but we have also the evidence that currents were moving in a similar direction along many distinct lines of telegraph, the bearings of which with the magnetic meridian are intermediate between the two extremes given. For example: by comparing fig. 4 with fig. 1, it will be seen that all these other groups, taken from Table XI. and entered in Table XII., fall between the two radii marked 17 and 26; they are in order N. 5, 13, 15, 32 and 28; so that we have here a large series of observations taken over a considerable area of country, each confirming the accuracy of the other, and all conspiring to prove that the point of the horizon from which the earth-currents came in 1857, as well as in 1860, was situated somewhere between 46° and 88° E. of the magnetic north. I have in the several columns entered the values of the currents in the words of the observers. They are sufficiently characteristic.

On December 17, 1857 (which, by the by, was at the period of the earthquake that committed so much devastation in the kingdom of Naples, and of which a Report was presented to the Royal Society by Mr. R. MALLET, on May 24, 1860*), the earth-

* Proceedings of the Royal Society, vol. x. p. 486.

current must have been very strong, seeing that the action was so great in both of the extreme groups, although their bearings with each other made an angle of no less than 138°, that the galvanometer needles in each case were described as being "hard over." In the later entries, which were of observations made subsequently to the erection of the graduated galvanometer at Ramsgate, the values are entered in degrees. If a query (?) occurs, it implies that the observation was made and the direction given, but the value was not noted. When blanks occur in the Table, it means that no observation was made on the group against which the blank appears, at the time in question. In all cases where simultaneous observations have been made, the direction of currents in intermediate groups is in strict conformity with the results obtained from the two extremes. And when the direction changes, as in Table XII. section 2, for one extreme, it changes also for the other, and for all the intermediate groups that are the subject of observation. The remarks, therefore, which have been made on section 1 are, *mutatis mutandis*, equally applicable to section 2. Simultaneous observations have now and then reached me from the Minster—Deal group, No. 19. I have entered cases, but pass them over here. They take 4° from the range, reducing it to 38° in the instances given.

The case shown in fig. 5 is the most complete; it has not attracted attention so frequently as the last. The telegraph group No. 23, London—Tonbridge, is less sensitive, is more liable to interruption and not so convenient for observations, and it is more distant from the centre of action. The observations on this group have a special interest of their own. There are two lines of telegraph between Tonbridge and London; one is $40\frac{1}{2}$ miles in length, and goes *via* Red Hill; the other is $57\frac{1}{4}$ miles in length, and takes a circuitous route by Paddock Wood, Maidstone, Strood, Gravesend, and Woolwich. The currents in these two groups in all instances coincide, and have reference to the bearings London—Tonbridge, and not to the route. This is the more striking because one wire, as may be seen by the Map, comes to Tonbridge from the eastward and the other from the westward, and the currents, as far as the wires are concerned, arrive from directly opposite points of the compass, and to all outward appearance are opposed to each other.

The bearing of No. 23, the London—Tonbridge group, is 13° W. of N. By treating these bearings as before, we have

No. 26 . . .	$90^\circ-44^\circ=46^\circ$ E. of N.;	the northern limit.
No. 23 . . .	$90-13=\underline{77}$ E. of N.;	the southern limit.
	31;	the total range.

The 3rd and 4th sections of Table XII. contain cases in point, each, as in sections 1 and 2, being the converse of the other. All the observations in these sections confirm those in the other two, with the advantage of having 11° more of azimuth, and reducing the range within which the true direction is to be sought, to 31°. By referring to fig. 1, it will be seen that between Nos. 23 and 25 there is a blank space which amounts to 31°. Had we possessed telegraph lines having azimuths that might fall within the vacant space, we should no doubt have been able to present results from lines situate either beyond No. 26 on the one hand, or beyond No. 23 on the other, and have contracted still more the range, now standing at 31°.

In the absence of these observations, we are still justified in concluding that neither No. 26 on the one hand, nor No. 23 on the other, are the boundary lines, because, when we look at the eight cases before us, four have *strong* currents in both limiting lines, and one has *very strong*; and if we turn back to sections 1 and 2 of Table XII., fourteen out of the eighteen cases have strong or very strong currents in the London—Dover boundary line.

Subject to correction by future observations, I have assumed that 10° may reasonably be allowed in each direction, making 20° in all to be deducted from 31°, leaving a limit of only 11° within which to seek for the true direction. For the place of this limiting arc, we have

$$\overset{\circ}{90} - 44 + 10 = \overset{\circ}{56} \text{ E. of N.; the northern limit.}$$
$$90 - (13 + 10) = 67 \text{ E. of N.; the southern limit.}$$
$$\overline{11} \text{; the total range.}$$

Its place is shown by the more deeply shaded part of fig. 5. From finding the London—Dover line (No. 25–26) the more active, I should be disposed to infer the true direction to be nearer the Dover—London than the London—Tonbridge line; and to divide the 11° unequally. Making the proportion as 7° to 4°, we have

$$\left.\begin{array}{l}\overset{\circ}{56} + \overset{\circ}{7} = \overset{\circ}{63} \text{ E. of Mag. N.} \\ 67 - 4 = 63 \text{ E. of Mag. N.}\end{array}\right\} \text{true direction.}$$

This direction is shown by the arrow R R′ in fig. 5, Plate III. And by deducting from this the magnetic declination of $21\frac{1}{4}°$, we have $63° - 21\frac{1}{4}° = 41\frac{3}{4}°$ E. of N. as the true geographical bearing of the point whence these earth-currents flow when in one direction, and $41\frac{3}{4}°$ W. of S. when in the other direction. And there is no evidence that they exist in other azimuths. We are not in a condition to detect secular changes, if any, as there may be. They would possibly be small; and our range in respect to such probable changes is large. For three years at least their direction has not greatly varied, at least so far as the south-eastern counties of England are concerned. The greater may contain the less; but I would pause before inferring the greater from the less, and contending that what is true of the small dot of the earth which has been the subject of my observations, may be equally true of the rest of Europe, to go no further, or even of the rest of this little island.

The contents of the reports referred to above, of the disturbances of Aug.–Sept. 1859, are too concise to contain materials from which the probable direction of the earth-currents elsewhere may be determined with accuracy. But the little information they contain helps for the most part to confirm the conclusions to which we have arrived, and to indicate that the N.E. and S.W. general direction of the currents is not confined to the spot under consideration, but is more general.

M. De la Rive, quoting a letter of M. Bergon's from the 'Comptes Rendus de l'Académie des Sciences de Paris' (1859, Sept. 5), says, "Les lignes les plus influencées ont été celles de Bordeaux, Toulouse et Marseille.... La ligne de Strasbourg, si on la compare aux lignes de même longueur, paraît avoir subi les moindres atteintes" (*op. cit.* p. 53).

The following Table gives the bearing geographically of these places in respect of Paris, and the angular distance of this bearing from the line arrived at above, whose bearing, as we have seen, is determined to be about $41\frac{3}{4}°$ E. of N.

Bordeaux . .	58° S. of W. . .	$9\frac{3}{4}°$ angular bearing.
Toulouse . .	80 S. of W. . .	$31\frac{3}{4}$ angular bearing.
Marseilles . .	75 S. of E. . .	$56\frac{3}{4}$ angular bearing.
Strasbourg . .	10 S. of E. . .	$58\frac{1}{4}$ angular bearing.

The Bordeaux line, making an angle of only $9\frac{3}{4}°$ with the assumed direction of the earth-currents, would necessarily be more affected, as it was reported to have been, than the Strasbourg line, making as it does an angle of $58\frac{1}{4}°$.

M. De la Rive also states (*op. cit.* 280): "Dès 7 heures de matin (Sept. 2), M. Hipp, informé de l'impossibilité de télégraphier, se transporta au bureau de Berne,.... il constata l'existence de courants énergiques dans les fils. Ces courants étaient à peu près constants; celui de Zurich fasait dévier l'aiguille de la boussole de 45°, celui de Lucerne de 33°, celui de Lausanne par Fribourg de 38°, celui de Olten de 38°."

The angular distances, as before, of these places and Berne, in respect to the $41\frac{3}{4}°$ E. of N. line, are in order.

Olten . . .	54° N. of E. . .	$5\frac{3}{4}°$ angular bearing . .	38°
Lausanne . .	34 S. of W. . .	$14\frac{1}{4}$ angular bearing . .	38
Zurich . .	29 N. of E. . .	$19\frac{1}{4}$ angular bearing . .	45
Lucerne . .	13 N. of E. . .	$35\frac{1}{4}$ angular bearing . .	33

Zurich is here out of order in the value of its current; but it is further from Berne; the others are in due order; but in the absence of precise information as to the direction and simultaneity of the observations, accurate deductions could not be expected; and therefore too much reliance must not be placed on the results that come out. The same may be said of the following, which is the only other comparative case cited, and in which the observations were made during an interval of an hour and a half, and may not have been quite simultaneous. M. De la Rive says, "Ainsi à Bâle, ... on avait entre $4\frac{1}{2}$ et 6 heures du matin un courant sur la ligne de Paris de 75°, sur celle de Saint-Gall de 40°, sur celle de la Chaux de Fonds de 50°, sur celle de Strasbourg de 34°" (*op. cit.* p. 282). The order in which these places fall, their bearings and angular distances, are as under:—

Chaux de Fonds . .	40° S. of N. . .	8¼° angular bearing . .	50°
Strasbourg	87 N. of E. . .	38¾ angular bearing . .	34
St. Gall	7 S. of E. . .	55¼ angular bearing . .	40
Paris	24 N. of W. . .	72¼ angular bearing . .	75

Here also, in the absence of the direction of the derived currents and of other necessary data, bearing in mind also the very unequal lengths of the lines on which the observations were made, we cannot trace out why Paris is last instead of first in order. Its distance is greatest.

We must not attempt to pursue this part of the inquiry further, for lack of data, as far as the Continent is concerned; and the same may be said of the Transatlantic observations. Here and there among the latter I find a solitary line of greatest activity given, but there are no other sufficient data with which to compare it; so that no reasonable conclusions can be arrived at.

Returning to England, we have traced the azimuth of the earth-currents at the present time in the south-eastern counties to be a few degrees north of N.E.

The same general direction prevailed as far back as the year 1847, and in another district of England. A set of observations were made by Mr. Barlow at Derby, on lines of telegraph radiating in various directions from that town. The conclusion to which he arrived then was that the direction in which the currents travel "will be between S. 28° W. and S. 75° W., and apparently strongest when the earth-connexions are about N.E. and S.W." On treating this as I have done the results to which I had myself arrived, we have it thus:—

S. 28 W. or 28° E. of geog. N.; the northern limit.
S. 75 W. or 75 E. of geog. N.; the southern limit.
47; range.

And we can get the N.E. bearing by dividing the range in the proportion of 17 : 30,

$$\left.\begin{array}{l}28^\circ+17^\circ=45^\circ \text{ or N.E.}\\ 75-30=45 \text{ or N.E.}\end{array}\right\}\text{the direction given.}$$

In the S.E. direction, which is at right angles with the inferred direction, he found that "the motion of the needles becomes undefined." The bearings of the groups nearest to S.E. which fell under his observation were S. 38° E. and S. 50° E.

I have more than once called attention to the greater activity of the Margate—Ashford line; and have also pointed out the remarkable activity manifested by the short Ramsgate—Margate line. There are other lines, differing but little in bearing from these, and equally or better favoured as to length, which have never been known to approach it in activity. Take, for instance, the Tonbridge—Hastings line, which differs in bearing from the Margate—Ramsgate by only 8° (see Table XI.). Currents are not very common on this line; when, however, they are observed, they always confirm the law as to *direction*, but always fall far below the Ramsgate—Margate in value. I have had only a solitary instance to quote in all four sections of Table XII., and this was of doubtful (?) value. Yet the length in one case is only three miles, and in the other twenty-six miles, in which latter, therefore, a greater rather than a less derived current might have been expected, and the more so as its galvanometers happen to be better.

Then, again, on comparing the respective values of the currents collected by the Margate—Ashford and the Ashford—Hastings wires, we find the same apparent contradictions. The former is 9° and the latter 11° from the determined direction, the angular distance differing by only 2°; yet the currents in the latter are invariably marked as "slight" and "middling," when those in the former are "strong" and "very strong" (see Table XII.). There is no material difference in mileage.

Again, the bearing of the London—Dover line is the *same* as that of the Reading—Red Hill. Currents, some even of high value, are frequent in the former, but have been rarely noticed, and then only in very small amount in the latter.

These apparent anomalies lead to the conclusion that the amount of current travelling through the substance of the earth during a magnetic storm is not the same in all parts of a large district; and this must needs be the case. The more favourably the conducting materials may be disposed in the geological strata of a district, the greater the value of the current-drift along the same may be expected to be. Where the materials are of inferior conducting power and ill arranged, there will the current that is present have a lower value. In fact these currents travel, as might be anticipated, in the conducting mass of the earth, just as they travel in all other conductors, and adjust and distribute themselves according to the known laws of resistance.

In STURGEON'S 'Annals of Electricity,' vol. i. p. 124, is a paper by Mr. HENWOOD "On the Electric Currents observed in some Metalliferous Veins," a discovery which the author rightly attributes to Mr. FOX*. In the 'Annual Reports' of the Royal Polytechnic Society of Cornwall for 1836, 1841, and 1842, are reports "On Mineral Veins," by ROBERT WERE FOX, and "On the Electricity of Mineral Veins," by ROBERT HUNT and Professor PHILLIPS. It is more than probable that the electric currents which were found by these gentlemen to be traversing the metallic veins in the mines of Cornwall, were in many instances portions of great floods of electricity, drifting along the district in which the mines were placed, forming in fact a portion of larger disturbances attending on magnetic storms. The derived currents which were collected by their galvanometers gave the same contradictory results as to direction that come out from any of our own cases, looked at individually; but in the papers before me I have no sufficient data from which to make groups of observations, in order to arrive at probable directions, nor do I gather whether changes of direction were noted. My impression is that I have heard of the value of currents being different, collected at different times at the same places. It would have been instructive, had it been possible, to compare some of the

* Philosophical Transactions, 1830, p. 399.

original notes made with the published magnetic observations of the Royal Observatory. I should scarcely think it possible when we collected electric currents of value so high in August and September 1859, by our probes or sounds thrust slightly into the earth, that the conducting metallic veins, large in bulk though more deeply beneath the surface, took no part in the general work of conduction.

It will be seen that when the direction of the current changes in one length of telegraph wire, it changes also in all the others then under observation; so that, should observations upon earth-currents at any future time form part of the work of magnetic observatories, it will by no means be essential to have an absolute N.E. line of wire for determining general direction and changes. It may in many cases be inconvenient or impracticable to select this direction,—as with the Royal Observatory, at this moment. In order to obtain maximum results such direction will of course be preferable. The derived currents collected from the earth are higher in value in proportion as the conducting wire is larger. It will therefore be better for comparative observations of values to select some wire most commonly met with,—as, for instance, No. 8 galvanized iron for suspension, being a wire $\frac{11}{64}$ inch in diameter, or, for buried wire, No. 16 copper, a wire $\frac{1}{16}$ inch in diameter.

On the Map, Plate II., I have laid down the line of direction through Greenwich of a wire coinciding in azimuth with the resultant direction determined herein for the earth-currents. I apprehend that a wire extended in this direction from the Royal Observatory to the River Thames, a distance of a mile or thereabouts, with a sensitive galvanometer, or possibly a WEBER'S dynamometer in circuit at the observatory, would enable the Astronomer Royal to study the general direction of earth-currents in juxtaposition with the movements of the magnetometers, and to obtain photographic registry of them side by side with those already recorded of the magnetic variations. For a further extension of the system to observations upon the actual azimuth, and the periodical or secular changes in such azimuth, a second wire in a direction at right angles to the other would be essential. Longer wires would necessarily be better.

It is not my purpose to enter into the complex problem of the magnetism proper of the earth, and of its variations. I am not competent to deal with these questions. Happily for science, they are well cared for in the hands of our Treasurer, the highly talented General SABINE. But having thus far succeeded in determining that there are actual currents of electricity, large in amount, travelling in now known directions through the mass of the earth, I have been naturally led to look at the magnetometers at observatories simply as magnets, and to inquire whether their behaviour, during the prevalence of these active states of the earth, was in accordance or not with the known reactions of current electricity and magnetism. My inquiries at present are rather tentative than complete. My means of observation are less perfect than is the systematic organization of an observatory, especially when further aided as it is by the introduction of photography. It may be also that the very small masses of metal of which my needles are formed are more readily moved, that is more promptly moved than are the larger masses of the declination magnetometer, or the horizontal-force magnetometer. I may or may not get changes in direction, when the transitions are quick, that are not recorded in the observatories. On the other hand, we on our part may omit to notice many changes. The best mode of making the comparison appeared to be to select some periods of what appeared the best and most continuous series of earth-current observations, and set them out in curves side by side with the curves registered at Greenwich or at Kew. My choice was limited to the series from August 8 to August 12, and that of September 7, 1860, which have been before referred to, and given in detail in Tables III. to VIII.

Various photograms of the Greenwich observations are before me, prepared under the eye of Mr. GLAISHER, and with which I have been kindly furnished by the Astronomer Royal. General SABINE also promptly supplied me with tracings of the Kew photograms, made by Mr. BALFOUR STEWART.

Plate IV., figs. 6, 7 and 8, shows results of this comparison. I have selected for illustration such parts of the photograms and Tables as admitted of ready comparison. Fig. 6 comprises the interval between 2.55 P.M. and 6.45 P.M. of August 8, 1860, civil time. The ordinary reaction between a magnet in the position of N. S., fig. 5, Plate III., and an electric current moving in the direction of the arrow-headed resultant R R′ in the same figure, is that the north end of the magnet moves to the right if the current is passing beneath it in the direction from R to R′, to the left if in the reverse direction; that is, a northerly current *increases* the declination of the magnet; a southerly *decreases* it. The upper curve in fig. 6 shows the value in degrees of the deflections of the galvanometer needle taken from Table III. The distance between the horizontal lines is 10°; the distance between the vertical lines is five minutes of time. The northern currents N. are set off below the zero line, the southern above, in order to correspond with the curves on the photograms. The lines are left broken where observations are wanting.

The lower curve is taken from the Greenwich photogram of the variations of the declination magnet, but is expanded so as to correspond in time with the galvanometer curve. It was found more practicable to expand the Greenwich than to contract the galvanometer curve. It is expanded in the proportion of 1 : 4·5. A portion of the declination scale, extending from 21° W. to 21° 45′ W. is attached. From 3.15 to 3.57 the photogram was defective. The general correspondence between the two curves is apparent. This is particularly the case at 4; 4.30; 4.45 to 5.15; 5.15 to 5.25; 5.30; and thence in the general range to the end of the curve.

Fig. 7 contains the interval between 2 P.M. and 5.50 P.M., August 9, 1860. The curve of the declination magnet in this case is taken from a tracing of the Kew photogram. It is expanded in the proportion of 1 : 4. I had not the scale before me; the omission, however, is of no moment, for we are merely comparing general directions, not values. These curves do not correspond so fully as those of fig. 6; but in the more active portions the resemblance is sufficiently obvious.

Fig. 8 is prepared from observations made on September 7, 1860. My observations on that day were close and frequent, and a very large number were recorded. As it was not easy to trace the curve complete with a five-minute period between the verticals, I have therefore limited them to $2\frac{1}{2}$ minutes; so that the Greenwich curve is expanded in the proportion of 1 : 9. There is a considerable resemblance between the two curves in this case also. It was a little difficult to read off the Greenwich photograms on this magnified scale; the inflections I have traced out seem a little in arrear of those of the galvanometer. I am unfortunately almost without night observations, and am thus unable to make comparisons with some more manageable and conspicuous portions of the photograms. Other portions I have been constrained to pass over when the movements of the magnets have been continuous, and the photogram has been so accurate that a wide white band with jagged projections was recorded.

My morning observations on September 7 were many and good. I would fain have compared them with the Greenwich photogram; but it was unfortunately defective for those hours; and, by a strange coincidence, on turning to the Kew tracing, the photogram there was defective at the same time.

I could scarcely expect to find a rigid correspondence between the two classes of results. The causes of magnetic disturbance are evidently of a mixed character, and remain to be determined. But I think the comparisons I have made between the movement of the magnet and the direction of the current, which, if not wholly, was, as I believe, in large part concerned in causing it to move, are sufficiently encouraging. Results of a more definite character would of a surety follow from a system of well-concerted observation, made under more favourable circumstances than we can expect to enjoy.

My attention was naturally directed also to the behaviour of the horizontal-force magnet during the times when the earth is thus active with electric currents. The position of the horizontal-force magnetometer is given by W.E. in fig. 5, Plate III.,—the magnet being at right angles to the magnetic meridian, or to the declination magnet N.S., its marked or north end being to the west, or in the position W. The tendency of the horizontal-force magnetometer under the influence of earth-currents is to take the position of the dotted line A B, at right angles to the resultant line R R′. The declinometer has a tendency to the same position under similar influence; so that, if no other causes than earth-currents were in operation, the motion of the horizontal-force magnetometer would be *towards* the north when that of the declination magnet was *from* the north, and *vice versâ*. And regarding the magnets merely as magnets, and without reference to the constrained suspension of the one as compared with the more free suspension of the other, the reaction of the earth-currents on the horizontal-force magnet might be expected to be greater than upon the declinometer, because of the less angle it makes with the resultant R R′. It might therefore be expected, as far as these sources of disturbance are concerned, that an increase of horizontal force would coincide with an increase in declination. This could hardly be expected to come out in every case, on account of the other and recondite causes of disturbance that are ever present.

On referring to such of the Greenwich photograms as are before me, I have selected those portions of the curves that show extreme departures from the mean position, and where the magnets are in tolerably steady motion. The cases which are in conformity with this view are more frequent than those which are not in accordance with it. The following are some cases in which the maxima and minima, either or both, in any given day, coincide in point of time, both being large:—

		Declination.	Horizontal force.
1858. April 9.	4th to 5th hour.	Minimum very large.	Minimum very large.
1859. August 27.	h m 19 50	Minimum ° ′ 20 51	Minimum 0·086
	23 25	Maximum 21 32	Maximum 0·093
1859. August 31.	16 15	Maximum out of range.	Maximum out of range.
	19 35	Minimum 20 32	Minimum 0·077
1859. Sept. 1.	2 0	Maximum 21 43	Maximum 0·091
1859. Sept. 4.	2 15	Maximum 21 42	Maximum 0·094

On the 3rd of this September the magnets were very active; and from the third to the sixth hour there was a very bold and remarkable increasing curve for both instruments; and from about the sixth to the tenth hour an equally conspicuous decreasing curve. For the present, these examples must be accepted as general illustrations, and as suggestions to point out the direction in which the further pursuit of these inquiries may be most profitably carried on.

One or two questions have occurred to me while discussing these observations, which I had proposed to solve on the first day of disturbance that presented itself. From September 7, 1860, to January 20, 1861, the day on which I am writing, that is, for the unusually long period of five months, the earth has been almost inactive. Not a single storm-day has occurred: two or three solitary currents, small in value and brief in duration, have occasionally, though but rarely, been collected; but with these rare exceptions, it has been a period of perfect calm.

Since writing the last sentence, the returns for the week ending January 26 have reached me, from which I perceive that the earth was again showing signs of a relapse into an active state. Currents made their appearance in tolerable numbers from January 22 to January 26 inclusive, especially on January 24; on which day I notice that from 6.30 to 6.37 the Margate—Ashford needles were horizontal for a north current, and from 6.37 to 6.52 were horizontal for a south current. Other high values occurred throughout these days. On January 26 the observer at Ramsgate noticed "that the deflections, instead of moving steadily as usual, kept continually oscillating, more particularly at 1.35 P.M., when they incessantly went from right to left, making somewhat sudden movements for twelve minutes*."

* The earth has been further inactive to the date when this sheet is passing through the press, July 27, 1861.

I have made no reference in this communication to feeble currents, which are possibly at all times to be collected from the earth, and in which a periodicity has been traced, but have strictly confined myself to the larger disturbances, the concomitants of "Magnetic Storms." Nor have I made any attempt to trace the origin of these earth-currents, or to offer any theoretical views thereon. I find current-electricity in the earth in a very marked degree at certain times; I simply take it as I find it, and endeavour to arrange the facts in some degree of order, so as to throw a little more light than we have heretofore possessed upon these interesting phenomena. I have touched very lightly upon terrestrial magnetism, and have given no suggestion as to the probable causes of disturbance, save in the one case that necessarily arises out of the present inquiry. Other influences than those exerted by electric currents upon magnets may or may not be in play; but one thing is very certain, that at least a large portion of the motion presented by the magnetometers on storm-days is connected with the then prevalence of earth-currents; and doubtless some portion of all the more regular and less violent disturbances may be more or less due to the same causes. At any rate, although we are considerably in the dark as to the forms of force in operation to make up the *whole* of the causes concerned in magnetic disturbance, we are yet quite certain that the current-form of force is at least in *part* concerned. But we can collect this force, and measure it, and deal with it independently. We can receive the results and record them photographically, as foreshadowed by the Astronomer Royal, side by side with those presented by the magnetometers. And doubtless should such combined results come at any future day under discussion, and the more so should they pass into the hands of General SABINE, he would devise a method of eliminating the values due to these known causes, that is, due to earth-currents absolutely collected, and would by so doing render the values thus corrected more manageable, and might get one step nearer towards penetrating into the more recondite causes of the earth's magnetism and its variations. This will not be accomplished until Mr. AIRY's suggestion is brought to bear, and the duties of a magnetic observatory shall be extended to the observation of earth-currents. I hope, ere long, that some attempts of this kind may be made. Preliminary observations are necessary before endeavours are made to organize a system that shall admit of general application. An electrical survey of the mass of the earth promises to be rich in results akin to those presented by the magnetic survey. They are evidently twin phenomena. The magnetic survey requires three instruments and their adjuncts, and a considerable amount of delicate manipulation. An electrical survey would require, as far as one can yet see, a single instrument only, after the resultant line for the place had been determined, and no larger amount, if so large, of manipulative skill.

TABLE I.—Magnetic Storm: 1859, August 29 to September 2.
Action of Earth-Currents upon the Telegraph Instruments at Ramsgate.

Date.	Time.	Telegraph line.	Direction.	Value.
August 29	7.10 to 7.25 A.M.	Ashford and Margate.	S.	Strong.
	7.36 7.45	Ashford and Margate.	S.	Hard over.
	7.46 7.49	Ashford and Ramsgate.	N.	Strong.
	7.50 8.0	Ashford and Margate.	S.	Hard over.
	9.45 10.0	”	N.	Hard over.
	10.20 10.27	”	N.	Strong.
	10.27 10.28	”	S.	Hard over.
	10.28 10.36	Ashford and Margate.	N.	Strong.
	10.37 10.40	Ashford and Ramsgate.	S.	Hard over.
	10.40 10.45	Ashford and Margate.	N.	”
	10.45 10.49	”	S.	”
	10.50 10.53	”	N.	Hard over.
	10.53 11.0	”	S.	Horizontal.
	11.2 11.25	”	N.	Horizontal.
	11.26 11.40 A.M.	”	N.	Hard over.
	11.45 12.20 P.M.	”	N.	Hard over.
	12.30 P.M. 12.45	”	N.	Strong.
	12.48 1.3	”	N.	”
	1.5 1.40	”	S.	Strong.
	2.40 2.53	”	N.	Very strong.
	3.40 3.50	”	N.	Very strong.
	3.52 4.5	Ashford and Margate.	S.	Horizontal.
	3.52 4.5	Ashford and Ramsgate.	S.	Very strong
	4.15 4.50	Ashford and Margate.	N.	”
	5.0 5.20	Ashford and Margate.	N.	”
	5.0 5.20	Ashford and Ramsgate.	N.	”
	5.25 5.48	Ashford and Margate.	N.	”
	6.10 6.23	”	S.	”
	6.50 7.20	”	S.	Very strong.
August 29	7.53 8.10	”	S.	Slight.
September 1	11.20 A.M. 11.26 A.M.	”	S.	Strong.
September 1	11.28 11.35	”	N.	Slight.
September 2	7.10 A.M. 7.42 A.M.	Ashford and Margate.	N.	Horizontal.
	7.10 7.50	Ramsgate and Margate.	N.	”
	7.10 7.42	Ashford and Ramsgate.	N.	Horizontal.
	7.43 7.48	Ashford and Margate.	S.	Strong.
	7.43 7.48	Ashford and Ramsgate.	S.	Strong.
	7.49 7.51	Ashford and Margate.	N.	Hard over.
	7.49 7.51	Ashford and Ramsgate.	N.	”
	7.51 7.56	Ashford and Ramsgate.	S.	”
	7.51 7.56	Ashford and Margate.	S.	”
	7.56 8.0	Ashford and Margate.	N.	”
	7.56 8.0	Ashford and Ramsgate.	N.	”
	7.56 8.0	Ramsgate and Margate.	N.	Hard over.
	8.0 8.7	Ashford and Margate.	S.	Strong.
	8.0 8.7	Ashford and Ramsgate.	S.	”
	8.0 8.7	Margate and Ramsgate.	S.	”
	8.8 8.12	Ashford and Margate.	S.	”
	8.8 8.12	Ashford and Ramsgate.	S.	”
	8.8 8.17	Ramsgate and Margate.	S.	Strong.
	8.12 8.17	Ashford and Ramsgate.	S.	Hard over.
	8.12 8.17	Ashford and Margate.	S.	”
	8.20 8.30	Ashford and Ramsgate.	N.	”
	8.20 8.30	Ashford and Margate.	N.	”
	8.31 8.46	Ashford and Margate.	S.	”
	8.31 8.40	Ashford and Ramsgate.	S.	”
	8.41 8.46	Ashford and Ramsgate.	N.	”
	8.41 8.46	Ashford and Margate.	N.	”
	8.47 8.54	Ashford and Margate.	S.	”
	8.47 8.54	Ashford and Ramsgate.	S.	Hard over.
	8.54 9.0	Ashford and Ramsgate.	N.	Strong.
September 2	8.54 to 9.0 A.M.	Ashford and Margate.	N.	Strong.

TABLE I. (continued).

Date.	Time.	Telegraph line.	Direction.	Value.
September 2	9.22 to 9.25 A.M.	Ashford and Margate.	N.	Strong.
	9.26 9.28	„	S.	„
	9.29 9.40	„	N.	„
	9.40 9.52	„	S.	„
	9.55 10.32	Ashford and Margate.	N.	„
	9.55 10.32	Ashford and Ramsgate.	N.	„
	10.35 10.38	Ashford and Margate.	S.	„
	10.38 10.40	„	N.	„
	10.41 10.46	„	S.	„
	10.55 11.0	„	S.	„
	11.2 11.15	Ashford and Margate.	N.	„
	11.2 11.15	Ashford and Ramsgate.	N.	„
	11.16 11.27	Ashford and Margate.	S.	„
	11.20 11.32	Ashford and Ramsgate.	S.	„
	11.38 11.40	Ashford and Margate.	N.	„
	11.40 11.45	„	S.	„
	11.45 11.49	Ashford and Margate.	N.	„
	11.45 11.49	Ashford and Ramsgate.	N.	„
	11.45 11.50	Margate and Ramsgate.	N.	„
	11.50 11.51	Margate and Ashford.	S.	„
	11.50 11.51	Ramsgate and Ashford.	S.	„
	11.50 11.51	Ramsgate and Margate.	S.	„
	11.52 11.54	Ramsgate and Ashford.	N.	„
	11.52 11.54	Ramsgate and Margate.	N.	„
	11.52 to 11.54 A.M.	Ramsgate and Ashford.	N.	„
	11.59 to 12.3 P.M.	Ramsgate and Ashford.	N.	„
	11.59 12.3	Ashford and Margate.	N.	„
	11.59 12.3	Ramsgate and Margate.	N.	Strong.
	12.4 12.14	Ashford and Margate.	S.	Horizontal.
	12.4 12.14	Ashford and Ramsgate.	S.	Strong.
	12.15 12.30	Ashford and Margate.	N.	Horizontal.
	12.15 12.30	Ashford and Ramsgate.	N.	Strong.
	12.30 12.35	Ashford and Margate.	N.	„
	12.30 12.35	Ashford and Ramsgate.	N.	„
	12.30 12.35	Margate and Ramsgate.	N.	„
	12.36 12.57	Margate and Ashford.	N.	„
	12.36 12.57	Margate and Ramsgate.	N.	„
	12.36 12.57	Ashford and Ramsgate.	N.	„
	12.57 1.18	Ashford and Margate.	S.	„
	12.57 1.18	Ashford and Ramsgate.	S.	„
	12.57 1.18	Margate and Ramsgate.	S.	„
	1.20 1.44	Ashford and Margate.	N.	„
	1.20 1.44	Ashford and Ramsgate.	N.	„
	1.20 1.44	Margate and Ramsgate.	N.	„
	1.44 1.47	Ashford and Ramsgate.	S.	„
	1.44 1.47	Ashford and Margate.	S.	„
	1.47 1.54	Ashford and Margate.	N.	„
	1.47 1.54	Ashford and Ramsgate.	N.	„
	2.0 2.15	Ashford and Margate.	N.	„
	2.0 2.15	Ashford and Ramsgate.	N.	„
	2.15 2.18	Ashford and Margate.	S.	„
	2.15 2.18	Ashford and Ramsgate.	S.	Strong.
	2.21 2.31	Ashford and Margate.	S.	Horizontal.
	2.21 2.37	Ashford and Ramsgate.	S.	Horizontal.
	2.38 2.52	Margate and Ramsgate.	N.	Strong.
	2.38 2.52	Ashford and Ramsgate.	N.	„
	2.38 2.52	Ashford and Margate.	N.	„
	2.52 2.55	Ramsgate and Margate.	S.	„
	2.52 2.55	Ramsgate and Ashford.	S.	„
	2.52 2.55	Margate and Ashford.	S.	„
	2.55 3.2	Margate and Ramsgate.	N.	„
	2.55 3.2	Ashford and Ramsgate.	N.	„
September 2	2.55 to 3.2 P.M.	Ashford and Margate.	N.	Strong.

Table II.—Galvanometer Tests.

1. In short circuit.

Battery: Zinc and Platinized Graphite, 4 in. × 2 in.

	Right.	Left.	Mean.
	°	°	°
1 cell	37	37	37
2 cells	56	58	57
3 cells	64	68	66
4 cells	68	73	$70\frac{1}{2}$
5 cells	71	77	74
6 cells	73	79	76

2. In Margate—Ashford Telegraph Circuit, $51\frac{1}{4}$ miles.

Battery: Zinc and Copper in sand, 3 in. × 3 in.

	°
3 cells	5
6 cells	13
12 cells	26
18 cells	32
24 cells	44
30 cells	48
36 cells	54
42 cells	59
48 cells	62

Good telegraph signals produce	60
Middling " "	54
Weak " "	40

TABLE III.—Direction, Duration, Changes and Values of Earth-Currents.

Date.	Time.	General direction from N. or S.					
		Duration.		Values.			
				Margate			
				To Ashford (27½ miles).		To Ramsgate (3 miles).	
		N.	S.	N.	S.	N.	S.
	h m h m	min.	min.	°	°	°	°
August 8, 1860.	2.55 to 3.5 P.M.	......	10	......	10	......	8
	3.5 3.20 }	......	......	20	......	18	
	3.20 3.23 }	18	......	70	......	76	
	3.23 3.24	......	1	......	20	......	12
	3.24 3.25 }	......	......	23	......	18	
	3.25 3.27 }	3	......	40	......	25	
	3.27 3.28	......	1	......	28	......	29
	3.28 3.53	25	......	82	......	71	
	3.53 3.54	......	1	......	23	......	15
	3.54 3.55	1	......	45	......	27	
	3.55 3.56	......	1	......	64	......	34
	3.56 3.58	2	......	48	......	31	
	3.58 4.11	......	13	......	62	......	55
	4.11 4.23	11	......	74	......	70	
	4.24 4.30	......	6	......	20	......	10
	4.30 4.31	1	......	10	......	7	
	4.31 4.34	......	3	......	26	......	27
	4.34 4.36	2	......	12	......	10	
	4.38 5.13 }	......	......	......	60	......	63
	5.13 5.17 }	......	39	......	40	......	24
	5.17 5.19	2	......	29	......	23	
	5.19 5.20	......	1	......	40	......	24
	5.20 5.23	3	......	40	......	24	
	5.23 5.24	......	1	......	12	......	9
	5.24 5.25	1	......	13	......	8	
	5.25 5.29 }	......	......	......	60	......	73
	5.29 5.44 }	......	19	......	73	......	86
	5.44 5.48	4	......	40	......	34	
	5.49 5.53	......	4	......	23	......	10
	5·53 5.59 }	......	......	35	......	21	
	6·0 6.12 }	18	......	38	......	25	
	6.12 6.13	......	1	......	20		
	6.13 6.14	1	......	25	......	12	
	6.14 6.16	......	2	......	16	......	6
	6.16 6.17	1	......	18	......	10	
	6.17 6.18 }	......	......	......	10	......	6
	6.19 6.21 }	......	4	......	35	......	14
	6.21 6.25	4	......	42	......	32	
	6.25 6.26 }	......	......	......	48	......	35
	6.27 6.40 }	......	15	......	60	......	43
	6.45 6.49	4	......	10	......	9	
	7.15 7.25	......	10	......	40	......	18
	7.25 7.33	8	......	20	......	15	
	7.33 7.40	......	7	......	39	......	27
	7.40 7.55	15	......	20	......	23	
	7.55 8.10	......	15	......	40	......	43
	8.10 8.20	10	......	50	......	40	
	8.20 8.28	......	8	......	38	......	27
	8.28 8.45	17	......	20	......	12	
	8.45 8.55	......	10	......	10	......	7
	8.55 9.3	8	......	20	......	12	
August 8, 1860.	9.3 to 9.39 P.M.	......	36	......	39	......	27
	Sum................	159	208				
	Means	7·22	9·04	33·76	35·40		

TABLE IV.—Direction, Duration, Changes and Values of Earth-Currents.

Date.	Time.		General direction from N. or S.					
			Duration.		Values.			
					Margate To Ashford (27½ miles).		Margate To Ramsgate (3 miles).	
			N.	S.	N.	S.	N.	S.
	h m	h m	min.	min.	°	°	°	°
August 9, 1860.	10.4	to 10.10 A.M.	6	......	3			
	10.15	10.17	......	2	......	20		
	10.17	10.20	3	......	14	......	7	
	10.37	10.47	......	10	......	23	......	12
	10.47	10.49	2	......	10	......	9	
	10.49	10.50	......	......	15			
	10.50	10.54	......	......	50			
	10.55	10.56	......	7	......	20	......	12
	10.56	10.58	2	......	12			
	10.58	10.59	......	1	......	16		
	11.0	11.0½	5	......	13	......	7	
	11.½	11.1½	......	1	......	40	......	19
	11.2	11.2¼	0·25	......	20			
	11.2¼	11.4	......	1·75	......	54	......	43
	11.4	11.5	1	......	30	......	6	
	11.5	11.7	......	2	......	50	......	52
	11.7	11.8	1	......	10	......	7	
	11.8	11.10	......	2	......	20	......	15
	11.10	11.11	1	......	20	......	23	
	11.11	11.13	......	2	......	30	......	25
	11.13	11.20	......	......	26	......	19	
	11.20	11.21	8	......	10			
	11.21	11.21½	......	0·5	......	10	......	8
	11.22	11.26	4	......	40	......	24	
	11.26	11.27	......	......	......	12	......	9
	11.28	11.35	......	9	......	20	......	18
	11.35	11.36	1	......	10	......	8	
	11.36	11.37	......	1	......	3		
	11.37	11.37½	0·5	......	10			
	11.38	11.38¼	......	0·25	......	4		
	11.38¼	11.40	1·75	......	30	......	25	
	11.41	11.43	......	2	......	12		
	11.43	11.46	3	......	18	......	8	
	11.46	11.48	......	2	......	10		
	11.48	11.50	2	......	14			
	11.50	11.55 A.M.	......	5	......	20	......	18
	12.0	12.3 P.M.	3	......	40	......	40	
	12.3	12.5	......	2	......	50	......	31
	12.5	12.10	......	......	10	......	7	
	12.10	12.12	7	......	14	......	9	
	12.12	12.15	......	3	......	20		
	12.15	12.16	1	......	10			
	12.16	12.18	......	2	......	20		
	12.18	12.19	1	......	10			
	12.19	12.21	......	2	......	34	......	31
	12.21	12.22	1	......	12	......	7	
	12.22	12.24	......	2	......	20	......	9
	12.24	12.27	3	......	14	......	18	
	12.27	12.28	......	1	......	4	......	4
	12.28	12.30	2	......	10	......	10	
	12.30	12.32	......	2	......	22	......	12
	12.33	12.35	2	......	10	......	11	
	12.39	12.41	......	2	......	20	......	9
	12.42	12.44	2	......	10	......	9	
August 9, 1860.	12.44	to 12.48 P.M	......	4	......	6	......	6

TABLE IV. (continued.)

Date.	Time.	General direction from N. or S.					
		Duration.		Values.			
				Margate To Ashford (27½ miles).		Margate To Ramsgate (3 miles).	
		N.	S.	N.	S.	N.	S.
	h m h m	min.	min.	°	°	°	°
August 9, 1860.	12.48 to 12.50 P.M.	2	......	7	......	8	
	12.50 1.10	......	20	......	14	......	9
	1.10 1.31	......	......	36	......	15	
	1.32 2.0	50	......	36	......	18	
	2.0 2.5	......	5	......	10		
	2.7 2.10	......	3	......	18		
	2.10 2.11	1	......	20	......	10	
	2.11 2.12	......	1	......	22	......	10
	2.12 2.14	2	......	......	......	12	
	2.16 2.19	......	......	30	......	18	
	2.19 2.23	......	......	40	......	31	
	2.23 2.29	13	......	30	......	24	
	2.29 2.29½	......	0·5	......	16	......	7
	2.29½ 2.34	......	......	48	......	35	
	2.34½ 2.50	......	......	54	......	38	
	2.50½ 3.2	32·5	......	38	......	9	
	3.3 3.6	......	3	......	25	......	12
	3.8 3.20	12	......	50	......	27	
	3.21 3.24	......	......	......	12	......	6
	3.25 3.33	......	12	......	36	......	15
	3.36 3.55	......	19	......	44	......	12
	3.57 3.59	2	......	12	......	6	
	4.0 4.2	2	......	30	......	15	
	4.13 4.15	2	......	13	......	6	
	4.16 4.18	......	2	......	20	......	8
	4.19 4.23	4	......	20	......	10	
	4.25 4.31	6	......	60	......	34	
	4.32 4.38	......	6	......	28	......	12
	4.39 4.40	1	......	10	......	6	
	4.41 4.43	......	2	......	20	......	10
	4.44 4.46	......	2	......	10	......	6
	4.46 4.47	1	......	8			
	4.49 4.53	......	4	......	20	......	13
	4.55 4.57	......	......	30	......	15	
	4.57 5.7	12	......	40	......	18	
	5.8 5.12	4	......	42	......	24	
	5.13 5.15	2	......	38			
	5.16 5.25	9	......	16	......	10	
	5.25 5.43	......	18	......	24	......	10
	5.45 5.49	......	4	......	18	......	6
	6.0 6.1	......	1	......	10	......	6
	6.3 6.8	......	......	42	......	24	
	6.8½ 6.26	23	......	60	......	38	
	6.26 6.28	......	2	......	14	......	8
	6.30 6.32	......	2	......	12	......	8
	6.36 6.46	......	10	......	26	......	12
	6.50 7.2	......	12	......	40	......	21
	7.4 7.7	......	3	......	30	......	15
	7.8 7.27	......	19	......	28	......	12
	7.28 7.42	14	......	40	......	24	
	7.45 8.10	......	25	......	45	......	32
August 9, 1860.	8.12 to 8.20 P.M.	......	8	......	18	......	15
	Sum	253½	252				
	Means	5·63	5·14	24·45	21·96		

TABLE V.—Direction, Duration, Changes and Values of Earth-Currents.

Date.	Time.		General direction from N. or S.					
			Duration.		Values. Margate			
					To Ashford ($27\frac{1}{2}$ miles).		To Ramsgate (3 miles).	
			N.	S.	N.	S.	N.	S.
	h m	h m	min.	min.	°	°	°	°
August 10, 1860.	12.13 to	12.17 P.M.	......	4	......	19		
	12.21	12.25	......	4	......	24		
	12.40	12.42	2	......	30	......	15	
	12.43	12.50	......	7	......	10	......	6
	1.1	1.3	......	2	......	20	......	15
	1.4	1.5	1	......	10	......	6	
	1.6	1.9	3	......	22	......	12	
	1.9	1.20	......	11	......	34	......	12
	1.20	1.24	4	......	38	......	21	
	1.24	1.32	......	8	......	36	......	12
	1.33	1.38	5	......	20	......	10	
	1.38	1.42	......	4	......	10	......	6
	1.43	1.49	6	......	12	......	6	
	2.2	2.11	......	......	8	......	8	
	2.12	2.49	47	......	12	......	6	
	2.57	3.10	......	13	......	12	......	6
	3.27	3.33	......	6	......	10		
	3.34	3.45	......	11	......	18		
	4.8	4.12	4	......	40	......	24	
	4.16	4.21	......	5	......	20	......	10
	4.30	4.32	......	2	......	17	......	4
	4.40	4.43	3	......	50	......	38	
	4.45	4.47	2	......	58	......	32	
	4.55	4.57	2	......	50	......	35	
	4.59	5.15	16	......	70	......	53	
August 10, 1860.	5.18 to	6.14 P.M.	......	56	......	60	......	38
	Sum..................		95	133				
	Means		7·91	9·46	32·30	22·30		

Table VI.—Direction, Duration, Changes and Values of Earth-Currents.

Date.	Time.		General direction from N. or S.					
			Duration.		Values.			
					Margate.			
					To Ashford (27½ miles).		To Ramsgate (3 miles).	
			N.	S.	N.	S.	N.	S.
	h m	h m	min.	min.	°	°	°	°
August 11, 1860.	7.50 to	8.0 A.M.	......	10	......	40	......	32
	8.0	8.2	2	......	24	......	12	
	8.4	8.7	......	3	......	26	......	10
	8.7	8.20	13	......	20	......	8	
	8.26	8.33	......	7	......	18		
	8.39	8.47	......	8	......	10		
	8.47	8.48	1	......	30 (?)			
	8.48	8.49	......	1	......	40 (?)		
	8.49	8.50	1	......	30 (?)			
	8.50	8.55	......	1	......	10		
	8.55	8.55½	0·5	......	3			
	8.55½	9.5	......	9·5	......	54	......	35
	9.15	9.20	......	......	20	......	15	
	9.20	9.22	7	......	10			
	9.23	9.30	......	7	......	15	......	6
	9.30	9.40	10	......	10 (?)			
	9.40	10.12	......	32	......	20		
	10.12	10.14	2	......	20	......	6	
	10.14	10.24	......	......	......	18	......	15
	10.24	10.30	......	16	......	30	......	10
	10.36	10.50	......	......	18 (?)			
	10.50	10.54	......	......	38	......	32	
	10.54	11.0	24	......	18 (?)			
	11.0	11.10	......	10	......	34		
	11.10	11.13	3	......	12			
	11.14	11.36	......	......	20	......	8	
	11.36	11.38	......	......	30	......	10	
	11.38	11.43	29	......	20	......	15	
	11.43	11.45	......	2	......	20	......	15
	11.45	11.55 A.M.	10	......	18 (?)			
	11.55	12.18 P.M.	......	23	......	20	......	15
	2.31	2.34	......	3	......	18	......	15
	2.36	2.40	......	......	15	......	10	
	2.40	2.55	19	......	30 (?)			
	2.57	2.59	2	......	30 (?)			
	2.59	3.5	......	......	......	60	......	15
	3.5	3.17	......	18	......	16	......	8
	3.17	3.19	2	......	46	......	27	
	3.27	4.10	43	......	16	......	10	
	4.23	4.28	5	......	22	......	12	
	4.32	4.50	18	... .	36	......	15	
	4.50	4.51	......	1	......	30 (?)		
	4.51	5.26	35	......	36	......	29	
August 11, 1860.	5.27	5.45 P.M.	......	18	......	10 (?)		
	Sum..............		226½	169½				
	Means		11·92	9·97	22·88	25·73		

TABLE VII.—Direction, Duration, Changes and Values of Earth-Currents.

Date.	Time.		General direction from N. or S.					
			Duration.		Values.			
					Margate			
					To Ashford (27½ miles).		To Ramsgate (3 miles)	
			N.	S.	N.	S.	N.	S.
	h m	h m	min.	min.	°	°		
August 12, 1860.	9.30 to	9.52 A.M.	......	22	......	68	......	?
	9.52	10.2	10	......	36	......	?	
	10.2	10.10	......	12	......	74	......	?
	10.10	10.21	11	......	48	......	?	
	10.21	10.22	......	1	......	30	......	?
	10.22	10.56	34	......	74	......	?	
	10.56	11.12	......	16	......	30	......	?
	11.12	11.15	3	......	32	......	?	
	11.15	11.16	......	1	......	28	......	?
	11.16	11.17	1	......	44	......	?	
	11.17	11.26	......	9	......	68	......	?
	11.26	11.40	14	......	30	......	?	
	11.40	11.50 A.M.	......	10	......	15 (?)		
	11.51	12.10 P.M.	19	......	10 (?)			
	12.10	12.15	......	5	......	35 (?)		
	12.15	12.34	29	......	46	......	?	
	12.34	12.45	......	11	......	50 (?)		
	12.46	12.55	9	......	35			
	12.55	1.20	......	25	......	38	......	(?)
	1.20	1.50	30	......	20	......	(?)	
	1.50	1.52	......	2	......	30 (?)		
	1.52	2.10	......	......	20			
	2.10	2.39	......	......	30			
	2.39	3.3	71	......	50			
	3.4	3.6	......	2	......	30 (?)		
	3.7	3.10	3	......	40			
	3.10	3.16	......	6	......	18 (?)		
	3.16	3.20	4	......	8 (?)			
	3.20	3.45	......	......	......	48	......	(?)
	3.45	4.30	......	70	......	38		
	4.30	5.25	55	......	50			
	5.36	5.45	......	......	......	15 (?)		
	5.45	6.30	......	......	......	38	......	?
	6.30	7.35	......	119	......	15 (?)		
August 12, 1860.	7.55	8.1 P.M.	......	6	......	40		
	Sum...............		293	317				
	Means		20·92	19·81	35·81	37·26		

TABLE VIII.—Direction, Duration, Changes and Values of Earth-Currents.

Date.	Time.		General direction from N. or S.					
			Duration.		Values.			
					Margate To Ashford (27½ miles).		Margate To Ramsgate (3 miles).	
			N.	S.	N.	S.	N.	S.
	h m	h m	min.	min.	°	°	°	°
Sept. 7, 1860 ...	7.12	to 7.18 A.M.	......	6	......	44		
	7.18	7.19	1	......	8			
	7.19	7.19½	......	0·5	......	6	......	8
	7.19½	7.22	1·5	......	64	......	40	
	7.22	7.24	......	2	......	44	......	48
	7.24	7.28	4	......	34	......	16	
	7.28	7.29	......	......	......	38	......	57
	7.29½	7.30	......	......	......	16	......	34
	7.30½	7.33	......	......	......	58	......	61
	7.33	7.40	......	12	......	8		
	7.40	7.42	2	......	30			
	7.42	7.44	......	2	......	20	......	15
	7.44	7.45	1	......	22	......	21	
	7.45	7.46	......	......	......	30	......	12
	7.46½	7.47	......	2	......	38	......	21
	7.47	7.50	......	......	40	......	34	
	7.50	7.52	5	......	18	......	10	
	7.52	7.53	......	1	......	14	......	8
	7.53	7.57	4	......	30	......	34	
	7.57	7.58	......	1	......	8		
	7.58	8.0	2	......	20	......	34	
	8.1	8.2	......	1	......	20	......	10
	8.2	8.3	1	......	10	......	6	
	8.3	8.5	......	......	......	20	......	10
	8.6	8.6½	......	3·5	......	10	......	6
	8.6½	8.7	0·5	......	6	......	10	
	8.7	8.8	......	......	......	20	......	15
	8.8½	8.18	......	11	......	38	......	24
	8.18	8.19	1	......	16	......	8	
	8.19	8.20	......	......	......	12	......	8
	8.21	8.24	......	5	......	18	......	10
	8.24	8.25	1	......	24	......	8	
	8.25	8.27	......	2	......	12		
	8.27	8.27½	0·5	......	6			
	8.27½	8.28	......	1	......	8		
	8.28	8.29	......	......	12			
	8.29	8.30	2	......	12			
	8.30	8.32	......	2	......	12	......	18
	8.32	8.32½	0·5	......	9			
	8.32½	8.33	......	0·5	......	5		
	8.33	8.35	2	......	12			
	8.35	8.36	......	1	......	3		
	8.36	8.37	1	......	4			
	8.37	8.38	......	1	......	5		
	8.38	8.42	4	......	36	......	15	
	8.42	8.46	......	4	......	26	......	15
	8.46	8.48	2	......	6	......	6	
	8.48	8.49						
	8.49	8.51	......	3	......	8		
	8.51	9.1	10	......	20	......	8	
	9.1	9.2	......	1	......	10	......	9
Sept. 7, 1860 ...	9.2	to 9.5 A.M.	3					

TABLE VIII. (continued).

Date.	Time.		General direction from N. or S.					
			Duration.		Values.			
					Margate			
					To Ashford (27½ miles).		To Ramsgate (3 miles).	
			N.	S.	N.	S.	N.	S.
	h m	h m	min.	min.	°	°	°	°
Sept. 7, 1860 ...	9.5	9.6 A.M.	......	1	......	10	......	9
	9.6	9.7	1	......	5			
	9.7	9.10	......	3	......	11	......	10
	9.10	9.13	......	......	11			
	9.13	9.14	4	......	5			
	9.14	9.14½	......	0·5	......	4	......	5
	9.14½	9.15	0·5	......	5			
	9.15	9.15½	......	......	......	18		
	9.16	9.18	......	3	......	10	......	9
	9.19	9.20	1	......	5			
	9.20	9.21	......	1	......	4	......	5
	9.21	9.22	2	......	6			
	9.22	9.25	......	3	......	50	......	45(?)
	9.25	9.28	3	......	40	......	43(?)	
	9.28	9.30	......	2	......	18	......	18
	9.30	9.36	6	.....	30	......	15	
	9.36	9.37	......	1	......	25	......	18
	9.37	9.40	3	......	24	......	15	
	9.40	9.43	......	3	......	27	......	25
	9.43	9.43½	0·5	......	29	......	12	
	9.43½	9.46	......	......	......	28	......	13
	9.46	9.55	......	......	......	14	......	10
	9.55	9.56	......	12·5	......	20	......	23
	9.56	9.58	2	......	12	......	10	
	9.58	9.59	......	1	......	24	......	28
	9.59	10.0	1	......	?			
	10.0	10.6	......	6	......	43(?)	......	18
	10.6	10 8	......	......	10	......	8	
	10.8	10.10	4	......	45			
	10.10	10.14	......	4	......	24	......	15
	10.14	10.15	1	......	9			
	10.15	10.19	......	4	......	25		
	10.19	10.20	1	......	10			
	10.20	10.21	......	6	......	......	5	
	10.21	10.22	1	......	7			
	10.22	10.23	......	1	......	13	......	12
	10.23	10.30	......	......	17	......	9	
	10.30	10.32	......	......	6			
	10.32	10.34	......	......	9			
	10.34	10.50	27	......	17			
	10.50	10.52	......	2	......	8		
	10.52	10.52½	......	......	6			
	10.52½	10.54	4	......	9			
	10.54	10.55	......	1	......	4		
	10.55	10.58	......	......	17	......	8	
	10.58	11.0	5	......	19			
	11.0	11.4	......	4	......	34	......	12
	11.4	11.7	3	......	12	......	24	
	11.7	11.8	......	......	......	8		
	11.8	11.10	......	3	......	28	......	15
	11.10	11.12	2	......	10			
Sept. 7, 1860 ...	11.12 to	11.14 A.M.	......	2	......	27		

TABLE VIII. (continued).

Date.	Time.		General direction from N. or S.					
			Duration.		Values.			
					Margate To Ashford (27½ miles).		Margate To Ramsgate (3 miles).	
			N.	S.	N.	S.	N.	S.
	h m	h m	min.	min.	°	°	°	°
Sept. 7, 1860 ...	11.14	to 11.15 A.M.	......	......	36	......	24	
	11.15	11.18	......	......	30	......	24	
	11.18	11.20	6	......	12	......	21	
	11.20	11.22	......	2	......	18	......	10
	11.22	11.23	1	......	50	......	54	
	11.23	11.25	......	2.5	......	25		
	11.25	11.25½	......	......	......	18	......	12
	11.25½	11.26	0·5	......	34			
	11.26	11.28	......	2	......	60 (?)		
	11.28	11.30	2	......	38	......	7	
	11.30	11.33	......	3	......	18	......	12
	11.33	11.36	3	......	20	......	12	
	11.36	11.39	......	3	......	10	......	10
	11.39	11.44	5	......	23	......	23	
	11.44	11.48	......	4	......	26	......	24
	11.48	11.53	5	......	8	......	6	
	11.53	11.57	......	4	......	14	......	13
	11.57	11.59 A.M.	2	......	17			
	11.59	12.2 P.M.	......	3	......	13	......	12
	12.3	12.7	4	......	12			
	12.7	12.10	......	3	......	10	......	7
	12.13	12.14	......	1	......	10	......	7
	12.14	12.19	5	......	25			
	12.19	12.20	......	1	......	17		
	12.20	12.20½	0·5	......	10			
	12.21	12.21½	......	0·5	......	10		
	12.22	12.22½	0·5	......	25			
	12.22½	12.25	......	2·5	......	34	......	29
	12.25	12.28	3	......	50	......	27	
	12.28	12.29	......	1	......	50	......	27
	12.29	12.31	2	......	27			
	12.31	12.34	......	3	......	17	......	12
	12.34	12.35	1	......	9			
	12.35	12.37	......	2	......	24	......	23
	12.44	12.50	......	......	17	......	12	
	12.50	12.58	......	......	64			
	12.58	1.0	......	...	17			
	1.0	1.5	15	......	30	......	27	
	1.5	1.9	......	4	......	35		
	1.9	1.13	4	......	20	......	5	
	1.13	1.14	......	1	......	12	......	10
	1.15	1.20	5	......	12	......	6	
	1.20	1.22	......	2				
	1.22	1.25	......	......	17			
	1.25	1.40	18	......	25	......	27	
	1.40	1.44	......	......	(?)			
	1.44	1.47	......	7	(?)			
	1.53	1.54	......	1	(?)			
	1.59	2.0	......	1	(?)			
	2.0	2.3	3	......	8	......	8	
	2.3	2.7	......	4	......	18	......	12
Sept. 7, 1860 ...	2.7	2.10 P.M.	3	......	12	......	10	

TABLE VIII. (continued).

Date.	Time.	General direction from N. or S.					
		Duration.		Values.			
				Margate To Ashford ($27\frac{1}{2}$ miles).		Margate To Ramsgate (3 miles).	
		N.	S.	N.	S.	N.	S.
	h m h m	min.	min.	°	°	°	°
Sept. 7, 1860 ...	2.10 to 2.11 P.M.	......	1	......	8	......	8
	2.11 2.15	4	......	34	......	24	
	2.15 2.20	......	5	......	24		
	2.20 2.30	10	......	28			
	2.30 2.32	......	2	......	16		
	2.32 2.35	......	......	14			
	2.35 2.37	......	......	(?)			
	2.37 2.38	6	......	16			
	2.38 2.40	......	2	......	12	......	12
	2.40 2.43	3	......	7			
	2.43 2.45	......	2	......	10	......	5
	2.45 2.48	3	......	11			
	2.48 2.49	......	1	......	9		
	2.49 2.50	1	......	8			
	2.50 2.55	......	5	......	11		
	2.55 2.59	4	......	10			
	2.59 3.0	......	1	......	12		
	3.0 3.5	5	......	16			
	3.5 3.7	......	2	......	4		
	3.7 3.9	2	......	10			
	3.9 3.10	......	1	......	8		
	3.10 3.17	7	......	14	......	10	
	3.17 3.18	......	1	......	8		
	3.18 3.20	2	......	14	......	10	
	3.21 3.25	......	4	......	20	......	12
	3.25 3.28	3	......	19			
	3.28 3.29	......	1	......	4		
	3.29 3.40	11	......	38	......	18	
	3.40 3.50	......	10	......	8	......	7
	3.50 4.5	......	......	0			
	4.5 4.7	2	......	10			
	4.7 4.8	......	1	......	5		
	4.8 4.10	2	......	7			
Sept. 7, 1860 ...	4.10 4.40 P.M.	......	30	......	12	......	12
	Sum	$274\frac{1}{2}$	253				
	Means	3·51	3·12	18·87	18·61		

ANALYSES OF EARTH-CURRENTS.

TABLE IX.—Values in Time.

a. Daily Numbers for each Value.

Duration.	August 8.	August 9.	August 10.	August 11.	August 12.	September 7.	Sums.
minutes.							
$\frac{1}{4}$	0	2	0	0	0	0	2
$\frac{1}{2}$	0	4	0	1	0	12	17
$\frac{3}{4}$	0	0	0	0	0	0	0
Under 1	0	6	0	1	0	12	19
1	12	16	1	5	3	43	80
$1\frac{1}{2}$	0	0	0	0	0	1	1
$1\frac{3}{4}$	0	2	0	0	0	0	2
2	4	29	5	5	2	30	75
$2\frac{1}{2}$	0	0	0	0	0	2	2
3	3	8	2	3	2	22	40
$3\frac{1}{2}$	0	0	0	0	0	1	1
4	5	6	5	0	1	19	36
5	0	2	2	1	1	10	16
1 to 5	24	63	15	14	9	128	253
6 10	9	11	4	9	6	11	50
11 15	5	6	3	1	4	5	24
16 20	4	4	1	5	2	1	17
21 25	1	2	0	2	2	0	7
26 30	0	0	0	1	2	2	5
31 35	0	1	0	2	1	0	4
36 40	2	0	0	0	0	0	2
41 45	0	0	0	1	0	0	1
46 50	0	1	1	0	0	0	2
51 55	0	0	0	0	1	0	1
56 60	0	0	1	0	0	0	1
61 to 120	0	0	0	0	3	0	3
Sums	45	94	25	36	30	159	389

b. Total duration of each Current.

	August 8.	August 9.	August 10.	August 11.	August 12.	September 7.	Sums.
	min.	min.	min.	min.	min.	min.	h m
N. Currents ...	159	253·5	95	226·5	293	274·5	21 41·5
S. Currents......	208	252	123	169·5	317	253	22 2·5
Wanting.........	37	110·5	143	66	21	40·5	6 58
Sums	404	616	361	462	631	568	50 42

c. Mean duration of each Current.

	August 8.	August 9.	August 10.	August 11.	August 12.	September 7.	Mean.
	min.	min.	min.	min.	min.	min.	min.
N. Currents ...	7·22	5·63	7·91	11·92	20·92	3·51	9·51
S. Currents......	9·04	5·14	9·46	9·97	19·81	3·12	9·42
Mean	8·13	5·38	8·68	10·99	20·36	3·31	9·46

Table X.—Values in Degrees of Deflection.

a. Daily numbers for each Value.

Deflections.	Aug. 8.		Aug. 9.		Aug. 10.		Aug. 11.		Aug. 12.		Sept. 7.		Sums.		Total.
	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	
1°—5° ”	0	0	1	3	0	0	1	0	0	0	5	9	7	12	19
6—10 ”	2	3	14	6	2	3	2	3	2	0	26	21	48	36	84
11—15 ”	2	1	10	6	2	1	2	1	0	3	14	14	30	26	56
16—20 ”	5	4	6	17	1	5	9	7	2	1	17	17	40	51	91
21—25 ”	2	2	0	5	1	1	2	0	0	0	7	7	12	15	27
26—30 ”	1	2	7	5	1	0	5	3	2	5	8	7	24	22	46
31—35 ”	1	1	0	1	0	1	0	1	2	1	3	3	6	8	14
36—40 ”	4	7	9	3	2	1	3	2	2	4	6	3	26	20	46
41—45 ”	2	0	2	2	0	0	0	0	1	0	1	3	6	5	11
46—50 ”	3	1	3	2	2	0	1	0	4	2	2	2	15	7	22
51—55 ”	0	0	1	1	0	0	0	1	0	0	0	0	1	2	3
56—60 ”	0	3	2	0	1	1	0	1	0	0	0	2	3	7	10
61—65 ”	0	2	0	0	0	0	0	0	0	0	2	0	2	2	4
66—70 ”	1	0	0	0	1	0	0	0	0	2	0	0	2	2	4
71—75 ”	1	1	0	0	0	0	0	0	1	1	0	0	2	2	4
76—80 ”	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
81—85 ”	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1
	25	27	55	51	13	13	25	19	16	19	91	88	225	217	442

b. Mean Value of each Current.

	Aug. 8.	Aug. 9.	Aug. 10.	Aug. 11.	Aug. 12.	Sept. 7.	Mean.
N. current	33°·76	24°·45	32°·30	22°·88	35°·81	18°·87	28°·01
S. current	35·40	21·96	22·30	25·73	37·26	18·61	26·87
Each	34·58	23·20	27·30	24·30	36·53	18·74	27·44

TABLE XI.—Telegraph Stations.

Bearings and Distances.

		Bearings.	Distances.	
			Direct.	Telegraph.
	I. On the Magnetic Meridian.			
N. S.	Whitstable—Canterbury	0°	miles. $5\frac{3}{4}$	miles. $5\frac{3}{4}$
	II. East of the Magnetic Meridian.	East of North.		
1— 2	Red Hill—Brighton	17°	$28\frac{1}{2}$	$29\frac{3}{4}$
3— 4	London—Brighton	25	$46\frac{1}{2}$	$50\frac{1}{2}$
5— 6	Ashford—Hastings	52	$23\frac{1}{2}$	$26\frac{1}{4}$
7— 8	London—Portsmouth	62	$66\frac{1}{2}$	$95\frac{1}{4}$
9—10	Maidstone—Paddock Wood	64	$8\frac{1}{2}$	$9\frac{3}{4}$
11—12	Red Hill—Portsmouth	70	$51\frac{1}{2}$	$71\frac{1}{4}$
13—14	Margate—Ashford	72	$27\frac{1}{2}$	$51\frac{1}{4}$
15—16	Ramsgate—Ashford	80	$27\frac{1}{2}$	30
	III. West of the Magnetic Meridian.	West of North.		
17—18	Margate—Ramsgate	2°	3	$3\frac{3}{4}$
19—20	Minster—Deal	6	$7\frac{1}{2}$	$8\frac{3}{4}$
21—22	Tonbridge—Hastings	10	26	$32\frac{1}{2}$
23—24	London—Tonbridge	13	$26\frac{1}{2}$	$40\frac{1}{2}$*
25—26	London—Dover	44	65	$87\frac{1}{4}$
	Reading—Red Hill	44	$38\frac{1}{2}$	$46\frac{1}{4}$
27—28	Ashford—Folkestone	50	15	$15\frac{1}{2}$
29—30	Red Hill—Tonbridge	57	19	$19\frac{3}{4}$
31—32	Tonbridge—Ashford	62	$26\frac{1}{2}$	$26\frac{1}{2}$
33—34	Red Hill—Shalford	82	18	$18\frac{1}{4}$

* Or $57\frac{1}{4}$ miles *viâ* Paddock Wood and Maidstone.

TABLE XII.—Absolute Direction of Earth-Currents.

1. Range 42°; extending from 46° E. of Magnetic N. to 88° E. of Magnetic N. (Fig. 4, Plate III.)

		1857, Dec. 17.	1860, July 1.			1860, August 8.		1860, August 12.		1860, Sept. 7.
		1.15 to 1.25 A.M.	3.50 to 4.30 P.M.	7.5 to 7.15 P.M.	7.40 to 8.3 P.M.	2.0 to 2.45 P.M.	3.28 to 3.53 P.M.	10.10 to 10.21 A.M.	10.22 to 10.56 A.M.	11.22 to 11.23 A.M.
19.	Minster to Deal	....	....	....	....	Strong.				
17.	Margate to Ramsgate	Hard over.	Middling.	Middling.	Middling.	Strong.	71°.	(?)	Very strong.	54°.
N.	Whitstable to Canterbury	....	....	....	....	Very strong.	Strong.	Very strong.	Very strong.	Strong.
5.	Ashford to Hastings	Strong.	....	....	Slight.	....	....	Strong.	Strong.	Strong.
13.	Margate to Ashford	Hard over.	Very strong.	Very strong.	Very strong.	64°	82°	48°	74°	50°
15.	Ramsgate to Ashford	Hard over.	Middling.	Middling.	Strong.	Strong.	Hard over.	Very strong.	Very strong.	Very strong.
32.	Ashford to Tonbridge	....	....	....	Very strong.	....	Slight.	Strong.	Strong.	Strong.
28.	Folkestone to Ashford	Slight.	....	....	Middling.	....	Slight.	Strong.	Strong.	....
26.	Dover to London	Hard over.	Slight.	Slight.	Very strong.	Strong.	Middling.	Strong.	Strong.	Strong.

2. Range 42°; extending from 46° W. of Magnetic S. to 88° W. of Magnetic S. (Fig. 4, Plate III.)

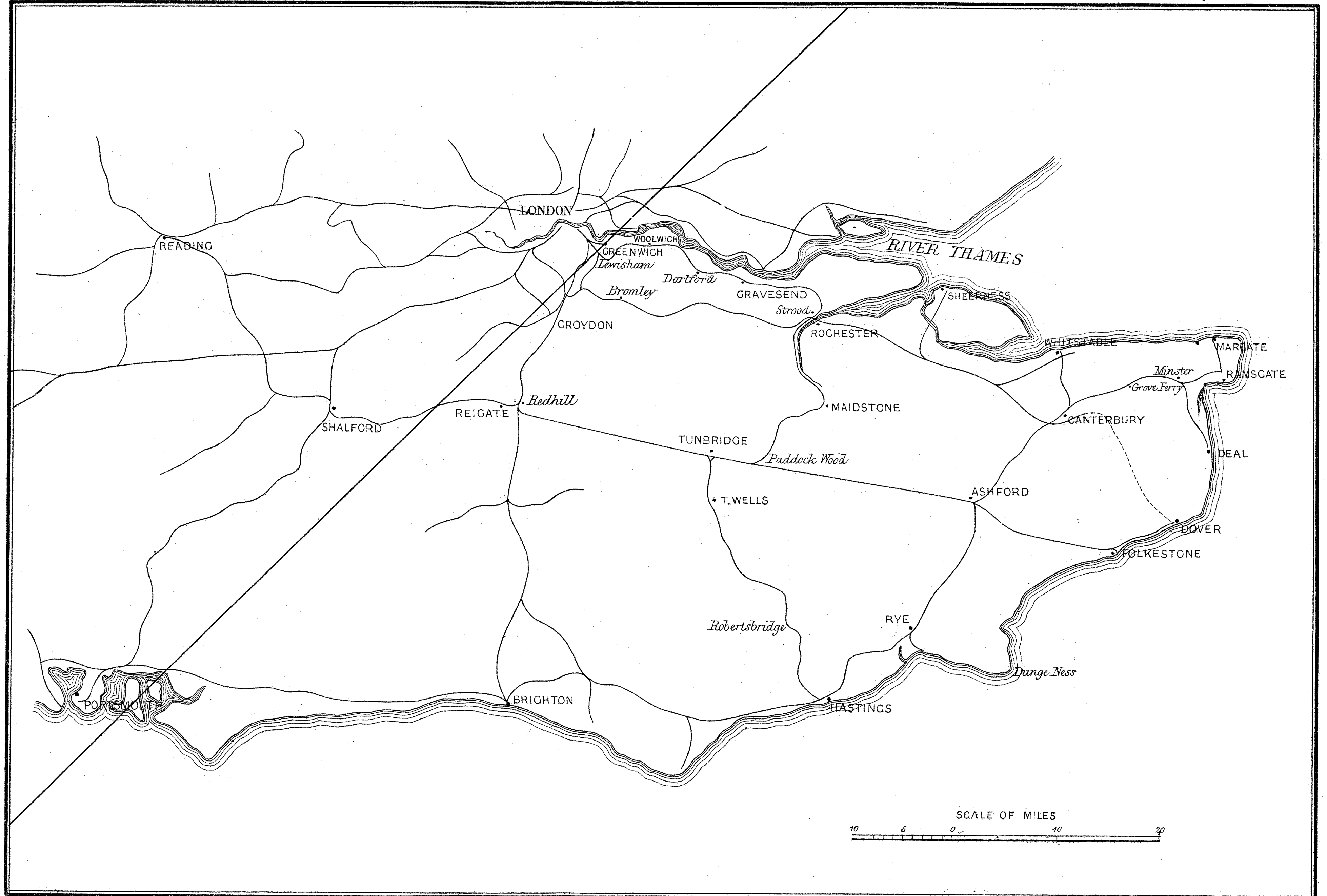
		1859, December 13.		1860, July 1.		1860, August 8.		1860, August 12.		1860, Sept. 7.
		1.39 to 1.50 P.M.	6.50 to 7.30 P.M.	8.10 to 9.13 P.M.	9·17 to 10.3 P.M.	4.38 to 5.13 P.M.	5.25 to 5·44 P.M.	9.30 to 9.52 A.M.	10.2 to 10.10 A.M.	7.10 to 7.18 A.M.
20.	Deal to Minster	....	....	....	....	....	Slight.	....	....	....
18.	Ramsgate to Margate	Slight.	Middling.	Slight.	Slight.	63°	86°	Very strong.	Very strong.	Slight.
S.	Canterbury to Whitstable	....	....	....	....	....	....	Very strong.	Very strong.	
4.	Brighton to London	....	Strong.							
6.	Hastings to Ashford	Middling.	Middling.	Slight.	Slight.	Slight.	Strong.	Strong.	Strong.	Slight.
14.	Ashford to Margate	Strong.	Very strong.	Strong.	Strong.	60°	73°	68°	74°	44°
16.	Ashford to Ramsgate.........	Middling.	Very strong.	Strong.	Strong.	Hard over.	Very strong.	Very strong.	Very strong.	Very strong.
31.	Tonbridge to Ashford	....	Very slight.	Middling.	Middling.	....	Slight.	Strong.	Strong.	
27.	Ashford to Folkestone	....	....	Slight.	Slight.	Slight.	Slight.	Strong.	Strong.	Slight.
25.	London to Dover	Slight.	Strong.	Strong.	Strong.	Very strong.	Very strong.	Very strong.	Strong.	Very strong.

3. Range 31°; extending from 46° E. of Magnetic N. to 77° E. of Magnetic N. (Fig. 5, Plate III.)

		1858, April 9.	1859, September 2.		
		3.40 to 3.58 P.M.	7.10 to 7.43 A.M.	7.56 to 8.0 A.M.	12.15 to 12.30 P.M.
23.	London to Tonbridge	Strong.	Very strong.	Strong.	Slight.
21.	Tonbridge to Hastings	....	(?)		
17.	Margate to Ramsgate.........	Strong.	Very strong.	Hard over.	
N.	Whitstable to Canterbury	....			
13.	Margate to Ashford	Very strong.	Very strong.	(?)	Very strong.
15.	Ramsgate to Ashford	Very strong.	Very strong.		Strong.
32.	Ashford to Tonbridge	....	(?)	Strong.	(?)
28.	Folkestone to Ashford	Strong.			
26.	Dover to London	Strong.	Very strong.	Strong.	Slight.

4. Range 31°; extending from 46° W. of Magnetic S. to 77° W. of Magnetic S. (Fig. 5, Plate III.)

		1859, September 2.			1860, March 28.
		7.43 to 7.48 A.M.	8.12 to 8.17 A.M.	12.4 to 12.15 P.M.	10.11 to 10.13 A.M.
24.	Tonbridge to London...........	Strong.	Slight.	Strong.	Very slight.
18.	Ramsgate to Margate...........	....	(?)	....	Strong.
6.	Hastings to Ashford	....	....	....	Slight.
14.	Ashford to Margate...........	Strong.	Hard over.	Very strong.	Very strong.
16.	Ashford to Ramsgate	Strong.	Hard over.	Very strong.	Very strong.
31.	Tonbridge to Ashford...........	(?)	(?)	(?)	Slight.
27.	Ashford to Folkestone.........	....	....	....	Slight.
25.	London to Dover	Strong.	Slight.	Strong.	Strong.



J. Basire, lith.

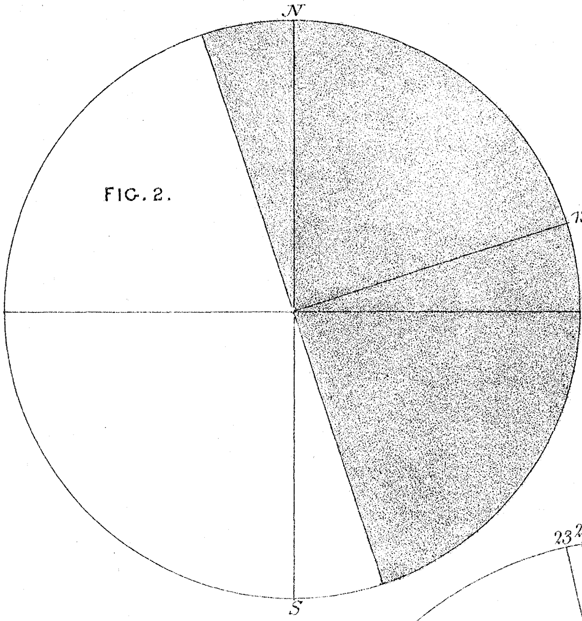


FIG. 2.

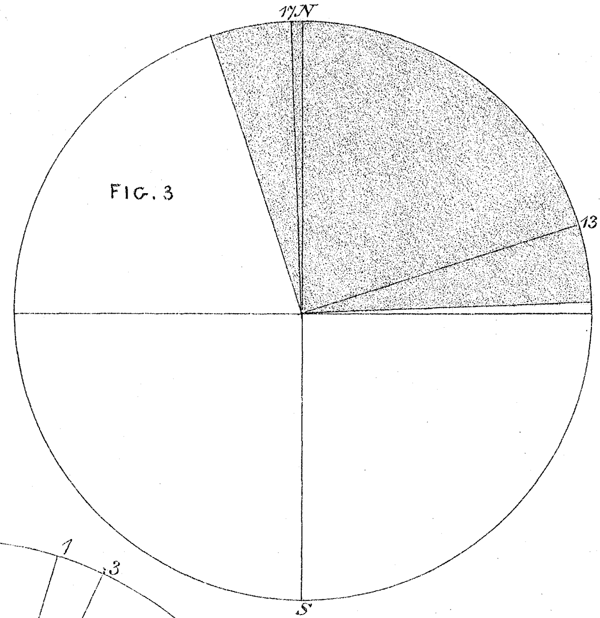


FIG. 3

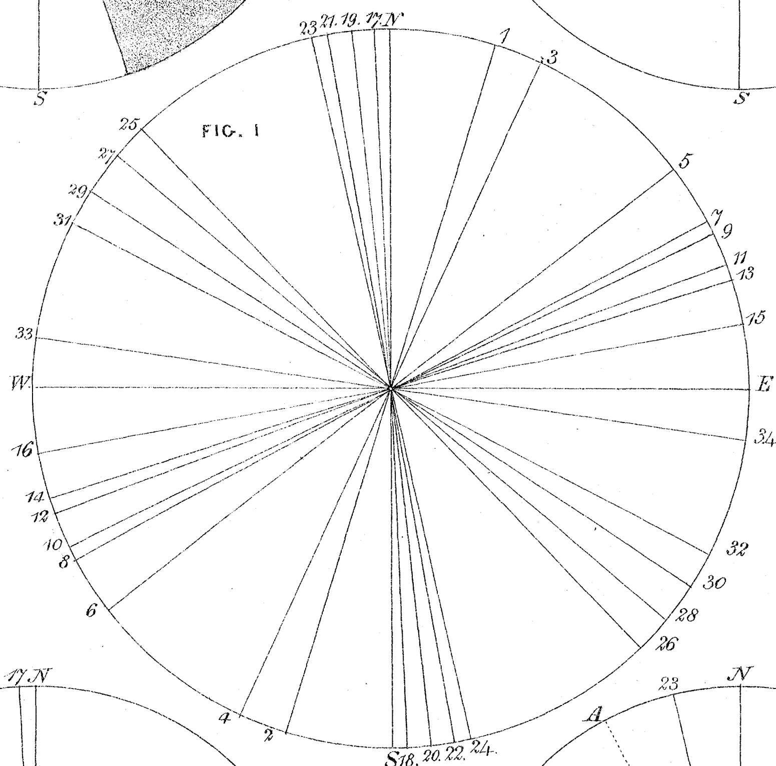


FIG. 1

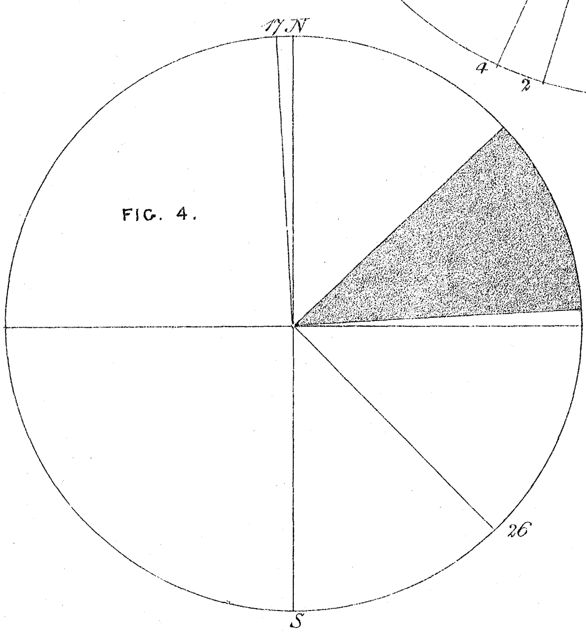


FIG. 4.

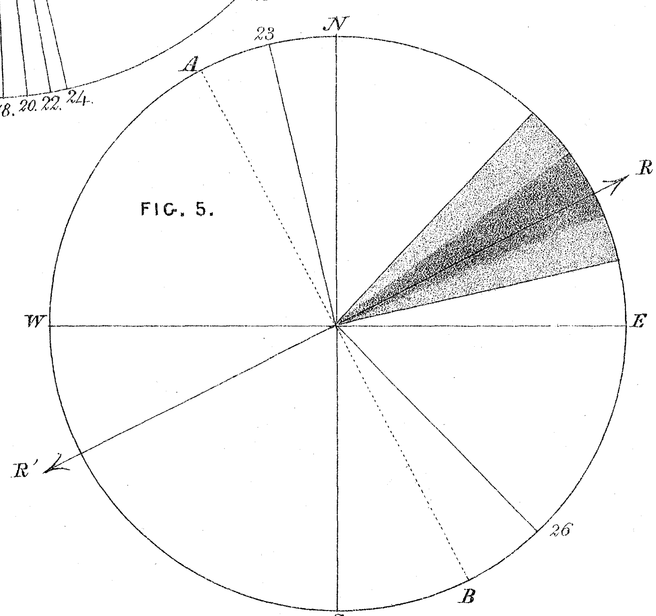


FIG. 5.

Fig: 6.

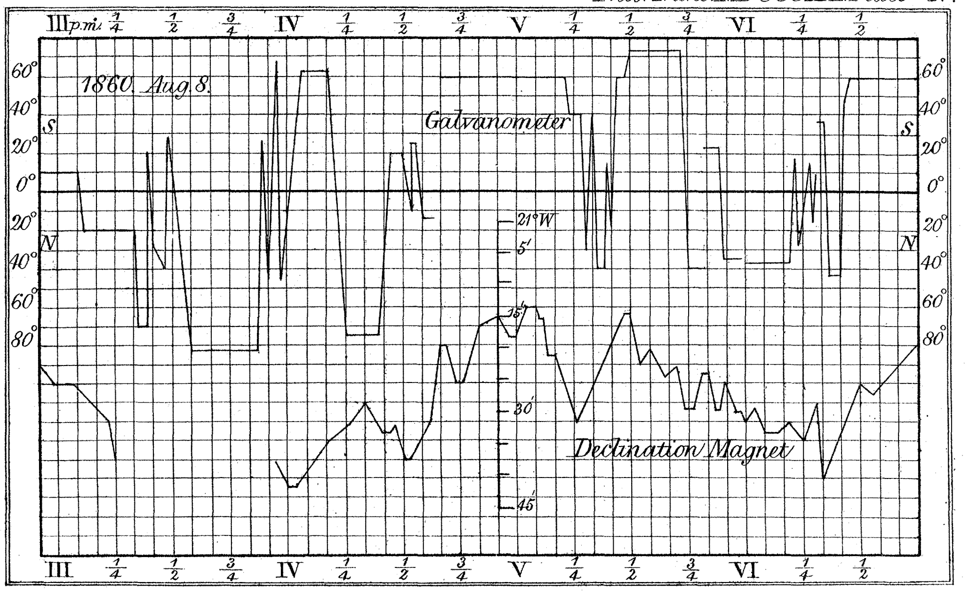


Fig: 7.

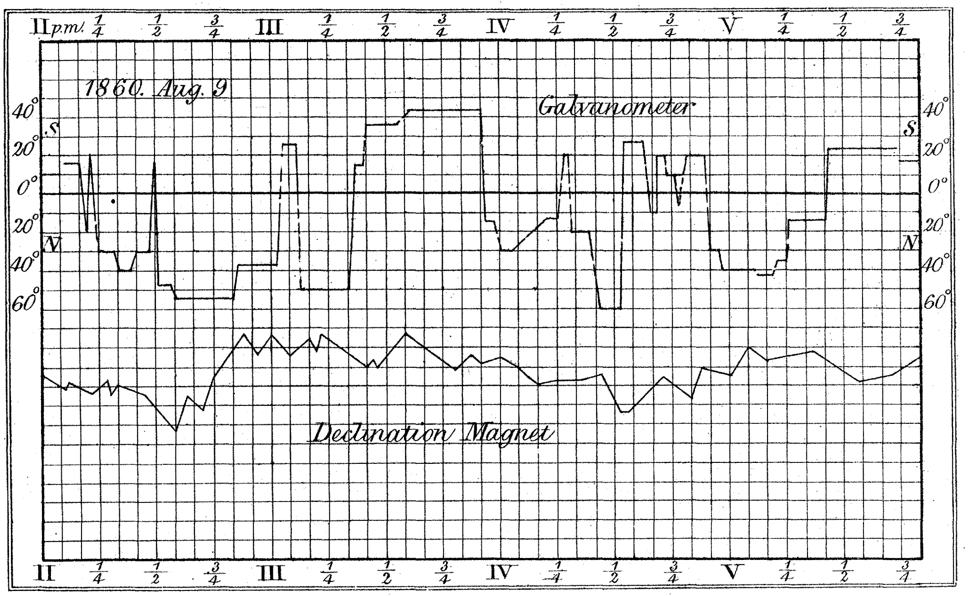
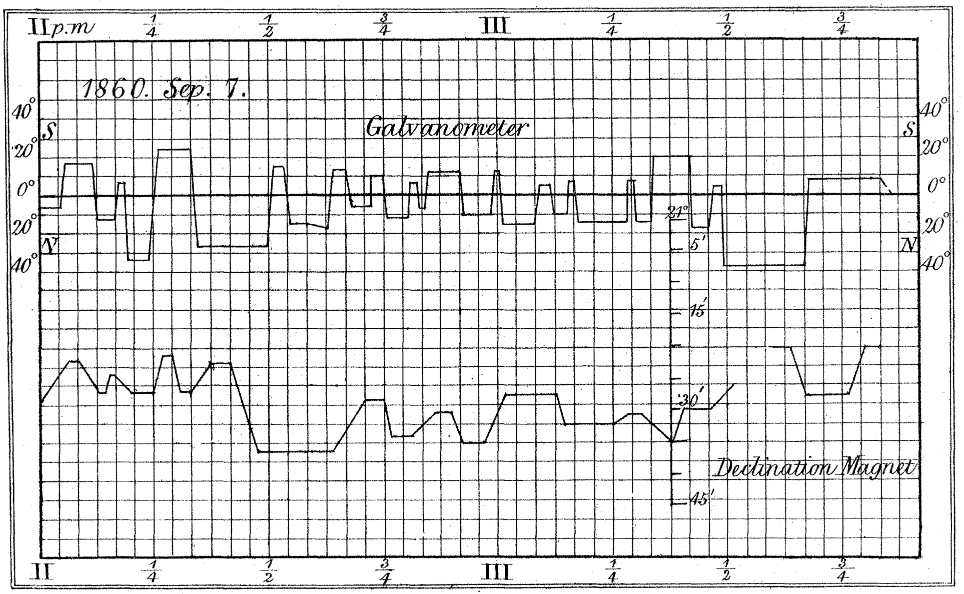


Fig: 8.



J. Basire lith.