

assertion were, (1) M. Siemens himself assumes in his first paper that the conducting power of his copper (étalon) varies 0.1 per cent. with each degree Centigrade; and (2) M. C. W. Siemens\*, in describing his resistance thermometer, assumes also the same; in fact he bases his calculation on Arndtsen's formula without stating the sort of copper he uses.

That my statement regarding the difference of the coefficients of the increase of resistance for different temperatures of coppers is correct, may be deduced from the following data:—M. Siemens finds (2nd paper) the resistances of a commercial copper he tested to vary between 0° and 100° C. 32.9 per cent.; Arndtsen finds copper containing traces of iron to vary 36 per cent.; von Bose and myself have found pure copper to vary 42 per cent.; and lastly, one commercial copper I have tested varies only about 8 per cent.

XXV. *On the True and False Discharge of a Coiled Electric Cable.* By Professor W. THOMSON, LL.D., F.R.S., and Mr. FLEEMING JENKIN, C.E.†

IN an article in the last May Number of this Magazine, "On the Galvanic Polarization of buried Metal Plates," translated from Poggendorff's *Annalen*, No. 10, 1860, Dr. Carl describes certain interesting experiments on the electro-polarization produced between two large zinc plates buried in the garden of the Observatory of Munich, by opposing and by augmenting the natural earth-current between them by the application of a single element of Daniell's; and concludes with the following remark:

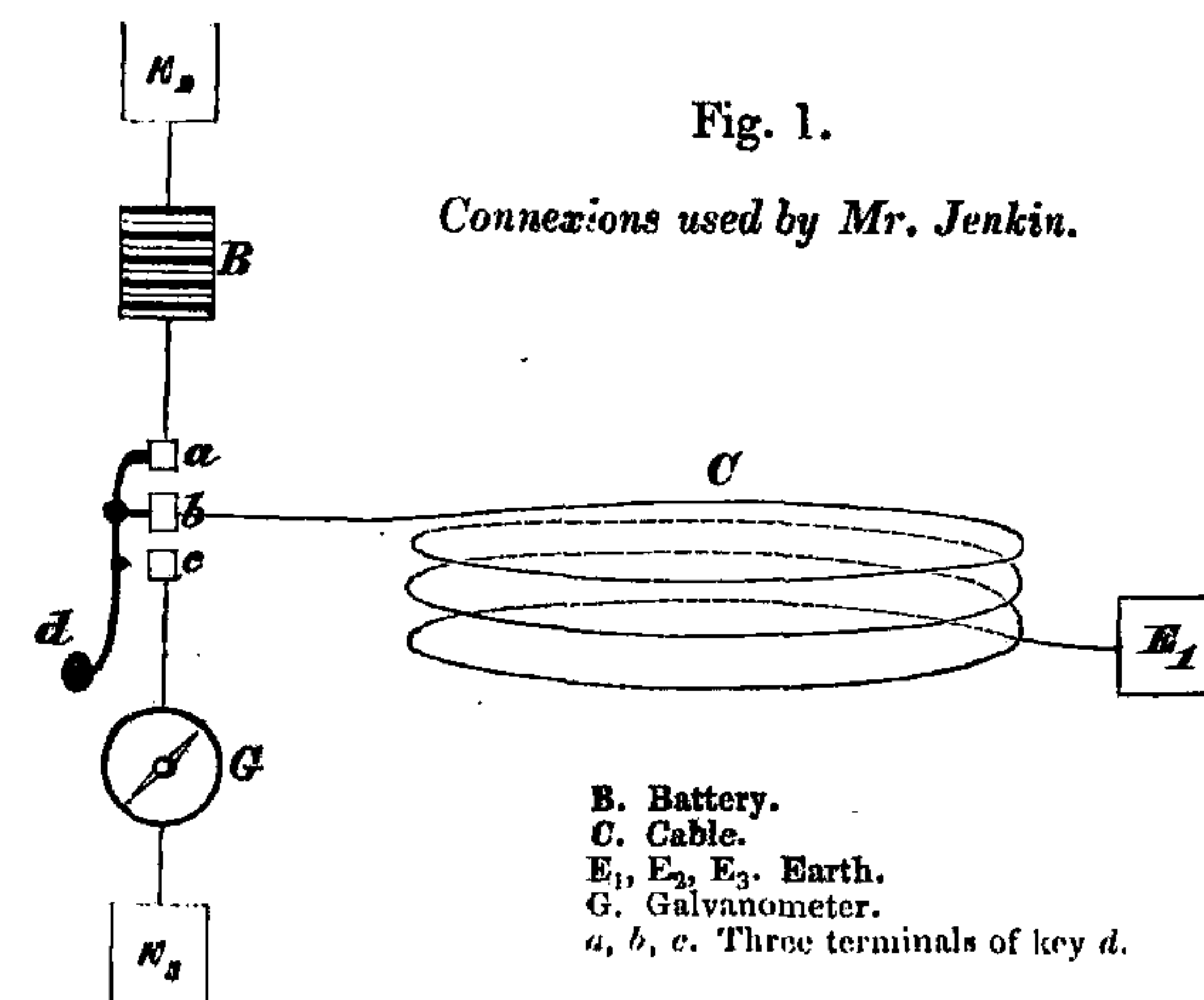
"The above experiments disclose nothing at variance with the known laws of galvanism; but it nevertheless appeared to me advisable to make them known, as they afford a simple explanation of certain phenomena which Professor Thomson has described (Report of the Twenty-ninth Meeting of the British Association, Aberdeen, 1859, Trans. of Sections, p. 26), and which he seems to attribute to entirely different causes."

In the report of Prof. Thomson's communication to the British Association here referred to, it is stated that (after mentioning certain experiments by Mr. F. Jenkin on submarine cables coiled in the manufactory of Messrs. Newall and Co., Birkenhead, in which one end of the battery used, and one end of the cable experimented on, in each case was kept in connexion with the earth while the other end of the cable, after having been for a time in

\* Phil. Mag. January 1861.

† Communicated by the Authors.

connexion with the insulated pole of the battery, was suddenly removed from the battery and put in connexion with the earth through the coil of a galvanometer) Prof. Thomson and Mr. Fleeming Jenkin remarked "that the deflections recorded in these



experiments were in the contrary direction to that which the true discharge of the cable would give;" and at Prof. Thomson's request "Mr. Jenkin repeated the experiments, watching carefully for indications of reverse currents to those previously noted. It was thus found that the first effect of pressing down the key [to throw the cable from battery to earth through galvanometer] was to give the galvanometer a deflection in the direction corresponding to the true discharge current, and that this was quickly followed by a reverse current generally greater in degree, which gave a deflection corresponding to a current in the same direction as that of the original flow through the cable.

"Professor Thomson explained this second current, or false discharge, as it has since been sometimes called, by attributing it to mutual electro-magnetic induction between different parts of the coil, and anticipated that no such reversal could ever be found in a submerged cable. The effect of this induction is to produce in those parts of the coil first influenced by the motion of the key, a tendency for the electricity to flow in the same direction as that of the decreasing current flowing through the remoter parts of the coil. Thus, after the first violence of the back flow through the key and galvanometer, the remote parts of the cable begin, by their electro-magnetic induction on the near parts, to draw electricity back from the earth through the galvanometer into the cable again, and the current is once more in one and the same direction throughout the cable."



The phenomena thus described and explained are entirely different from any that could result from the galvanic polarization supposed by Dr. Carl to account for them\*. It is true that the discharging earth-plate might become polarized by the discharge in certain cases sufficiently to cause a slight reversal in the current through the galvanometer coil, after the subsidence of the violent discharge current through it. But in no case could the whole quantity of electricity flowing in this supposed polarization current be more than a very small fraction of the quantity which previously flowed in the true discharge current, of which it is a feeble electro-chemical reflexion. Its effect on the galvanometer needle must in every case be as nothing in comparison to the great impulsive deflection produced by the true discharge current; and there is no combination of circumstances, as to size of the earth-plates, amount of the battery power, and rapidity or sensibility of the galvanometer needle, in which the cause supposed by Dr. Carl could possibly be adequate to explain the phenomena described in Prof. Thomson's communication.

In point of fact, all effects of polarization of the earth-plates were extremely small in comparison with the main currents observed, which in the experiments on cables with one end kept to earth, consisted of (1) the constant *through-current*, produced by a battery of 72 elements Daniell's in series; (2) the true discharge through the galvanometer to be observed instantly after breaking the battery connexion of the end of the cable to which the battery was applied, and making instead a connexion, through the galvanometer coil, between the same end of the cable and the earth; and (3) the "false discharge," so called because it must have been often mistaken for the true discharge, which almost necessarily escapes notice altogether when short lengths of coiled cable are tested with slow galvanometer nec-

\* They are also different from any effects which could result from polarization of the plate connecting the far end of the cable with earth—a cause suggested by Prof. Wheatstone in a report published by the Committee appointed by the Board of Trade to inquire into the Construction of Submarine Cables. In support of his opinion, Prof. Wheatstone quotes some experiments in which he could observe only the well-known effects due to polarization, which on the short pieces of wire at his command quite overpowered both the true and false discharge. The current from the polarized end of a cable is always in the direction of the true discharge when the battery has been long enough applied: it is observed on both straight and coiled cables, and is capriciously variable. The details given in the present paper show that the currents due to electro-magnetic induction, called false discharge currents, are on the contrary always in the opposite direction to that of the true discharge, that they can only be observed on coiled cables, and that they are in each case sensibly constant. The galvanometer used by Mr. Jenkin would not have been deflected half a degree by the current from a polarized earth-plate at the end of cables from 300 to 500 knots in length.

dles. The *through-current* (1) was measured at the beginning of the discharge experiments by introducing the galvanometer into the circuit of cable and battery. Neither the whole amount of the true and false discharges, nor the rapidly varying strength of the current from instant to instant, could be distinctly observed, because the period of vibration of the galvanometer needle, being about  $4\frac{1}{2}$  seconds each way, was neither incomparably greater nor incomparably smaller than the duration of the current in either direction. Thus the back-flow, or true discharge, which was of comparatively short duration, first gave the needle an impulse to the left (let us suppose); but before its natural swing, from even an instantaneous impulse, could have allowed it to begin to return, it was caught by the reverse current of false discharge and turned and thrown to the other side of zero through an angle to the right, which, except in the cases of the longest lengths of cable experimented on, was much greater than the angle of the first deflection to the left. It is obvious from what has been stated, that the durations of these deflections of the needle on the two sides do not even approximately coincide with the times during which the current flowed in the directions of the true and false discharges respectively, but that they depend in a complicated manner on the inertia of the needle and the varying forces to which it is subjected. The general character of the phenomena will be made sufficiently clear by the following examples, which are quoted from letters of Mr. Jenkin's to Prof. Thomson, of dates April 9 and April 22, 1859.

TABLE I.

| Lengths of cable in nautical miles*,—the first being for the Dardanelles, and the other three, of a different gauge, for the Alexandria and Candia telegraph. | Remote end of cable kept insulated. | Remote end of cable kept to earth. |
|---|-------------------------------------|------------------------------------|
|   | First throw of needle.              | First observed throw of needle.    |
| 123   | 1½ left                             | 3½ right                           |
| 137½  | 1½ "                                | 37 "                               |
| 261½  | 2½ "                                | 31 "                               |
| 399½  | 4½ "                                | 21 "                               |

To explain the cause of the deflections to the right recorded in the last column of this Table, the following observations were made, with care that the first motion of the needle in either direction, however slight or rapid, should not escape notice.

\* A nautical or geographical mile, or a knot as it is generally called in nautical language, is taken as 6087 feet.

TABLE II.—455 nautical miles of Alexandria and Candia Cable.

| Remote end of cable kept                                     | First throw of needle. | Recoil or second throw. | Excess of recoil above first throw. |
|--|------------------------|-------------------------|-------------------------------------|
| 1. To earth direct .....                                     | 24 right               | 24½ left                | 22                                  |
| 2. To earth through 10 German miles, resistance multi* ..... | 5 "                    | 22 "                    | 17                                  |
| 3. To earth through 50 "                                     | 11½ "                  | 18½ "                   | 7                                   |
| 4. To earth through 90 "                                     | 16½ "                  | 21 "                    | 4½                                  |
| 5. Insulated .....   | 44½ "                  | not observed            |                                     |
| 6. To earth direct, and key "pressed very sharp home" .....  | 3½ "                   | 24 "                    | 20¾                                 |

If the whole duration of current, with or without reversal, through the galvanometer coil had been infinitely small in comparison with the natural time of oscillation of the needle (which, reckoned in one direction, was about 4½ seconds), the recoils would have been sensibly equal to the first throws in the contrary direction, being only less by the effect of resistance of the air, &c. to the motion of the needle. Hence the numbers in the last column of the preceding Table prove that at some interval of time, not incomparably less than 4½ seconds, after the first motion of the needle, there was a current through the galvanometer coil opposite in direction to that which produced the first or *right* deflection, in each case except No. 5, or that in which the remote end of the cable was insulated. It may be safely assumed that the conductors used in cases 2, 3, and 4 to give the stated resistances between the remote end of the cable and the earth, exercised no sensible electro-magnetic influence, and held no sensible charge, in the actual circumstances; and it is interesting to see how the greater the resistance thus introduced, that is to say the more nearly the remote end is insulated, the greater is the first throw (due, as explained above, to true discharge), and the less is the excess of the recoil above it.

This excess, shown in the last column of the Table, exhibits the effect of the electro-magnetic induction from coil to coil which stops short the true discharge, and produces after it a reverse current constituting the "false discharge." The following experiments, performed by Mr. Jenkin on the 19th of April, 1859, on different lengths of the Red Sea cable, illustrate the relations between true and false discharge.

\* The resistance of this unit was found by experiment to be equal to about  $190 \times 10^6$  British absolute units of feet per second, or to 6½ nautical miles of the Alexandria and Candia cable, or to 4.39 of the Dardanelles, or to 7.44 of the Red Sea.

TABLE III.

| Lengths of Red Sea cable. | Remote end of length used kept insulated. Discharge from electrification of 36 cells. |                               |   | Remote end of length used kept to earth. True and false discharge from electrification and current of 72 cells. |   |  |
|---------------------------|---|-------------------------------|---|---|---|--|
|                           | First throw.  | Recoil.                       | Excess of first throw above recoil.         | First throw.  | Recoil.                                   | Excess of recoil above first throw.                                    |
| 312 nautical miles .....  | 20° left  | 19° right                     | 1   | 1½ left   | 18° right                                 | 16¾  |
| 546 "                     | 29½ "   | 27 "                          | 2½  | 5¾ "  | 15 "                                      | 9¼   |
| 858 "                     | 35 "  | 14 "                          | 21  | 17 "  | 22 "                                      | 5  |
| Col. 1.                   | Col. 2.<br>True discharge.  | Col. 3.<br>Inertia of needle. | Col. 4.<br>Effect of duration of discharge. | Col. 5.<br>True discharge.  | Col. 6.<br>"False discharge" and inertia. | Col. 7.<br>"False discharge," or effect of electro-magnetic induction. |

The great increase of the numbers in column 4, for the longer portions of cable, illustrates the fact first demonstrated by Prof. Thomson in 1854\*, that, when undisturbed by electro-magnetic induction, the discharge of a cable takes place at a rate inversely proportional to the square of the length. The duration of the discharge, which, when the remote end is kept insulated, is probably much increased by electro-magnetic induction, must be very considerable in the case of the 858 miles length, to produce so great a diminution as 21° in the recoil, from a throw of 35°, on a needle whose period of vibration was 4½ seconds. The diminution of 1° from the throw of 20°, as observed in the case of the 312 miles length, may be to some considerable proportion of its amount due to resistance of the air, although, as this is probably scarcely sensible on a single swing of the needle, it may be supposed that it is chiefly the effect of the duration of the discharge current. From column 7 it is clear that nearly all trace of the electro-magnetic influence would be lost sight of in comparison with the greater effect of true discharge, in the method of experimenting that was followed, if applied to lengths exceeding 1000 knots, in a coil or coils of similar dimensions to those actually used; while for the 546 knots, and shorter lengths, the effect of electro-magnetic induction is greater than that of the true discharge. It is remarkable that the effect of electro-magnetic induction is absolutely greatest for the shortest of the three lengths. These relations between the different lengths must of course, according to the explanation we have given, depend on the plan of coiling, whether in one coil or in several coils, and on the dimensions of the coil or coils, as

\* Proceedings of the Royal Society, 1855; and Phil. Mag. vol. xi. p. 146.



well as on the dimensions of the conductor, the gutta percha, and the outer iron sheath of the cable. The magnetic properties of the iron sheath must greatly influence the false discharge; and it would be interesting to compare the discharge from a plain gutta-percha-covered wire coiled under water with that from an iron-sheathed cable.

The following set of experiments, the last which we at present adduce, illustrate the influence of less or greater intervals of time during which the near end of the cable remains insulated, after removal from the battery but before application to earth through the galvanometer coil.

TABLE IV.—455 nautical miles of Alexandria and Candia Cable, remote end kept to earth. Battery of 72 cells Daniell's.

| Experiment. |                              | Throw of needle by true discharge. | Recoil, if any, and throw by false discharge. |
|-------------|------------------------------|------------------------------------|---|
| No. 1       | Key struck down .....        | 3° left                            | 27° right                                     |
| 2           | Key pressed down as usual.   | 23° "                              | 26° "   |
| 3           | Key pressed very gently ...  | 22° "                              | 20½° "  |
| 4           | Key held 5 seconds half-way. | 0° "                               | 14° "   |
| 5           | " 10 " "                     | 0° "                               | 17° "   |
| 6           | " 15 " "                     | 0° "                               | 4° "  |

In order to detect whether there might not have been "a slight hesitation in these three last instances, a much more delicate instrument was taken, but no such hesitation could be detected." These results are very remarkable, especially as regards the duration of the electro-magnetic influence. If the conductor of the cable were circumstanced like that of a common electro-magnet, and had no sensible electrostatic capacity, the "mechanical value\* of the current in it" at the instant of the connexion between its near end and the battery being broken, would be spent in a spark, or electric arc of sensible duration between the separated metal surfaces. But in the cable, the electrostatic capa-

\* See a paper "On Transient Electric Currents," by Prof. W. Thomson, *Phil. Mag.* June 1853, where it is shown that, like the mechanical value of the motion of a moving body, which is equal to half the square of its velocity, multiplied by its mass, the mechanical value of a current at any instant, in a coiled conductor, depending on electro-magnetic induction, is equal to half the square of the strength of the current through it, multiplied by a constant which the author defined as the "electro-dynamic capacity of the conductor," and which he showed how to calculate according to the form and dimensions of the coil. Additional explanations and illustrations will be found in Nichol's 'Cyclopædia of Physical Science,' second edition, 1859, under the heads "Magnetism—Dynamical Relations of," and "Electricity—Velocity of."

city of the near portions of the conductor has an effect analogous to that of Fizeau's condenser in the Ruhmkorff coils; and there was little or no spark (none was observed, although it was looked for, in the key) on breaking the battery circuit, and consequently, as nearly as may be, the whole mechanical value of the current left by the battery must have been expended in the development of heat in the conductor itself, and by induced currents in the iron of the sheath; and therefore we need not wonder at the great length of time during which electric motion remains in the cable.

The first column of results for experiments Nos. 1, 2, and 3, and the two columns for Nos. 4, 5, and 6, show that the continued flow of the main current through the cable, after the near end is removed from the battery and kept insulated, is to reduce its potential gradually from that of the battery (which for the moment we may call positive), through zero, to negative, in some time less than five seconds, and to keep it negative ever after, if it is kept insulated, as long as any trace of electro-dynamic action remains\*. It is probable that, at the same time, there may be oscillations of current backwards and forwards again†, and of potential to negative, and positive again, in some parts, especially towards the middle of the cable. The mathematical theory of the whole action is very easily reduced to equations; but anything like a complete practical analysis of these equations presents what may be safely called insuperable difficulties, because of the mutual electro-magnetic influence of the different parts of the cable with differently varying current through them. These peculiar difficulties do not, theoretically viewed, present any specially interesting features; and the problem is of little practical importance when once practical electricians are warned to avoid being misled by electro-magnetic induction, in testing by discharge during either the manufacture, the submergence, or lifting of a cable, and not to *under-estimate* the rate of signalling through a long submarine cable to be attained when it is laid, from trials through the same cable in coils, when electro-magnetic induction must embarrass the signalling more or less according to the dimensions and disposition of the coils, and probably does so in some cases to such an ex-

\* After what has been said in the text above, it is scarcely necessary to point out that this effect is both opposed to, and much greater than, anything producible by polarization of the earth-plates.

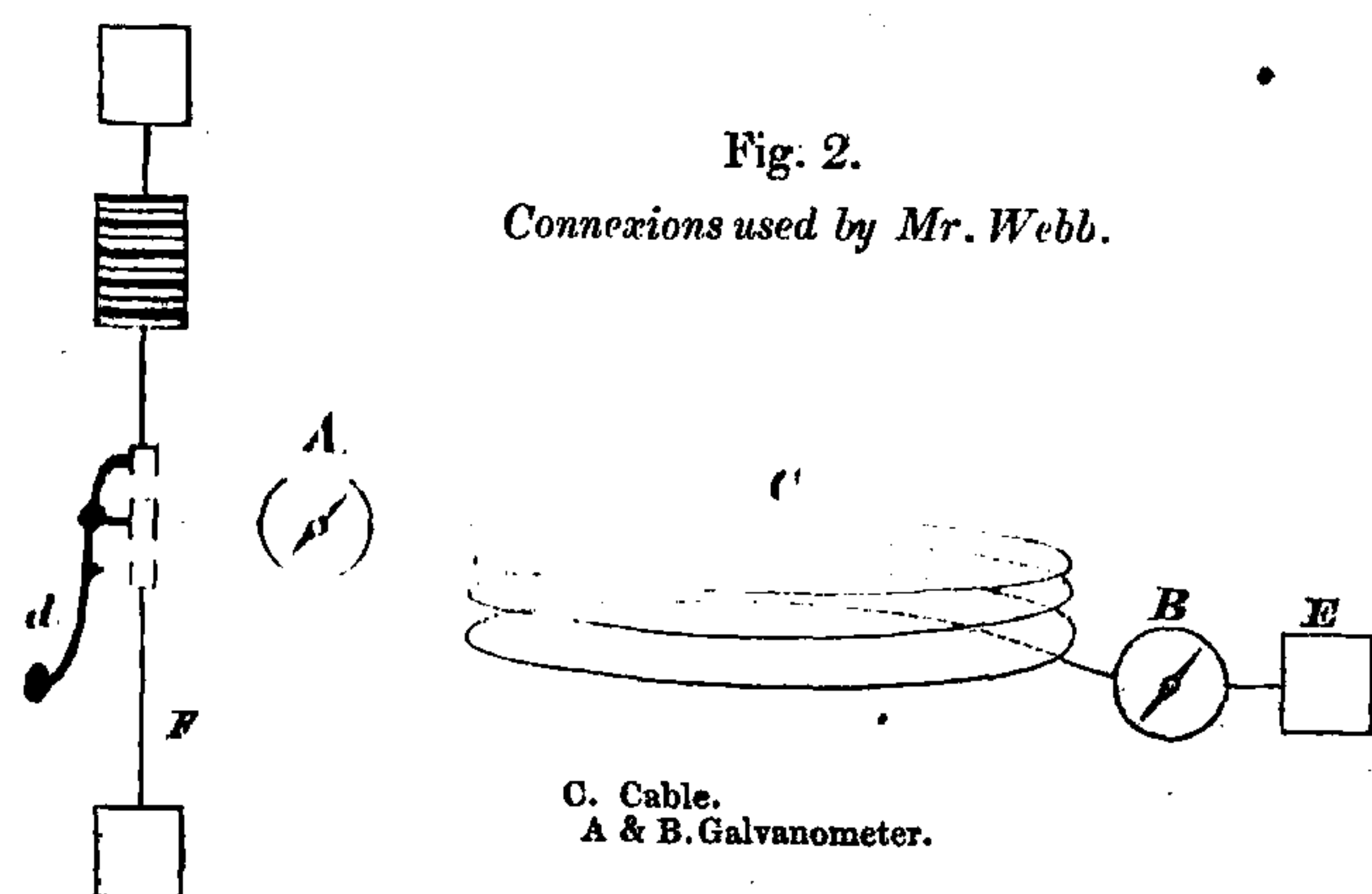
† As in the oscillatory discharge of a Leyden phial, investigated mathematically by Prof. Thomson ("Transient Electric Currents," *Phil. Mag.* June 1853), and actually observed by Feddersen, in his beautiful photographic investigation of the electric spark (*Poggendorff's Ann.* vol. cviii. p. 497, probably year 1860; also second paper, year 1861).



tent as to necessitate a considerably slower rate of working than will be found practicable after the cable is laid.

The theoretical conclusion that the "false discharge" would not be observed in submerged cables, has been recently verified by Mr. Jenkin on various lengths of Bona cable up to 100 miles, which he was engaged in recovering, and which, under careful tests, never gave the slightest indication of "false discharge," although, even when the remote end had completely lost insulation, they gave not only polarization effects\*, but also, in the same direction as these, but distinguishable from them, indications of true discharge. But, in fact, a fortnight before the theoretical conclusion was published by Prof. Thomson at the Aberdeen meeting, a most remarkable and decisive experimental demonstration of it was published by Mr. Webb, Engineer to the Electric and International Telegraph Company, who had independently discovered the phenomena which form the subject of this paper, and given substantially the same explanation as that which we now maintain. If there could be a doubt as to the electro-magnetic theory, the following extract from a letter of Mr. Webb's, published in 'The Engineer' of August 26, 1859, is decisive:—

"It is, however, on making contact at F with earth [that is to



say, putting what we have called the near end of the cable to earth] that the greatest and most singular difference occurs [between straight and coiled cables]. It will then be seen that the needle at A [that is to say, the needle of a galvanometer in circuit between key and cable instead of between key and earth, as in our experiments], instead of being reversed will continue

\* Of the same nature as those observed by Prof. Wheatstone on his short cables.

deflected in the original direction, and both needles will very gradually resume the perpendicular."

"There is a most marked difference between the effect produced between a coiled and a straight cable. The return current appears obliterated, or rather it is overpowered by the effects of the inductive action which takes place from coil to coil. The deflection thus produced is much greater than that produced by the return current. I have had perhaps peculiar facilities for observing this striking phenomenon. Whilst picking up a cable at sea, I frequently test the length I am operating on for return current; and as the cable becomes coiled into the ship the deflection of the needle, when testing for return current, becomes reversed.

"It is also my practice to cut the cable at certain distances as it is picked up, and then test such sections separately. On these occasions, sections which, when one end is insulated, will give a charge and discharge of 5°, will when that end is to earth, give a current at the battery end, after contact, of 90°, but in the reverse direction to that in which the discharge or return current would be if the cable were laid out straight."

XXVI. *On the Movements of Gases.* By J. A. WANKLYN, Demonstrator of Chemistry in the University of Edinburgh\*.

WHEN a gas heavier than air is placed in a cylindrical vessel closed at the top and open at the bottom, it does not descend rapidly. In like manner, a gas lighter than air contained in a cylinder closed below, but freely communicating with the atmosphere above, does not move upwards with rapidity.

By simply placing a gas in a vertical cylinder shut at one end, the ordinary course of gravitation is disturbed—to how great an extent few people would anticipate.

The following experiments show how remarkably the fall of gases is retarded by such an arrangement.

A tube† filled with carbonic acid was allowed to remain with its mouth open and directed downwards for the space of five seconds. After the lapse of that time, the gaseous contents of the tube were analysed in order to ascertain how much carbonic acid had made its escape.

The composition of the gas was—

|                         |       |
|-------------------------|-------|
| Air . . . . .           | 26.3  |
| Carbonic acid . . . . . | 73.7  |
|                         | 100.0 |

\* Communicated by the Author.

† Dimensions of the tube: Diameter, 14.5 millims.; length, 232 millims.; capacity, 37 cubic centims.