PHILOSOPHICAL TRANSACTIONS.

I. *On a Standard Voltaic Battery.* *By* Latimer Clark, *M.I.C.E.* *Communicated by Sir* William Thomson, *LL.D.*, *F.R.S.*

Received June 19,—Read June 19, 1873.

The object which the author had in view in pursuing the investigations alluded to in the following paper was to discover some form of voltaic battery which should have a perfectly constant electromotive force, and should maintain a uniform difference of electric potential between its poles. This want has been much felt by electricians; and the utility of such an investigation may be best shown by a brief reference to the recent history of electrical measurement.

In September 1861 a paper was read by the author before the British Association for the Advancement of Science advocating the adoption of a series of standard units of electrical measurement, and pointing out the mutual relations which should exist between such units. The subject was independently supported in Committee by Sir William Thomson, F.R.S., and the result was the appointment of a "Committee on Standards of Electrical Resistance," and a grant of money was set aside for the purposes of the Committee.

In 1862 the Committee presented their first Report; their numbers were then enlarged, further sums of money were voted for the continuation of their researches, and further Reports were presented in 1863, 1864, 1865, and 1867, after which the Committee was dissolved.

The Committee finally recommended the adoption of a system of natural electromagnetic units based on the metre and gramme*, in which the unit current flowing through a conductor of unit length exerts the unit force on the unit pole at the unit distance. As these units were unfitted in magnitude for practical use, certain multiples have been adopted in practice and have received names, and are now in almost universal use among electricians. These units are:—

1. Resistance.—The Ohm, equal to 10^7 absolute electromagnetic metre-gramme units.
2. Capacity.—The Farad, equal to 10^{-7} absolute electromagnetic units.
3. Potential.—The Volt, equal to 10^5 absolute electromagnetic units.

* They have since adopted the centimetre-gramme unit.

The measure of quantity is the same as that of electrostatic capacity, and in practice generally receives the same name, although it has been sometimes called the "Weber;" the weber or farad quantity is equal to 10^{-2} absolute units. Electrical currents are defined as currents of so many farads per second. In this system the volt electromotive force through the ohm resistance produces the unit current, or a current of one farad per second.

The Committee determined with great care the value of the ohm resistance and the farad capacity, and issued standards which have been very extensively copied and distributed. They would naturally have desired to issue a standard of electromotive force, or degree of potential, and thus complete the series; but in this they met with insuperable difficulties, and finally separated without accomplishing this part of their task.

This was a matter of regret, seeing that the electromotive forces of batteries and the strength of currents are among the measures most frequently required by the practical electrician.

The difference of potential between two bodies may be measured by measuring the force of attraction between two electrified planes of known dimensions at a known distance, or two coils conveying currents. It may also be determined by similar means to those employed by the Committee in their determination of the absolute unit of resistance—that is, by revolving a coil at a known speed in a field of known magnetic intensity. If the value of the earth's horizontal magnetic intensity (H) were uniform at different times and places, or easily obtained, and if the measurements were made at a distance from iron bodies, the tangent galvanometer would afford a means of absolutely measuring electromotive force.

All these methods, however, require complicated and expensive apparatus and great manipulative skill; and owing to these causes it may be safely asserted that not more than half a dozen absolute determinations of potential have ever yet been made. Practically electricians have been compelled to define electromotive forces by comparison with those of the GROVE'S or DANIELL'S cell, the copper and zinc cell, or other electromotive sources; and it is a curious circumstance that among the thousand galvanic combinations known to exist, not one has been hitherto found which could be relied upon to give a definite electromotive force: however pure the materials, and however skilful the manipulation, differences varying from four or five per cent. upwards constantly occur without any assignable cause; and different observers using different materials of course meet with still larger discrepancies.

The author, sustained by a conviction that this difficulty could not, in the nature of things, be insuperable, has carried on a course of experiments since 1867 with a view to discover and obviate the cause of these variations, and has devised a form of battery which he desires to lay before the Royal Society, and which appears to meet, in a very satisfactory manner, all necessary requirements.

The battery is formed by employing pure mercury as the negative element, the mercury being covered by a paste made by boiling mercurous sulphate in a thoroughly

saturated solution of zinc sulphate, the positive element consisting of pure distilled zinc resting on the paste.

The best method of forming this element is to dissolve pure zinc sulphate to saturation in boiling distilled water. When cool, the solution is poured off from the crystals and mixed to a thick paste with pure mercurous sulphate, which is again boiled to drive off any air; this paste is then poured on to the surface of the mercury, previously heated in a suitable glass cell; a piece of pure zinc is then suspended in the paste, and the vessel may be advantageously sealed up with melted paraffin-wax. Contact with the mercury may be made by means of a platinum wire passing down a glass tube, cemented to the inside of the cell, and dipping below the surface of the mercury, or more conveniently by a small external glass tube blown on to the cell, and opening into it close to the bottom. The mercurous sulphate ($Hg_2 SO_4$) can be obtained commercially*; but it may be prepared by dissolving pure mercury in excess in hot sulphuric acid at a temperature below the boiling-point: the salt, which is a nearly insoluble white powder, should be well washed in distilled water, and care should be taken to obtain it free from the mercuric sulphate (persulphate), the presence of which may be known by the mixture turning yellowish on the addition of water. The careful washing of the salt is a matter of essential importance, as the presence of any free acid, or of persulphate, produces a considerable change in the electromotive force of the cell.

The electromotive force of the elements thus formed is remarkably uniform and constant, provided the elements be not connected up and allowed to become weakened by working. A long series of comparisons was made between various elements, some of which had been made many months, and it was found that the greatest variation among them all did not differ from the mean value more than one thousandth part of the whole electromotive force; such a difference as this was, however, unusual, and might have been due to slight differences of temperature.

The following Table gives some of the results obtained. Temperatures are not stated, as the elements were approximately at the same temperature as the standards with which they were compared at the time.

No. of element or letter.	Date of construction.	Date of comparison.	Value.
96.	March 23, 1871	March 25, 1871	1·0000
16.	February 16, 1871	March 24, 1871	·9997
89.	March 23, 1871	March 25, 1871	·9991
90.	,,	,,	·9993
91.	,,	,,	·9985
92.	,,	,,	·9988
93.	,,	,,	·9991
94.	,,	,,	·9988
95.	,,	,,	·9998
97.	,,	,,	·9996
98.	,,	,,	·9996
99.	,,	,,	·9995
100.	,,	,,	·9993

* The author has obtained it from Messrs. HOPKINS and WILLIAMS, 5 New Cavendish Street.

TABLE (continued).

No. of element or letter.	Date of construction.	Date of comparison.	Value.
101.	March 24, 1871	March 25, 1871	1·0006
102.	”	”	1·0004
103.	”	”	1·0003
104.	”	”	1·0003
105.	”	”	1·0001
106.	”	”	·9995
115.	March 27, 1871	March 28, 1871	1·0008
116.	”	”	1·0005
117.	”	”	1·0002
118.	”	”	1·0005
119.	”	”	1·0002
120.	”	”	1·0001
A.	March 30, 1871	April 3, 1871	1·0003
C.	”	”	1·0003
E.	May 16, 1871	May 20, 1871	1·0005
F.	”	”	1·0005
D.	”	”	1·0003
L.	May 18, 1871	”	1·0004
155.	December 1, 1871	December 19, 1871	1·0001
156.	”	”	·9999
157.	”	”	1·0001
158.	”	”	1·0007
159.	”	”	1·0003
160.	February 17, 1872	February 26, 1872	1·0004
161.	”	”	1·0004
162.	”	”	1·0001
163.	February 24, 1872	”	1·0002
164.	”	”	·9999
165.	”	”	1·0001
166.	”	”	1·0001
167.	February 28, 1872	February 29, 1872	1·0007
W. 1.	September 11, 1872	October 9, 1872	·9999
2.	”	”	1·0001
3.	”	”	1·0003
4.	”	”	·9996
5.	”	”	·9996
6.	”	”	1·0001
7.	”	”	1·0003
8.	”	”	·9999
9.	”	”	·9997
10.	”	”	1·0006
11.	”	”	·9993
12.	”	”	1·0004
13.	”	”	·9993
14.	”	”	·9994
15.	”	”	1·0005
16.	”	”	·9996
17.	January 20, 1873	March 15, 1873	·9993
18.	”	”	1·0001
19.	”	”	1·0001
20.	”	”	·9993
21.	”	”	1·0004
22.	”	”	1·0001
23.	”	”	1·0005
24.	”	”	1·0000
25.	”	”	1·0005
26.	”	”	1·0005
		Mean value.........	·9999

Several experiments were made to determine the variation of the electromotive force at different temperatures; from the mean of these it appears that the force decreases with increase of temperature in the ratio of about ·06 per cent. for each degree Cent.; for example, an element gave relative values of ·9993 at 0° Cent. and of ·9412 at 100° Cent. The element varies much more at temperatures near 0° Cent. than at temperatures near 100° Cent. The variation for about 10 degrees above or below 15·5 is ·06 per degree Cent. When the temperature is lowered from 15°·5 to 0° the force increases at the rate of ·08 per cent. per degree; when raised from about 15°·5 to 100° Cent. it diminishes at the rate of ·055 per cent. per degree.

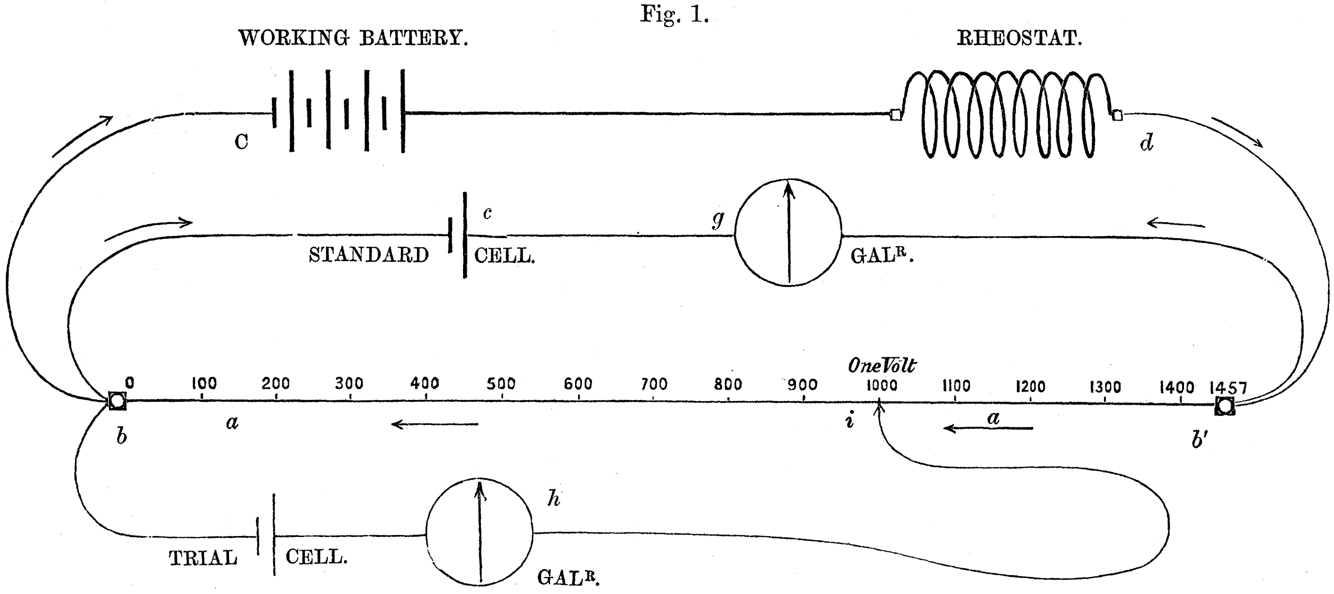
The element maintains a sensibly constant electromotive force for one or two years, and possibly longer if the salts be prevented from drying by an air-tight covering.

It is not intended that this element should supersede any of the existing combinations in practical use for the production of a current; for it, like the Marie Davy and many other batteries, falls rapidly in electromotive force when allowed to work through a circuit of small resistance, though it recovers its original electromotive force if allowed to remain inactive for a short time. It is intended to be used chiefly as a standard of electromotive force with which other elements or sources of potential can be compared by means of an electrometer or of instruments (similar to the one described below) which do not require any current.

It will, however, continue to supply a permanent current through a circuit of large resistance, say 10,000 ohms, without any sensible diminution of its force, and has been advantageously applied to the testing of submarine cables.

The instrument used in comparing the elements was one devised by the author in 1859 (see fig. 6, p. 14); the following diagram will explain its construction:—

Fig. 1.



a a represents a length of ten metres of platinum-iridium wire about ·5 millimetre

diameter wound on a cylinder of ebonite, the ends being connected to the axes *b b'*, which work in blocks of metal with mercury contacts: two batteries are also connected to the same blocks; the larger one, C, of several cells, sends a continuous current through the coil, the strength of which can be varied by means of the rheostat or resistance-coil, *d*; the smaller, *c*, is the standard element; it is connected with the terminal blocks, *b b'*, and it has a reflecting galvanometer, *g*, in circuit with it; as these two batteries are connected up in the same direction, they both tend to send a current through the coil *a a*. If the difference of potential maintained by the battery between the blocks *b b'* be greater than that of the standard cell, the battery will of course overpower the cell and send a reversed current through it; if, on the other hand, the difference of potential be less, then both the battery and the cell will jointly send a current through *a a*. In practice, however, the resistance, *d*, is so adjusted that the difference of potentials at *b* and *b'* is exactly the same as the difference of potential between the poles of the standard cell—in other words, is equal to its electromotive force, in which case no current passes through the galvanometer, *g*, and the cell remains inactive.

In comparing a trial cell with the standard, one pole of the cell is connected with that end of the coil to which the similar pole of the standard is fixed; the other pole is connected through a second galvanometer, *h*, to a sliding piece, *i*. By means of this sliding piece contact can be made at any point of the coil, *a a*, which is calibrated into 10,000 equal divisions. The point along the wire is readily found at which the potential is the same as that of the trial cell, and consequently no current passes through the galvanometer, *h*; in this case the reading or number of divisions gives the value of the trial cell in ten-thousandth parts of the standard element. As it is necessary that the standard element should have a higher electromotive force than that which is compared with it, two or more cells may be employed as a standard.

Having thus obtained a constant and easily reproducible measure of electric potential, it became necessary to ascertain its precise value in terms of the British-Association units and in absolute measure. There are two well-known methods by which this may be accomplished; the one is by the use of WEBER'S electrodynamometer *, and the other by means of the sine or tangent galvanometer †, in which the force of the current, acting on a suspended needle through a known resistance, is compared with that of the earth's horizontal intensity. It was determined to measure the element by both methods.

The electrodynamometer employed was an instrument constructed for the British-Association Committee, and referred to in their Report for 1867, page 478. This instrument had not been previously used.

In the electromagnetic system, the unit length of the unit current, acting on another similar current at the unit distance, exercises the unit of attractive or repulsive force. The value of the current (C) in absolute units may therefore thus be determined from its mechanical effect; and the resistance (R) of the circuit being known, the value of the

* TAYLOR'S Scientific Memoirs, vol. iii.

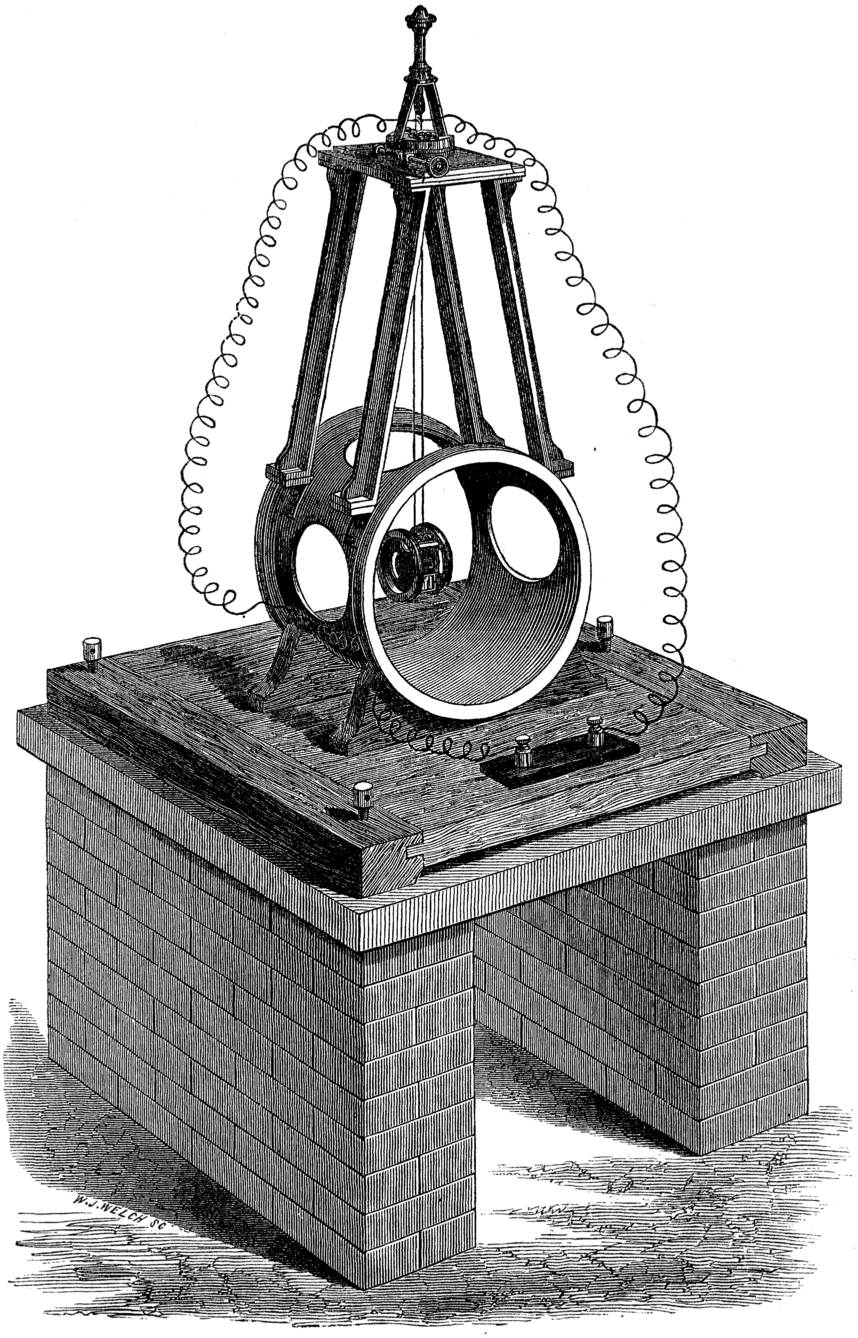
† British-Association Report, 1863, pp. 116, 141.

electromotive force (E) follows from OHM's formula,

$$C=\frac{E}{R} \text{ or } E=CR.$$

In the instrument in question (fig. 2) the large fixed coil is double, as in the arrange-

Fig. 2.

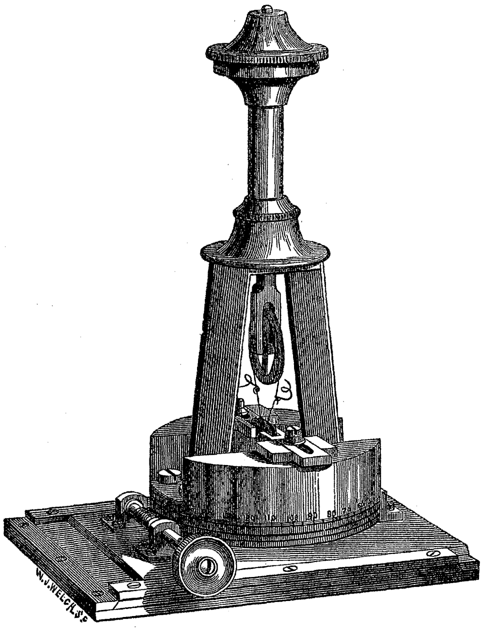


ment given by HELMHOLTZ and GAUGAIN to the tangent galvanometer, the two coils being in parallel vertical planes at a distance apart equal to their radius; the small coil is also

double, and is suspended bifilarly truly central to the fixed coils, the bifilar suspension-wires being used to convey the current between the fixed and movable coils.

The top of the instrument (fig. 3) is furnished with various contrivances for facilitating the central adjustment of the coils; these consist of two plates, forming a slide-rest movement fitted with verniers, by which horizontal motion can be given to the suspension in any direction. The upper plate carries a circular collar, which can be rotated by a tangent screw, and is graduated to 360 degrees. Into this collar fits a brass frame,

Fig. 3.



carrying two ebonite blocks, on which are two horizontal sliding pieces, diametrically opposite to one another, each furnished with a vernier, and terminating interiorly in small brass pulleys or rollers, against which the suspension-wires rest, and by which their distance apart can be regulated.

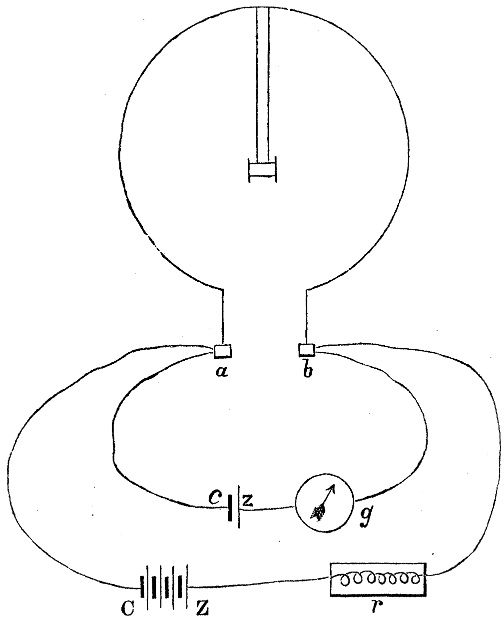
The frame carries a light pulley three centimetres diameter, which supports the suspension-wires by means of a silk cord passing over the pulley and attached to the wires near the top, so as to ensure an equality of tension on the two wires. The wires pass down through the collar and socket to the lower coil. The suspension-pulley admits of upward and downward adjustment by means of a milled head screw.

The electrodynamometer with its telescope and stand was supported on a solid brick foundation; the scale was a metre long, divided into millimetres, and was fixed at a distance of 2·7 metres from the centre of suspension. The scale was carefully adjusted at right angles to the axis of the telescope. A plate of silvered glass was fixed at the back of the large coils and adjusted parallel to them, and upon it was marked the centre of the coil accurately determined. When this centre mark, viewed through the telescope, was brought to coincide with the cross wires by moving the large coils, and when the

centre of the telescope reflected in the silvered glass also coincided with the cross wires, the telescope was of course directed normally to the centre of the plane of the coils, which were adjusted in the magnetic meridian; excessive care was taken with all the adjustments and readings, which were repeated with reversed currents and positions.

In order to maintain a current through the coils of the dynamometer and to ensure that the difference of potential between its poles should be precisely equal to that of the standard cell, an auxiliary battery was used in the manner before described. This consisted of five large DANIELL'S cells working through a circuit consisting of the dynamometer and a rheostat, *r* (fig. 4); *a* and *b* are the two terminals of the dynamometer, and the poles of the auxiliary battery, C, Z, are connected with them; the similar poles of the standard elements *c*, *z*, and the galvanometer, *g*, are also connected to the same terminals; and the rheostat *r* is adjusted so that no current passes through the galvanometer. In this case it is evident that the poles *a* and *b* are maintained at a difference of potential precisely equal to that of the standard elements. In this arrangement not the slightest difficulty is experienced in maintaining a perfectly steady and uniform current through the coils of the dynamometer. The poles of the dynamometer were so arranged that they could be connected immediately with a Wheatstone balance in order that its resistance could be measured promptly after each observation.

Fig. 4.



The winding of the large coils of the instrument was superintended by Professor CLERK MAXWELL, who kindly supplied me with the measurements as follows:—

	millimetres.
Mean circumference of first coil	1558·48
Mean circumference of second coil	1559·16
The depth of each coil is	12·90
The breadth of each coil is	15·00
The distance apart of the planes of the coils .	250

Each layer has 15 windings, and there are 15 layers, so that each coil has 225 windings.

The small coils were wound afresh by myself; the brass channels for the reception of the wire were of different sizes, and the same number of turns could not therefore be wound on it.

	millimetres.
Mean circumference of first coil	359·25
Mean circumference of second coil	357·45
Mean depth of the coils	6·67
Mean breadth of the coils	10·52
Mean distance apart	62·41
Number of windings on first coil	311
Number of windings on second coil	327

The moment of inertia of the suspended coil was determined from a great number of observations by different methods.

(1) The coil was vibrated on a fine steel wire, and the moment was then increased by a gun-metal cylinder passing through the centre of the coil; the increased time of vibration was then observed, and the moment of the coil calculated by the formula

$$I=\left(W\frac{l^2}{12}+\frac{d^2}{16}\right)\frac{t^2}{t'^2-t^2}, \quad \text{(1)}$$

where W is the weight of the cylinder in grammes, l and d its length and diameter in metres, and t' and t the times of vibration of cylinder and coil and of coil.

(2) From the value so ascertained the dimensions of a gun-metal cylinder were calculated, having about the same moment of inertia as the coil when vibrating on a transverse diameter: two of these rings were accurately formed by Mr. BECKER and carefully weighed; their times of vibration were compared with that of the coil when suspended from the same wire. The corrected moment of the coil was then calculated from these times by the formula

$$I=W\frac{t^2}{t'^2}\left(\frac{r^2+r'^2}{4}+\frac{a^2}{3}\right), \quad \text{(2)}$$

where t and t' are the times of a vibration of the coil and the ring, r and r' the external and internal radii of the ring, $2a$ its breadth, and W its weight.

(3) The moment of inertia was also determined by the vibration about its longitudinal axis of a metal cylinder of small thickness compared with its radius, as suggested by Sir WILLIAM THOMSON, F.R.S. (Proc. Royal Society, vol. xiv. p. 294), the coil and cylinder being alternately vibrated on the same wire.

The following were the results of the observations:—

First system, mean of five observations	1·27641
Second system, mean of twenty observations	1·27680
Third system, mean of one observation	1·27795
Moment of inertia employed in calculation	1·27691 metre-gramme.

It is not necessary to give the mathematical formula used in calculating the values of E, but the following Table gives the results of the whole of the series of observations with the electrodynamometer.

Date.	Value of E in volts.	Remarks.
8 December 1871 ...	1·4585	3 cells.
9 " "	1·4651	3 cells.
14 " "	1·4616	3 cells.
15 " "	1·4561	3 cells.
15 " "	1·4579	2 cells.
16 " "	1·4586	3 cells.
" " "	1·4517	3 cells, coil turned 180°.
" " "	1·4552	2 cells, coil turned back 180°.
" " "	1·4565	3 cells.
" " "	1·4535	2 cells.
" " "	1·4564	3 cells.
18 " "	1·4649	3 cells.
19 " "	1·4562	3 cells, coil turned 180°.
" " "	1·4558	3 cells, coil turned back 180°.
20 " "	1·4615	3 cells.
" " "	1·4539	3 cells.
" " "	1·4551	2 cells.
21 " "	1·4549	3 cells.
Mean value of E	1·45735 volt.	Temperature 15°·5 Cent.

The cells were frequently changed during the course of the experiments. Values were also obtained when the suspended coil was moved two millims. in various directions about the centre, but they did not differ sensibly from the above.

As a verification of the results obtained with the electrodynamometer, the electromotive force of the new element was also determined by means of the sine galvanometer by a method which is well known, viz.

$$E=\left(\frac{K}{2\pi n} H \sin\theta\right)\times R, \qquad (3)$$

where E is the electromotive force, K is the radius of the circle, n the number of turns, H the horizontal intensity of the earth's magnetism, θ the angle through which the coils must be turned in order to maintain the needle in the plane of the coils, and R the resistance of the circuit in absolute measure.

The instrument employed was specially constructed for these experiments, and presents some novelties. The needle was one centimetre in length, and was furnished with a mirror of parallel glass silvered by the chemical process, so that the reflection from either side could be observed in the telescope. The coil was 140 millimetres in diameter, and was furnished with a large mirror accurately parallel to its plane, silvered on the observing or front side, and having the centre of the coil marked upon it; by the aid of the telescope and these mirrors it was easy to adjust the needle accurately to the centre of the coil, and to ensure that the plane of the coil was truly vertical, and coincided with the magnetic meridian.

The telescope was carried on an arm one metre in length, which with the coil turned

on a pair of theodolite plates; and thus readings could be taken to half minutes. The experiments were performed within five miles of the Royal Observatory. The value of H, a knowledge of which is necessary for the determinations with this instrument, was kindly supplied to me by the Astronomer Royal for each day on which the observations were taken. No iron was near the instrument.

A difference of potential equal to that of one standard cell was maintained between the poles of the sine galvanometer, by the use of an auxiliary battery, rheostat, and galvanometer, in the manner described when treating of the dynamometer observations.

The following Table gives the results of these experiments.

Date.	Value of H.	Value of E.	Remarks.
9 Feb.	1·788	1·45605	Galvanometer wound with 8 turns German silver wire.
9 „	„	1·45457	
9 „	„	1·45400	
10 „	1·788	1·45809	
10 „	„	1·45669	
11 „	1·788	1·45799	
18 „	1·787	1·45566	Rewound with 28 turns German silver wire.
19 „	„	1·45671	
19 „	„	1·45680	Rewound with 27 turns German silver wire.
20 „	1·787	1·45752	
20 „	„	1·45645	
24 „	1·786	1·45522	
24 „	„	1·45492	
Mean value of E ...		1·4562 volt.	Temperature 15°·5 Cent.

The observations are corrected for the temperature of the element and of the coils; but the correction for the breadth and depth of the coil, according to Professor CLERK MAXWELL'S formula*, was so small as only to appear in the fifth place of decimals, and was therefore neglected. The instrument was rewound twice with various lengths of wire.

We have therefore the mean value of the electromotive force of the standard cell,—

	volt.
1. As determined by the electrodynamometer (18 observations)	1·45735
2. As determined by the sine galvanometer (13 observations) .	1·45621
Mean value of E	1·45678

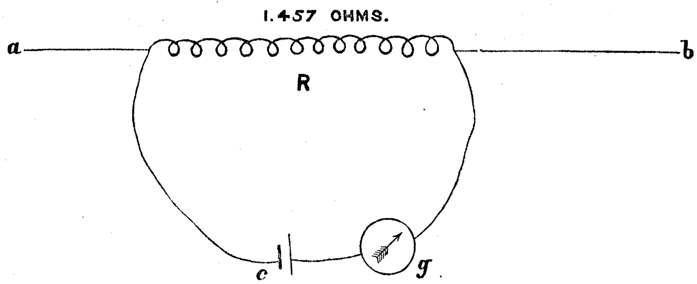
or, since no importance can be attached to the figures beyond the third place of decimals, 1·457 volt, equal to 145700 absolute electromagnetic units.

The uses of this standard element to practical electricians are sufficiently obvious. It may be used for determining the electromotive force of other elements by the use of an electrometer or by the discharge from a condenser. Or a condenser having a capacity of $\frac{1}{1\cdot457}$ farad charged by the standard cell would contain the B. A. unit quantity of electricity (one Weber), or $\frac{1}{100}$ of the absolute unit of quantity.

* British-Association Report, 1863, p. 170.

It is also of great value for maintaining a current of known strength in any circuit for the purposes of experimental research. Thus if it be desired to produce in any circuit (a b, fig. 5) a current equal to the B. A. unit of current ($\frac{1}{100}$ absolute units), it is only

Fig. 5.



necessary to insert in the circuit a wire R having a resistance of 1·457 ohm, and to connect to each end of this wire the poles of a standard cell, c, with a galvanometer, g, and to vary the strength of the current in $a\,b$ until no deflection is produced on the galvanometer; the current through a b will then be equal to one B. A. unit of current, or 1 farad per second, whatever its length or resistance.

By varying the resistance of R, or by varying the number of elements c, any given current can be steadily maintained through $a\,b$ at pleasure; on the other hand, the value of any given current can be measured by so varying the resistance R that no deflection is produced on the galvanometer. The value of the passing current will then be

$$C=\frac{1{\cdot}457}{R} \text{ farad per second.}$$

It is also evident that, knowing the value of E, we may determine the horizontal intensity of the earth's magnetism, H, in any place quickly and simply by means of an ordinary sine or tangent galvanometer.

Thus by transposing the equation (3) we have for the tangent galvanometer

$$H=\frac{E\,2\pi n}{R\,K\tan\theta} \quad \ldots\ldots\ldots \quad (4)$$

In fact the standard of electric potential is second only in importance to that of the standard of electric resistance; and the use of such a standard, combined with an auxiliary battery in the manner described in the foregoing paper, admits of a variety of applications which it is believed will be found of great value in electrical research.

In conclusion I have to acknowledge the great assistance I have received from Mr. HERBERT TAYLOR, C.E., and Dr. ALEXANDER MUIRHEAD, in conducting these experiments.

Fig. 6.