Measurement of Strong Galvanic Currents with Low Resistance According to Absolute Measure

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Abstract

English translation of Wilhelm Weber's 1841 paper "Messung starker galvanischer Ströme bei geringem Widerstande nach absolutem Maasse", [Web41a].

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By Wilhelm Weber[1,2,3]

It has happened several times in the article on magnetic friction[4,5] that it was important to determine the intensity of a galvanic current based on an absolute measure in order to be able to compare it with the intensity of other currents under any conditions. For instance, when an iron wheel was magnetized by a galvanic current to measure its magnetic friction, it was of interest to measure more closely the current that had produced this effect. For this purpose, the procedure that Faraday has indicated in the seventh series of his experimental investigations on electricity (*Philosophical Transactions* for 1834 and Poggendorff's *Annalen* 1834, Vol. 33, pp. 316 ff.),[6] could have easily been used. In this procedure the strength of the current is measured by the amount of water it decomposes in a given time. However, if the current had been passed through a water decomposition apparatus, it would have been significantly weakened, which should not be the case in those attempts which required an undiminished current.

It happens quite often that the measurement of the absolute current intensity by the amount of decomposed water is not permissible because of the necessary conduction of the current through a water decomposition apparatus. This is especially the case when simple circuits are used, where a very strong current through that apparatus is so weakened that there is no water decomposition and therefore there can be no question of measuring the decomposed water. In such cases a different method must be used, where the current is only passed through thick[7] and short copper wires, which do not increase the resistance noticeably.

Instead of the method specified by Faraday, the following very simple method was used for the above experiments where a certain piece of the thick current carrying wire was passed in a straight line at some distance from a magnetic needle, so that the latter deviated considerably from the magnetic meridian, while the rest of the circuit was positioned in such a large distance to the needle that its effects did not need to be considered.

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[1] [Web41a].

[2] Translated by H. Härtel, haertel@astrophysik.uni-kiel.de and http://www.astrophysik.uni-kiel.de/~hhaertel/index_e.htm. Edited by A. K. T. Assis, www.ifi.unicamp.br/~assis. We thank R. W. Gray for relevant suggestions.

[3] The notes by H. Weber, the editor of the third volume of Weber's *Werke*, are represented by [Note by HW:]; the notes by W. E. Weber are represented by [Note by WEW:]; while the notes by A. K. T. Assis are represented by [Note by AKTA:].

[4] [Note by HW:] Wilhelm Weber's *Werke*, Vol. II, p. 200.

[5] [Note by AKTA:] [Web41b].

[6] [Note by AKTA:] [Far34b] with German translation in [Far34a].

[7] [Note by AKTA:] *Starke* in the original.

From the measured deflection of the needle and taking into account the length and position of the active conducting wire as well as the absolute intensity of the Earth's magnetism at the point of observation, an absolute determination of the intensity of the galvanic current is possible — as has been given on p. 49 of the *Resultaten des magnetischen Vereins im Jahre 1840*.[8,9] Incidentally, this method has the advantage that it allows for the determination of the absolute current intensity for every moment, while when using Faraday's method only mean results are obtained for longer periods of time. Experiments can also be carried out where the intensity of one and the same current is measured simultaneously according to this and Faraday's method, and thereby a comparison of the units on which both methods are based would be possible; this comparison, however, is not necessary for the absolute determination of the current intensity. Such a comparison is only necessary when using an ordinary galvanometer, which consists of a magnetic needle provided with a multiplier and which is not directly suitable to obtain absolute determinations, as Jacobi did in Poggendorf's *Annalen*, Vol. 48.[10]

Given the frequently occurring need to determine the absolute intensity of galvanic currents in simple circuits, and with Faraday's method failing, an instrument which is constructed according to the principles mentioned above and which leads directly to the goal can be of great use, which is why some explanations are given here about its most advantageous facility and about some measurements made with it.

The instrument is constructed more appropriately, the greater the distance of the current carrying wire compared to the needle length, because then the distribution of the magnetism in the needle does not need much consideration; all this under the assumption that this greater distance leads to a deflection of the needle which can be observed with sufficient accuracy. From this the advantage is self-evident if the current carrying wire, instead of being guided in a straight line past the needle (which was just done in the above-mentioned attempts in the absence of a proper instrument and merely for the sake of easier execution), it will be guided in a wide vertically directed circle all around the needle. With the same deflection, the distance of all parts of the current carrying wire can then be much larger.[11] In addition, if the conductor forms exactly a vertical circle around the center of the needle, it becomes very simple and easy to calculate the absolute intensity

[8] [Note by HW:] Wilhelm Weber's *Werke*, Vol. II, pp. 202 and 203.

[9] [Note by AKTA:] [Web41b, pp. 202-203 of Weber's *Werke*].

[10] [Note by AKTA:] [Jac39].

[11] [Note by AKTA:] That is, the distance of any portion of the circular wire to the needle can be much larger than the distance of the straight wire to the needle in the previous case.

of the galvanic current from the observed deflection of the needle. This circular shape of the conductor has finally the special advantage that the rest of the conductor can be positioned very easily so that it has no noticeable influence on the needle. For this [purpose,] it is only necessary to put the two conductors, which feed the current in and out, very close to each other, where their effects on the needle mutually cancel. The first pieces of the conducting wires, starting at the ring, should best be conducted through two copper tubes, one enclosing the other but isolated from each other, as shown in Figures 1 to 4. The cross section of the circular conductor must be so large that its resistance is imperceptible.

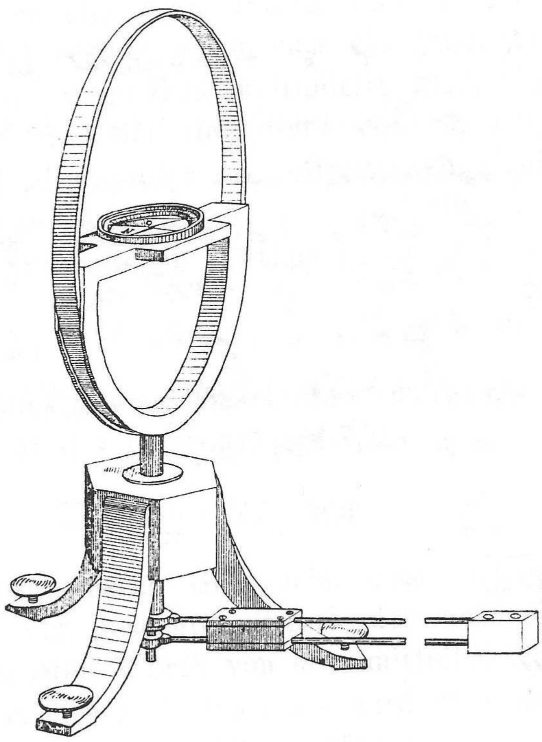

Fig. 1.

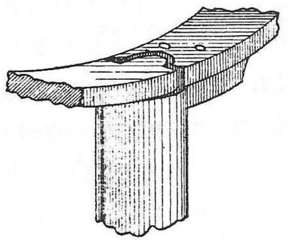

Fig. 2.

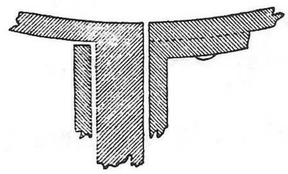

Fig. 3.

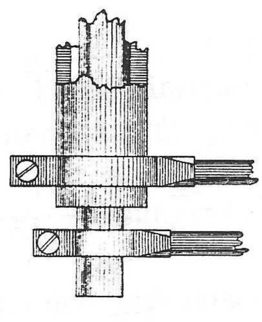

Fig. 4.

I had an instrument set up following this description, where the copper ring was $198\frac{1}{2}$ millimeter in diameter and the cross-section of which was 30 square millimeters. This ring was cut open at the bottom and one end was soldered to the feeding-in and the other end to the feeding-out conductor. These conductors, plugged into tubes, one plucked into another but insulated, led the current 100 millimeter down to two 4 millimeter thick, 1 meter long conducting wires, which run close to each other to two mercury cups, which could be connected to the two plates of the galvanic circuit. The magnetic needle stood in the middle of the circle on a wooden plate attached to the circle. The circle itself stood on a wooden tripod with set screws. The length of the needle was 50 millimeter and it moved on a circular arc divided into degrees. The use of the instrument requires no explanation. The calculation of the absolute intensity from the observed deflection of the needle consists in multiplying the tangent of the deflection angle by a constant number which is derived from the size of the copper ring and from the absolute horizontal intensity of the Earth's magnetism at the observation site. If R ($= 99.125\ mm$) denotes the radius of the ring, T ($= 1.7833$) the horizontal intensity of the Earth's magnetism (in Göttingen),[12] then that constant factor is:

$$\frac{1}{\pi} \cdot RT = 56.2675 \ .$$

If φ denotes the observed deflection, then the desired absolute intensity of the measured current is:

$$\frac{1}{\pi} \cdot RT \cdot \tan\varphi = 56.2675 \cdot \tan\varphi \ .$$

For more convenient use, a Table can easily be set up, which shows directly the desired value of the absolute current intensity for each observed value of φ. One will not be able to carry out such absolute measurements as easily and quickly with any other instrument as with this one.

One word remains to be said about the unit of measure of the current intensity on which this calculation is based. That current is assumed to be the unit of measure if, by flowing around the unit area, acts in the same way as the unit of free magnetism which is defined in the *Intensitatis vis*

[12][Note by AKTA:] As first measured by Gauss, with Weber's help, in his work on the intensity of the Earth's magnetic force reduced to absolute measure, announced at the Königlichen Societät der Wissenschaften zu Göttingen in December 1832, [Gau32]. The original paper in Latin was published only in 1841, although a preprint appeared already in 1833 in small edition, [Gau41] and [Rei19]. Several translations have been published. There are two German versions, one by J. C. Poggendorff in 1833 and another one in 1894 translated by A. Kiel with notes by E. Dorn; a French version by Arago in 1834; two Russian versions, one by A. N. Drašusov of 1836 and another one by A. N. Krylov in 1952; an Italian version by P. Frisiani in 1837; an English extract was published in 1935, while a complete English translation by S. P. Johnson and edited by L. Hecht appeared in 1995; and a Portuguese version by A. K. T. Assis in 2003: [Gau33], [Gau34], [Gau36], [Gau37], [Gau94], [Gau35], [Gau52], [Gau75], [Gau95] and [Ass03].

magneticae.[13,14,15,16]

It should also be noted that the observations are greatly facilitated if the compass is provided with a damper, which causes it to come to rest quickly. For more precise measurements it would be necessary to exchange the compass with a small magnetometer, but a much larger copper circle would have to be used, even if the needle was very short, and would only be for instance 60 to 80 millimeter long. The deflection of the needle when measuring strong currents would then still be measurable if the copper ring would also be 600 millimeter in diameter.

Some measurements made with this instrument may now be cited. To assess the greatest effects that can be produced with galvanic currents, it is important to measure the current intensities of the simple circuits without noticeably increasing the resistance they have due to the conductive wires. This measurement then gives directly the maximum of the current intensity, which can be approached by increasing the number of plate pairs in case the current has to overcome a larger resistance. The following Table shows the results of these measurements for 5 simple circuits of various sizes and compositions:

Indication of the circuit	Observed deflection	Calculated absolute intensity
A.	72°2′	173.52
B.	78°15′	270.52
C.	66°40′	130.44
D.	54°2′	77.54
E.	73°2.5′	184.52

[13] [Note by AKTA:] See footnote 12.

[14] [Note by WEW:] Note that this current is half as strong compared to a current whose measurement (see page 49 above) was based on a current exerting the unit of torque [or moment of force] on the magnetic needle, given the unit of length of the conductor and [the unit] of distance from the magnetic needle, and [also] given the unit of free magnetism in the needle. This arises easily from the basic law of galvanism, as stated in Section 1 of the *Allgemeine Lehrsätze* in the previous volume of the *Resultate* and has already been mentioned here on page 48.

[15] [Note by HW:] See Wilhelm Weber's *Werke*, Vol. II, pp. 202 and 203; and Gauss' *Werke*, Vol. V, p. 198.

[16] [Note by AKTA:] [Web41b, pp. 48-49 of the *Resultate aus den Beobachtungen des magnetischen Vereins im Jahre 1840* and pp. 202-203 of Weber's *Werke*]. The *Allgemeine Lehrsätze* mentioned by Weber refers to Gauss' work "Allgemeine Lehrsätze in Beziehung auf die im Verkehrten Verhältnisse des Quadrats der Entfernung wirkenden Anziehungs- und Abstossungs-kräfte", [Gau40, p. 198 of Gauss' *Werke*], with English translation in [Gau43]: "General propositions relating to attractive and repulsive forces acting in the inverse ratio of the square of the distance".

The following should be noted about the size and composition of these circuits:

A was a Daniell's cell,[17] where the copper area touched by the copper vitriol solution was 9 square decimeter. The copper vitriol solution, as well as the water surrounding the amalgamated zinc rod, was mixed with 10 percent sulphuric acid.

B was a Grove's cell.[18] A platinum beaker with a surface area of 1.9 square centimeter was filled with ordinary nitric acid, while a small porous clay pot filled with dilute sulphuric acid stood in the middle and an amalgamated zinc rod was immersed in the latter. The sulphuric acid was mixed with 80 percent water.

C was a cell according to Professor Poggendorf[19] with an iron plate in smoking nitric acid, instead of the platinum plate in ordinary nitric acid from Grove's column. Nitric acid touched the iron plate from both sides, but the total contact area was only 3/4 decimeter. The sulphuric acid surrounding the clay pot and in which an amalgamated zinc cylinder was immersed was diluted with 90 percent water.

D was a cell of the same size and composition as the previous one, with the only difference that the zinc plate of the previous cell immersed in dilute sulphuric acid was also replaced by an iron plate. Attention has already been drawn to the fact that only one metal is needed for the strong currents that arise here (*Göttinger gel. Anz.* 1841, 81. Stück).[20,21]

E finally was a cell according to Professor Bunsen in Marburg.[22] A coal cylinder made of hard coal and cokes, which was permeated with nitric acid, was immersed in dilute sulphuric acid with a surface area of $1\frac{7}{10}$ square decimeter and surrounded by a zinc cylinder at a short distance. The sulphuric acid was diluted with 90 percent water.

The above results are the largest which were obtained when testing several cells of the same construction. Four examples were tested from the first, fourth and fifth type, two examples from the third type and only one example from type two. The greatest difference in these repetitions occurred with the

[17] [Note by AKTA:] The Daniell's voltaic cell or element was named after its inventor, John Frederic Daniell (1790-1845).

[18] [Note by AKTA:] The Grove voltaic cell or element was named after its inventor, William Robert Grove (1811-1896).

[19] [Note by AKTA:] Johann Christian Poggendorff (1796-1877) edited the *Annalen der Physik und Chemie* from 1824 to 1876, where many of Weber's papers were published. The modern *Annalen der Physik* is the successor to this Journal.

[20] [Note by HW:] Wilhelm Weber's *Werke*, Vol. III, p. 4.

[21] [Note by AKTA:] [Web41c, p. 4 of Weber's *Werke*].

[22] [Note by AKTA:] The Bunsen voltaic cell or element was named after its inventor, Robert Wilhelm Eberhard Bunsen (1811-1899).

fifth type and was probably due to the often imperfect conduction of the electricity from the coal into the copper wire. The other 3 cells had given about half the current as the one above.

The strongest current among those measured here was obtained in the above experiments with the Grove circuit, whose intensity was found = 270.52. Such a current, if it passed unimpeded through water, would decompose 2.536 milligram water every second, or develop about $4\frac{3}{4}$ cubic centimeter of detonating gas,[23] as will be shown in the following article. If such a current encompasses a square meter of area, it exerts just as great magnetic forces at a distance as a very strong steel magnet weighing 676.3 gram (where you can count 400 [absolute] units of measure of magnetism on 1 milligram of steel).

Thin platinum wires are often used to estimate by their glow the intensity of the current. A measurement showed that a clear, daytime glow of a 2/15 millimeter thick platinum wire was produced by a current whose absolute intensity was = 20. In order to get hold of the amount of heat released in such a wire, a $28\frac{1}{2}$ millimeter long piece of that 2/15 millimeter thick platinum wire was passed through 114 grams of distilled water. The heat released in the water by a galvanic current which was conducted through this wire was shared with the surrounding water and could be measured by the temperature increase of the water in which a thermometer was immersed. The same current, which caused the heating of the wire and of the water, was conducted through the copper circle of the galvanometer and deflected the magnetic needle, placed at the center, from the magnetic meridian. The following Table shows the results of such a series of measurements, where the initial temperature of the water was 15° centigrade.

Time	Deflection	Water-Temperature
11′0″	52°30′	21.5
11′30″	52°30′	22.0
13′30″	51°30′	23.0
15′0″	51°30′	24.0
17′0″	52°0′	25.0
19′50″	51°50′	26.0
20′30″	51°20′	27.0
22′30″	51°0′	28.0
24′30″	50°30′	28.5
26′0″	50°10′	29.0
29′0″	49°20′	30.0

[23] [Note by AKTA:] *Knallluft* in the original. See [Pat17, p. 142].

The difference x between the initial temperature of the water and the temperature after t minutes can then be determined as:

$$x = 0.95 \cdot t - 0.015 \cdot t^2 ,$$

from which it follows that if the heat development in the wire is proportional to the current intensity,[24] a current whose intensity is $= 1$ would heat the described platinum wire during 1 minute so that the temperature of 1 gram of water would rise by 1.4° centigrade. If the wire was cut inside the water, the deflection of the needle was zero, to prove that no measurable part of the current was flowing through the water.

It is to be hoped that in experiments with strong galvanic currents, their absolute intensity is always measured and stated in a similar manner as described here, in order to make the results obtained under different conditions comparable by different observers and to be able to check their agreement.

[24][Note by AKTA:] As a matter of fact, Joule discovered also in 1841 that the heat which is evolved is proportional to the square of the intensity of the current, multiplied by the resistance of the wire, [Jou41].

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