Comments on the Paper: "Investigation into the Electric Arc" by Prof. E. Edlund

Wilhelm Weber

Editor's Note: An English translation of Wilhelm Weber's posthumous paper "Bemerkungen zu der Abhandlung: "Untersuchung über den galvanischen Lichtbogen" von Prof. E. Edlund.[1]

Posted in February 2024 at www.ifi.unicamp.br/~assis

[1] [Web94].

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Chapter 1

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Wilhelm Weber[2,3,4,5]

Professor Edlund in Stockholm reported interesting experiments and measurements relating to the *electric arc* in the 131st volume of Poggendorff's Annalen.[6] Using a rheostat specially set up for these experiments, he was able to keep the current strength of a Bunsen cell of 70 to 80 elements,[7] measured by a tangent galvanometer,[8] constant, even if the carbon tips[9] used to close the circuit were brought out of contact and at different distances from one another, whereby the electric arc was created between them. Every time the distance was increased there had to be a reduction in the rheostat resistance, every time the distance was reduced there had to be an increase in the rheostat resistance; apart from the sign, the measurements showed that the magnitude of the change in distance was very closely proportional to the magnitude of the change in resistance of the rheostat. According to this, Mr. Edlund equates the real resistance in the current section associated with a change in distance of the two carbon tips to the corresponding change in resistance of the rheostat.

However, when the two carbon tips gradually approached each other until contact was made, there was, in addition to this, a sudden reduction in resistance, which had to be

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2[Web94].

3Translated and edited by A. K. T. Assis, www.ifi.unicamp.br/~assis. I thank L. Hecht for relevant suggestions.

4The Notes by H. Weber, the editor of the fourth volume of Weber's *Werke*, are represented by [Note by HW:]; while the Notes by A. K. T. Assis are represented by [Note by AKTA:].

5[Note by HW:] This essay, which W. Weber wrote down after reading Edlund's treatise, was found in his posthumous works without a heading.

6[Note by AKTA:] [Edl67], see also [Edl86]. Erik Edlund (1819-1888) was a Swedish physicist. The German expression *galvanische Lichtbogen* can be translated as electric arc, voltaic arc or galvanic arc.

7[Note by AKTA:] In German: *Bunsen'-schen Säule*. The Bunsen voltaic cell or element was named after its inventor, Robert Wilhelm Eberhard Bunsen (1811-1899).

8[Note by AKTA:] In German: *Tangentenboussole*. The tangent galvanometer was invented by Johan Jakob Nervander (1805-1848), [Ner33] and [Sih21]. Friedrich Kohlrausch discussed measurement of currents with the tangent galvanometer, [Koh83, Chapters 64 and 65, pp. 188-192].

9[Note by AKTA:] In German: *Kohlenspitzen*.

compensated for by a considerable increase in the rheostat resistance, which Mr. Edlund distinguishes from the *real* resistance of the current piece between the two carbon tips, because it has no relation to the length of this current piece. Mr. Edlund considers this only an *apparent* change in resistance, which is due to a *change in the electromotive force equivalent to the measured current*. It is obvious that this change in the electromotive force must occur in the carbon tips at the moment when the contact is removed.

The investigation of this electromotive force occurring in the carbon tips at the moment of breaking the contact now forms the main goal of the further investigation carried out by Mr. Edlund, using as a guide that if E is the electromotive force of the Bunsen's cell and L the resistance of the whole circuit, the current work or its equivalent is represented by $E \cdot [E/L]$. If now, at the moment when the contact is removed, the force D opposite to the electromotive force E, which has its seat in the carbon tips, is added, the current, which was $= E/L$ at the contact, would be reduced by D/L, and in the same way the actual current work would drop from $E \cdot [E/L]$ to $(E - D) \cdot [(E - D)/L]$.

On the other hand, Mr. Edlund rightly states facts and laws according to which such a reduction of the work of the current does not take place when the current continues after the contact is removed and therefore compares this phenomenon with the phenomena of damping, where the damper reduces the work of the original current by the electromotive force it exerts on the closed circuit of the original current, but for which the work of the current induced in the damper itself gives an equivalent. Such an equivalent, says Mr. Edlund, is the work required to tear off the carbon particles[10] from which the arc originates.

I now completely agree with Mr. Edlund on the two main points, namely, *firstly*, that at the moment the contact is removed, a separating force D opposite to the electromotive force of the cell E is added to the carbon tips, and *secondly*, that the sum of the work done in the arc and the current work of the rest of the circuit is equal to the current work $E \cdot [E/L]$, which the Bunsen cell performs during the contact, then in order to avoid any contradiction a third point seems to deserve closer consideration.

If the electromotive force of the Bunsen's cell is the only one that has worked in the *closed* circuit from the resistance L up to now, but the electromotive force $= -D$ is added at the moment the contact is removed, then if the circuit also had the same resistance L after the contact has been removed, the value of the previous current work $E \cdot [E/L]$ would from now on necessarily fall to $(E - D) \cdot [(E - D)/L]$, without any equivalent for this loss, just as if a cell[11] with infinitesimally small resistance of the force D had been inserted *upside down* into the previous circuit of the force E.

But since such a reduction in work does not actually occur when the work in the circuit and in the electric arc is combined, it is clear that in order to eliminate the contradiction it must be discussed in more detail whether the circuit is really still *closed* after the contact has been removed and whether there is therefore a *real* resistance to the piece of current lying between the two tips of the carbon, as Mr. Edlund has determined it, in that the *real resistance of a conductor* is understood to be the constant ratio of the electromotive force acting in this conductor to the strength of the current thereby produced in the conductor.

In my opinion, after the contact has been removed, there is no closed circuit and no real resistance for the current section between the carbon tips that are out of contact, because such resistance only applies to a real conductor that is not present between the carbon tips.

I distinguish between a *closed electrical current* and a *closed galvanic circuit*, in that every

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[10] [Note by AKTA:] In German: *Kohlentheilchen*.

[11] [Note by AKTA:] In German: *Becher*. That is, a voltaic cell or element.

closed galvanic circuit also forms a closed current, but not vice versa every closed current forms a closed galvanic circuit. Ohm's law,[12] according to which the current strength is represented by the quotient E/L (when E denotes the electromotive force, L the resistance), only applies to *closed galvanic circuits* (i.e. for electrical currents in closed conductors) but in no way to closed currents *without a closed conductor*.

Assuming this, it is essentially a question of what Mr. Edlund described and measured as the *real* resistance of the section of current between the carbon tips. I also consider it only as an *apparent* resistance, which is based on an *electromotive force equivalent to the measured current intensity.*

Mr. Edlund denotes the *real* resistance (which is proportional to the distance of the carbon tips) for the unit of distance with b, the *apparent* resistance with a and assumes that a has its basis in an electromotive force $= -D$, the current intensity $= (E - D)/(M + nb)$ when n denotes the distance of the carbon tips, instead of putting it $= E/(a+nb)$ as it should be if a would be a real resistance, like nb. Instead I set the current intensity $= (E - D)/M$ because I am looking for the source of all the *apparent* resistance $a + nb$ in the electromotive force $-D$.

According to his calculation, Mr. Edlund finds the electromotive force D, expressed in parts of the electromotive force of the cell, to be almost constant, namely

$$D = 0.3239 \ .$$

On the other hand, according to my calculation, I find that it increases almost proportionally with the length of the arc, namely

Length of the arc in scale divisions	D
5	0.377
4	0.371
3	0.362
2	0.355
1	0.349

The essential point that comes into consideration in this various calculation is that Mr. Edlund has to look for a new unknown source after his calculation for the electromotive force D; According to my calculation, the source of this electromotive force arises automatically and necessarily from the laws of distribution of electricity in an unclosed galvanic circuit.

For in a closed galvanic circuit, the current path is surrounded by a surface on which such a distribution of free electricity takes place that the ratio of the electromotive force to the resistance is balanced in all current elements;[13] in an unclosed galvanic circuit, on the other hand, the surface charged with free electricity also envelops the two ends of the circuit which have been brought out of contact, just as in a self-discharge jar[14] the positive and negative charge also extends over the surfaces of the two buttons of the spark micrometer which face each other and are separated by a small intermediate space.

However, this electricity distributed on the surface plays a completely different role when the circuit is not closed than when the circuit is closed; in the latter it has no influence

[12][Note by AKTA:] Georg Simon Ohm (1789-1854). Ohm's law is from 1826: [Ohm26a], [Ohm26c], [Ohm26d], [Ohm26b] and [Ohm27] with French translation in [Ohm60] and English translation in [Ohm66].

[13][Note by AKTA:] For a discussion of surface charges in resistive conductors carrying steady currents, see [AH07], [AH09], and [AH13].

[14][Note by AKTA:] In German: *Selbstentladungsflasche*. That is, a self-discharge Leyden jar.

at all on the value of the entire electromotive force E, because the integral value of the electromotive forces exerted by each particle on all elements of a *closed* line in the direction of the same is known to be zero. However, the integral value of the electromotive forces exerted by each particle on all elements of an *unclosed* line (which forms the unclosed circuit) in the direction of the same is different from zero and therefore has a very large influence on the value of the entire electromotive force E, so that at electrical equilibrium (when the unclosed galvanic circuit is surrounded by a perfect insulator), the value of E is completely canceled.

Just as in a self-discharging jar the charges on the buttons can disappear at the moment of self-discharge, but are always recreated as the jar is continuously connected to the electrostatic machine,[15] so is the case with the galvanic circuit when sparks flash over between the ends that are out of contact and form the arc. Even if there were a *continuous* withdrawal of electricity from both ends in some way other than through a *conductor closing the circuit*, these charges and their influence on the value of the entire electromotive force E would not disappear.

If an amount of electricity were continuously withdrawn from the two ends (in any other way than through a conductor closing the circuit), which would be in the ratio of $n : 1$ to the amount passing through the cross-section of the circuit when contact was made, then on the surface of the unclosed circuit, such a distribution of electricity would form that in all elements of the circuit the ratio of the electromotive force to resistance would be like $nE : L$, so that the whole electromotive force in the whole length L of the circuit would be equal to nE only a fraction of the electromotive force of the cell, while the rest of the latter, namely $(1-n)E$, would be completely canceled out by the influence of the electrical distribution on the surface of the unclosed conductor. The electrical charge on the surface of the galvanic circuit after contact has been removed therefore exerts the electromotive force $-(1-n)$, the same as that described above as $-D$.

Of the process in the arc, by which the two ends of the galvanic circuit which have been brought out of contact are continually deprived of electricity, only so much is known that it is not mediated by any conductor closing the circuit. Now imagine this process consisting of a small conductor oscillating between the ends that have been brought out of contact. Provided that no other force acts on this conductor than that resulting from the interaction of its electrical charge and the charges of the two ends, and that when it hits the immovably held ends, this conductor is thrown back according to elastic laws in such a way that it

[15][Note by AKTA:] In German: *Elektrisirmaschine*. That is, an electrostatic generator or electrostatic machine.

loses nothing of its living force,[16] its speed would increase to infinity, and the position of a conductor closing the circuit would be more and more perfectly represented by it.

But if the conductor were not thrown back according to elastic law, or if living force were to be withdrawn from the pendulating conductor in some other way, and indeed with each repetition of its movement the same fraction of the total living force it possessed, then its speed would soon approach a limit where it would remain constant. The renewal of the living force withdrawn from the oscillating conductor at this speed forms the work A done by the electricity between the two ends (in the arc) and the equation used to determine this limit state:

$$A + nE \cdot \frac{nE}{L} = E \cdot \frac{E}{L} \, .$$

It is easy to see that if the determinations of $(1-n)E = D$, as given by Mr. Edlund, could be combined with determinations of the periodicity of the discharges through the arc, in the manner given by Mr. Feddersen[17] for the discharge spark of a Leyden jar, considerably more insight into the still little known process in the arc would be gained.

If the two carbon tips were suddenly completely isolated from each other with the removal of the contact, the value of $-D$ would suddenly jump from zero to $-E$. Due to the unknown process between the carbon tips, by which electricity is still transported from one carbon tip to the other even after the contact is removed, this sudden jump in the value of $-D$ is somewhat reduced, namely from o to $-(1-n)E$. But it is obvious that by gradually increasing the distance of the carbon tips from each other, the value of $-D$ must also gradually change from $-(1-n)E$ to $-E$, thus D must increase with the distance of the carbon tips, as it also resulted from Edlund's measurements according to my calculation above.

[16][Note by AKTA:] The Latin expression *vis viva* (*living force* in English or *lebendige Kraft* in German) was coined by G. W. Leibniz (1646-1716).

Originally the *vis viva* of a body of mass m moving with velocity v relative to an inertial frame of reference was defined as mv^2, that is, twice the modern kinetic energy. However, during the XIXth century many authors like Weber and Helmholtz defined the *vis viva* as $mv^2/2$, that is, like the modern kinetic energy.

In 1847 Helmholtz expressed himself as follows, [Hel47, p. 9] with English translation in [Hel53, p. 119]:

> For the sake of better agreement with the customary manner of measuring the intensity of forces, I propose calling the quantity $\frac{1}{2}mv^2$ the quantity of *vis viva*, by which it is rendered identical with the quantity of work.

In 1872 he made an analogous definition, [Hel72a] with English translation in [Hel72b, p. 533]:

> If we, as has always hitherto been done, name *vis viva* or *actual energy* the sum of the moved inert masses multiplied each by half the square of its velocity, then, [...]

Weber also utilized the expression *vis viva* as $mv^2/2$. This can be seen, for instance, in [Web71, footnote 1, pp. 256-257 of Weber's *Werke*] with English translation in [Web21, footnote 140, pp. 74-75].

[17][Note by AKTA:] Berend Wilhelm Feddersen (1832-1918) was a German physicist.

Bibliography

[AH07] A. K. T. Assis and J. A. Hernandes. *The Electric Force of a Current: Weber and the Surface Charges of Resistive Conductors Carrying Steady Currents*. Apeiron, Montreal, 2007. Available at www.ifi.unicamp.br/~assis.

[AH09] A. K. T. Assis and J. A. Hernandes. *A Força Elétrica de uma Corrente: Weber e as Cargas Superficiais de Condutores Resistivos com Correntes Constantes*, volume 73 of *Coleção Acadêmica*. Edusp and Edufal, São Paulo and Maceió, 2009.

[AH13] A. K. T. Assis and J. A. Hernandes. *Elektrischer Strom und Oberflächenladungen: was Wilhelm Weber schon vor mehr als 150 Jahre wußte*. Apeiron, Montreal, 2013. German translation by H. Härtel. Available at www.ifi.unicamp.br/~assis.

[Edl67] E. Edlund. Untersuchung über den galvanischen Lichtbogen. *Annalen der Physik und Chemie*, 131:586–607, 1867.

[Edl86] E. Edlund. On the resistance in the voltaic arc. *Philosophical Magazine*, 21:131:366–368, 1886.

[Hel47] H. von Helmholtz. *Über die Erhaltung der Kraft*. Engelmann, Leipzig, 1847. Reprinted in H. Helmholtz, Wissenschaftliche Abhandlungen (Johann Ambrosius Barth, Leipzig, 1882), Vol. 1, Article 2, pp. 12-75.

[Hel53] H. Helmholtz. On the conservation of force; a physical memoir. In J. Tyndall and W. Francis, editors, *Scientific Memoirs,* Vol. on Natural Philosophy, pages 114–162, London, 1853. Taylor and Francis. Translated by J. Tyndall. Available at https://books.google.com.br/books?id=C1i4AAAAIAAJ&hl=pt-BR&source=gbs_navlinks_s.

[Hel72a] H. Helmholtz. Ueber die Theorie der Elektrodynamik. *Monatsberichte der Berliner Akademie der Wissenschaften*, pages 247–256, 1872. Reprinted in H. Helmholtz, Wissenschaftliche Abhandlungen (Johann Ambrosius Barth, Leipzig, 1882), Vol. 1, Article 34, pp. 636-646.

[Hel72b] H. von Helmholtz. On the theory of electrodynamics. *Philosophical Magazine*, 44:530–537, 1872.

[Koh83] F. Kohlrausch. *An Introduction to Physical Measurements — with appendices on absolute electrical measurement, etc.* J. & A. Churchill, London, 2nd edition, 1883. Translated from the fourth German edition by T. H. Waller and H. R. Procter.

[Ner33] J. J. Nervander. Mémoire sur un Galvanomètre à châssis cylindrique par lequel on obtient immédiatement et sans calcul la mesure de l'intensité du courant électrique qui produit la déviation de l'aiguille aimantée. *Annales de Chimie et de Physique*, 55:156–184, 1833.

[Ohm26a] G. S. Ohm. Bestimmung des Gesetzes, nach welchem Metalle die Kontakt-Elektrizität leiten, nebst einem Entwurfe zu einer Theorie des Voltaschen Apparates und des Schweiggerschen Multiplikators. *Journal für Chemie und Physik*, 46:137–166, 1826. Reprinted in *Ostwald's Klassiker der exakten Wissenschaften*, Nr. 244, C. Piel (ed.), (Akademische Verlagsgesellschaft, Leipzig, 1938), pp. 8-29.

[Ohm26b] G. S. Ohm. Ein Nachtrag zu dem vorstehenden Aufsatz. *Annalen der Physik und Chemie*, 7:117–118, 1826.

[Ohm26c] G. S. Ohm. Versuch einer Theorie der durch galvanische Kräfte hervorgebrachten elektroskopischen Erscheinungen. *Annalen der Physik und Chemie*, 6:459–469, 1826.

[Ohm26d] G. S. Ohm. Versuch einer Theorie der durch galvanische Kräfte hervorgebrachten elektroskopischen Erscheinungen (Beschluss). *Annalen der Physik und Chemie*, 7:45–54, 1826.

[Ohm27] G. S. Ohm. *Die Galvanische Kette, mathematisch bearbeitet*. T. H. Riemann, Berlin, 1827.

[Ohm60] G. S. Ohm. *Théorie Mathématique des Courants Électriques*. L. Hachette et Co., Paris, 1860. Traduction, préface et notes de J.-M. Gaugain.

[Ohm66] G. S. Ohm. The galvanic circuit investigated mathematically. In R. Taylor, editor, *Scientific Memoirs,* Vol. 2, pages 401–506, New York, 1966. Johnson Reprint Corporation. English translation by W. Francis.

[Sih21] A. Sihvola. Johan Jacob Nervander and the quantification of electric current. *IEEE Antennas & Propagation Magazine*, 63:123–128, 2021. Doi: 10.1109/MAP.2020.3039803.

[Web71] W. Weber. Elektrodynamische Maassbestimmungen insbesondere über das Princip der Erhaltung der Energie. *Abhandlungen der Königlich Sächsischen Gesellschaft der Wissenschaften zu Leipzig, mathematisch-physischen Classe*, 10:1–61, 1871. Reprinted in *Wilhelm Weber's Werke*, Vol. 4, H. Weber (ed.), (Springer, Berlin, 1894), pp. 247-299.

[Web94] W. Weber. Bemerkungen zu der Abhandlung: "Untersuchung über den galvanischen Lichtbogen" von Prof. E. Edlund. In H. Weber, editor, Wilhelm Weber's *Werke,* Vol. 4, pages 578–583, Berlin, 1894. Springer.

[Web21] W. Weber. Electrodynamic measurements, sixth memoir, relating specially to the principle of the conservation of energy. In A. K. T. Assis, editor, *Wilhelm Weber's Main Works on Electrodynamics Translated into English*, volume IV: Conservation of Energy, Weber's Planetary Model of the Atom and the Unification of Electromagnetism and Gravitation, pages 67–111, Montreal, 2021. Apeiron. Available at www.ifi.unicamp.br/~assis.