On Electrothermism

Wilhelm Weber

Editor's Note: An English translation of Wilhelm Weber's posthumous paper "Ueber Elektrothermismus".[1]

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[1] [Web94].

Contents

Chapter 1

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About Electricity and Heat

After the first fundamental phenomenon of *electromagnetism* was discovered by Oersted,[5] other fundamental phenomena were also discovered very soon and hand in hand with these discoveries the theory of electromagnetism was developed, so that the theory often anticipated and provided the guide to the discovery of those fundamental phenomena.

Things were completely different with the fundamental phenomena and with the theory of *electrothermism*. Despite the fact that most of the fundamental electrothermal phenomena were discovered earlier than the electromagnetic ones, the theory of electrothermism has still remained completely undeveloped.

The fundamental electrothermal phenomena discovered so far are as follows:

1. A tourmaline, as it cools, is positively charged at one end and negatively charged at the other. Vice versa while it is being heated. Hankel, Elektrische Untersuchungen (Electrical Investigations). Ninth Treatise (Abh. d. Königl. Sächs. G. d. W. math.-phys. Klasse, Vol. X, No. IV, 1872).[6]

2. A current in a closed conductor generates *heat* in a piece of the latter which has resistance w in the time element dt, the mechanical equivalent of which is $= wi^2 dt$, with w and i expressed in absolute measure.[7]

3. A current occurs in a closed conductor made of two different metals if the conductor has unequal temperatures at the two points where the different metals touch each other. (Seebeck's fundamental phenomenon).[8]

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[2][Web94].

[3]Translated and edited by A. K. T. Assis, www.ifi.unicamp.br/~assis

[4]The 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 AKTA:] Hans Christin Ørsted (1777-1851). See [Oer20b], [Oer20a], [Oer20c], [Oer65], [Ørs86] and [Ørs98]. See also [Fra81] and [Rei13].

[6]Wilhelm Gottlieb Hankel (1814-1899) was a German physicist. See [Han74].

[7][Note by AKTA:] This result is due to James Prescott Joule (1818-1889). See [Jou41b]; [Jou41a] with French translation in [Jou42]; [Len43c], [Len43a], [Len43b], [Len44b] and [Len44a]. See also [MS20] and [Mar22].

[8][Note by AKTA:] Thomas Johann Seebeck (1770-1831). See [See25] and [See26] with partial Portuguese

4. If a current passes through a conductor made up of two different metals, which has the same temperature everywhere, then (apart from the heat generated by the current in the individual pieces of conductor in proportion to their resistance) there is generation in the one contact surface of the metals, in the other disappearance of heat takes place. (Peltier's fundamental phenomenon).[9]

A basis for a theory of electrothermism (10th volume of the Treatises of the Königl. Ges. d. Wissenschaften zu Göttingen — Royal Society of Sciences in Göttingen, 1862, "Zur Galvanometrie" — On Galvanometry, Section 33,[10,11] and 10th volume of the Treatises of the math.-phys. Klasse der Königl. Ges. der Wissenschaften, Leipzig, 1871, "Elektrodynamische Maassbestimmungen, insbesondere über das Princip der Erhaltung der Energie" — Electrodynamic measurements, sixth memoir, relating specially to the principle of the conservation of energy, Sections 19 and 20)[12,13] has now been sought in the adoption of Ampère's hypothesis of molecular currents[14] and in a further development of this hypothesis.[15]

As one can easily see, the assumption of molecular currents in all magnetic and diamagnetic bodies consistently leads to a completely new view of the behavior of the electrical fluids in conductors in the so-called electrostatic equilibrium states. One is led to never see the stillness of the electrical fluids, but rather the constant movement of them in circles around the individual molecules, after which the entire electrostatics developed by Poisson has to be transformed.[16]

Furthermore, one is led to a new view of galvanic currents, namely that the total electric fluids in the conductor, at so-called constant currents, by no means move at constant speed, but that only individual particles of the electric fluids are torn loose from the molecular currents to which they belong, pass jerkily to the next molecular currents, to which they then belong, until they are torn loose again, and so on.

The electromotive force that causes the breakaway, accelerates the movement of the broken-away particles until they enter the next molecular stream. This results in an increase of living force,[17] which is equivalent to the mechanical work determined by the product of

translation in [FS16].

[9][Note by AKTA:] Jean Charles Athanase Peltier (1785-1845). See [Pel34].

[10][Note by HW:] Wilhelm Weber's *Werke*, Vol. IV, p. 91.

[11][Note by AKTA:] [Web62, Section 33, p. 91 of Weber's *Werke*].

[12][Note by HW:] Wilhelm Weber's *Werke*, Vol. IV, p. 291 and 294.

[13][Note by AKTA:] [Web71] with English translation in [Web72] and [Web21].

[14][Note by AKTA:] In German: *Molekularströmen*.

[15][Note by AKTA:] Weber is referring to the hypothesis of molecular currents developed by André-Marie Ampère (1775-1836) between 1820 and 1827, see Chapter 5 (Ampère's Conception of Magnetism) of [AC15].

Ampère's masterpiece was published in 1826, [Amp26] and [Amp23]. There is a complete Portuguese translation of this work, [Cha09] and [AC11]. Partial English translations can be found at [Amp65] and [Amp69]. Complete and commented English translations can be found in [Amp12] and [AC15].

A huge material on Ampère and his force law between current elements can be found in the homepage *Ampère et l'Histoire de l'Électricité*, [Blo05].

[16][Note by AKTA:] Siméon Denis Poisson (1781-1840). See [Poi12a], [Poi12b] with English translation in [Poi19], [Poi13] and [Poi14].

[17][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,

the electromotive force in the distance of the two molecular currents.

But now it has emerged that the mechanical work determined in this way is the mechanical work equivalent of the heat generated by the current in the conductor, from which it can be concluded that the *heat and living force of the electrical fluids moving in the molecular currents are identical*. This is essentially the theory of the second fundamental phenomenon of electrothermism, which is based on Ampère's molecular currents.

But if, according to this theory of the second fundamental phenomenon of electrothermism, *heat* is the living force of the electrical fluids moving in the molecular currents, then it follows that the different degrees of temperature *in one and the same body* must be due to different *speeds* of the electrical fluids moving in the molecular currents, while the *masses* of the electrical fluid moving in the molecular currents are not different. Because the mass of the moving electrical fluid is given by the always equal mass of the fluids firmly connected to the core of the molecular current.

However, *different bodies* will differ from each other by the difference in the fluid that is firmly connected to the cores of the molecular currents and therefore, if there is *no charge*, also by the different *masses* of the moving electrical fluid.

If various such bodies come into contact at the same temperature and the large masses of electrical fluids moving in them are denoted by e and e' and their velocities by u and u', then according to the definition the same temperature of different bodies

$$\varepsilon u^2 = \varepsilon' u'^2 \ ,$$

where ε denotes the electrical mass torn from the first molecular current and passed to the other, ε' denotes the electrical mass torn from the other [molecular current] and passed to the first. So if the velocities u and u' belonging to two different bodies at the same temperature are different, then the masses ε and ε' are also different. So there is a charging on the molecules, namely a *positive* of one and a *negative* of the other, that is, a separating force[18] acts on the contact surface, which is the *principle of galvanism*.

> 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.

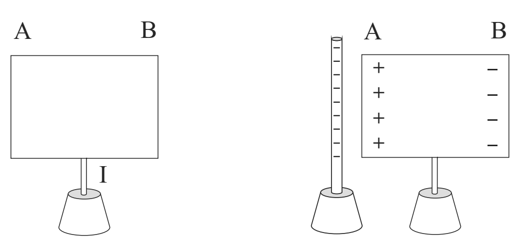
In 1872 he made an analogous definition, [Hel72a] with English translation in [Hel72b, p. 533]:

> 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].

[18][Note by AKTA:] In German: *Scheidungskraft*. This expression can also be translated as "force of separation" or "segregating force".

I present here a simple example of a separating force. Consider a metal plate AB insulated from the ground by a dielectric support I as in Figure (a) of this footnote:



(a) (b)

If we designate that temperature with t, then with a and a' the specific heats of the two bodies and with b and b' the number of temperature degrees below zero for which the living force of the molecular currents in these two bodies would be reduced to zero in proportion, so one has

$$t = \frac{e}{a}u^2 - b = \frac{e'}{a'}u'^2 - b' \tag{1}$$

for a temperature t' one obtains in the same way:

$$t' = \frac{e}{a}w^2 - b = \frac{e'}{a'}w'^2 - b'$$

or putting

$$w^2 = u^2 + v^2, \qquad w'^2 = u'^2 + v'^2 ,$$

[one obtains:]

$$t' = \frac{e}{a}\left(u^2 + v^2\right) - b = \frac{e'}{a'}\left(u'^2 + v'^2\right) - b \tag{2}$$

Equation (1) subtracted from (2) gives

$$\frac{e}{a}v^2 = \frac{e'}{a'}v'^2$$

or

$$v'^2 = \frac{e}{e'}\frac{a'}{a}v^2 . \tag{3}$$

From equations (1) it follows

$$u'^2 = \frac{a'}{e'}\left(\frac{e}{a}u^2 + b' - b\right) . \tag{4}$$

So if you add (3) and (4), you get

$$u'^2 + v'^2 = \frac{a'}{e'}\left[\frac{e}{a}\left(u^2 + v^2\right) + b' - b\right]$$

or

If a negatively charged straw is placed close to side A of the plate, the charges on the plate become separated as illustrated in Figure (b). Side A of the plate becomes positively electrified, while side B becomes negatively electrified. This polarization of the plate is caused by the electric force of the negatively electrified straw acting on the free electrons of the plate. I presented several interesting experiments on this topic made with simple material, together with many quotes from original sources, in the 2 volumes of the book *The Experimental and Historical Foundations of Electricity* which is available in English, Portuguese, Italian and Russian: [Ass10a], [Ass10b], [Ass15], [Ass17], [Ass18a], [Ass18b] and [Ass19].

Another effect of a separating force takes place in electrolysis. The electric forces in general are proportional to the charge q of the test particle on which they are acting. A positively electrified particle with $q > 0$ experiences a force in one direction, while a negatively electrified particle with $q < 0$ will be forced in the opposite direction. If these particles are free to move as in electrolysis, a double current will be produced due to this separating electric force. That is, the positive particles will move in one direction and the negative particles will move in the opposite direction.

$$w'^2 = \frac{a'}{e'}\left(\frac{e}{a}w^2 + b' - b\right) .$$

But from the temperature equality of both bodies, namely $= t'$, it follows

$$\eta w^2 = \eta' w'^2$$

where η denotes the electrical mass torn from the first molecular current and passed to the other, η' denotes the electrical mass torn from the other and passed to the first. From this it follows

$$\frac{\eta}{\eta'} = \frac{a'}{e'}\left(\frac{e}{a} + \frac{b' - b}{w^2}\right)$$

or, since $w^2 = [a/e](t' + b)$,

$$\frac{\eta}{\eta'} = \frac{e}{e'}\frac{a'}{a}\left(1 + \frac{b' - b}{t' + b}\right) .$$

The choice of the ratio η/η' (i.e. the magnitude of the separating force at the contact surface of both bodies) depends on the difference in temperature t', if the value $b' - b$ for the two body is different from zero, i.e. if the number of temperature degrees below zero, for which the living force of the molecular currents would disappear in proportion, is different for one body than for another body.

It is obvious that for all bodies for which the value of the specific heat changes more or less with temperature, the value of $b' - b$ must be different from zero. This probably occurs to a particularly high degree for bismuth and antimony.

This dependence of the magnitude of the separating force at the contact surface on the temperature contains the principle of Seebeck's fundamental phenomenon, or the third electrothermal fundamental phenomenon.

The principle for Peltier's fundamental phenomenon or for the fourth electrothermal fundamental phenomenon follows itself from this.

Let E be the amount of electricity that passes through the cross section of the circular conductor in a unit of time, and let u and u' be the speeds at which the electrical fluids in the molecular currents of the two bodies (metallic conductors), which make up the circular conductor, move. E then flows from the first conductor into the second conductor at speed u, and E flows further away from the boundary layer of the second conductor into the following layer at speed u'. The living force of the molecular currents of the second conductor at the boundary layer is therefore increased by $E\,(u^2 - u'^2)$ per unit of time, or heat is developed in this boundary layer, whose mechanical equivalent is $= E\,(u^2 - u'^2)$.

Further, E flows into the first conductor from the second conductor with velocity u', and E flows further away from the boundary layer into the first conductor with velocity u. Thus, the living force of the molecular currents of the first conductor at this boundary layer is decreased by $E\,(u^2 - u'^2)$ in the unit time, or heat disappears at this boundary layer, whose mechanical equivalent is $= E\,(u^2 - u'^2)$. This is the principle of Peltier's fundamental phenomenon.

If, after this theoretical consideration, we move on from the second, third and fourth fundamental electrothermal phenomenon to the first, we must initially observe that tourmaline is an insulator. The molecular currents in an insulator are such that, even under the influence of a separating force, no particle is torn off from the fluid in the molecular flow[19] and driven over to the following molecular current. There is also very weak heat conduction in such an insulator, but there is not a complete lack of heat conduction, since the different temperatures of the different parts of a tourmaline balance themselves out over a moderately long time. This heat conduction must therefore be based on a different principle than the separation of individual particles of the fluids in molecular flow and their transfer to neighboring molecular currents.

Without such a migration of electric particles ε with the speed u that occurs to them in the molecular currents (i.e. with the heat, the mechanical equivalent of which is $= \varepsilon u^2$), heat transfer from one molecular current to the other can only occur by induction. This induction arises when one considers that the radius of the molecular currents sometimes increases, sometimes decreases, and is always changing. However, if the cooling state of the tourmaline were to be explained in this way, the associated positive and negative charges on the opposite end surfaces of the tourmaline would still not be explained. It is also obvious, because this electrical charge occurs as a result of cooling only in tourmaline and similar crystals, that its explanation has to be more closely related to the crystalline structure, i.e. with the positional relationships of the molecular currents in these crystals.

Although crystallography gives determinations about these situational conditions, it does not give any determinations about the forces through which they came into existence and are maintained. If one describes the reason for the preservation of these layer relationships by the name of the strength (or elasticity) of the aggregate state, then one has no knowledge of the laws of interaction between the molecular currents (molecules) with one another, from which such a solid aggregate state results.

In general, one would have to take three types of interactions into account, namely, (1) the electrical interactions, the laws of which are given, (2) interactions of electricity with the ponderable cores of the molecular currents. If one maintains that such an interaction does not take place at a distance, all that remains is the interaction by means of which the ponderable cores of the molecular currents remain firmly connected to a certain amount of one electrical fluid. In addition, (3) the interactions between the ponderable cores of the molecular currents, which they exert on each other from a distance, must be taken into account. These latter, as far as they arise from the law of gravitation, would hardly come into consideration because of their small size. Although no such interactions are known in detail that are independent of the law of gravity, there is reason to suspect that such interactions exist and that they are so large that they are of great importance for the formation of solid crystalline aggregate states.

In the absence of complete knowledge of this type of interaction, the best way to give an account of the formation of solid crystalline aggregate states is to investigate in more detail everything that could arise from the *electrical interactions of the molecular currents.*

Theorem. Two Ampère's molecular currents whose aligned axes lie in a straight line attract each other at greater distances and repel each other at smaller distances.

Theorem. Every relative movement of two such Ampère's molecular currents is dampened by interaction, i.e. the mechanical movement, which consists of displacements of the molecular currents relative to one another, is transformed into molecular flow (heat energy).

The law of electrical interaction teaches *how* the conversion of mechanical kinetic energy into thermal energy is accomplished. If such Ampère's molecular currents form the molecules of solid bodies, then, according to the first stated theorem, the solidity of these bodies is

[19] [Note by AKTA:] In German: *Molekularströmung*.

explained by the interaction of these molecular currents at certain positions and distances.

Briot, *Théorie de la Chaleur*, Introduction p. 2, leads the explanation back to an attractive force of the ponderable particles $= mm' \cdot a/r^n$ and to a repulsive force of their two aether atmospheres $= mm' \cdot b/r^{n+p}$.[20] However, this only determines the distance between the particles in equilibrium, but not the position of the straight line connecting them. According to the former explanation, this position is given by the axis of the first molecular current, and the position of the second molecular current is also determined by the fact that its axis should be parallel to that of the first.

A series of such molecular currents, all in a straight line and equally spaced, form a column. A second, identical column of molecular currents is held at a certain distance from the first, so that oppositely directed currents come to lie next to each other in the two columns. A series of such columns, all at equal distances from one another and all in one plane, form a layer, which in turn holds an equal layer at a certain distance, etc.

In this way one obtains a fixed system of molecular currents extending over the entire space, not only with certain *distances* of the molecules from one another, but also with a certain direction and position of the molecules relative to one another. This solid system would be a crystal system with three mutually perpendicular elasticity axes, two of which had the same elasticity moduli. However, it does not seem that the explanation of the other crystal systems could be found in this way.

[20][Note by AKTA:] Charles Auguste Albert Briot (1817-1882) was a French mathematician. See [Bri69].

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