Converting Heat into Electric Energy with Static Electric and Magnetic Fields

Gerhard KAINZ E-Mail: gerha@geocities.com

Abstract - **Static crossed electric and magnetic fields force electrons to move in cycloids in one direction. While moving, they are able to convert heat into electric energy. This can be used to produce an electric potential and current, which contradict the 2nd law of thermodynamics. This fact is proved in an average velocity electron model.**

Index Terms – II. B. 9d) Magnetotransport, Hall effect, I. B. 1) Electric machines and transformers

Introduction

The paradox described in this paper uses the fact that in a crossed electric and magnetic field electrons drift in cycloid movements always in the same direction. The proof that a special arrangement can convert heat (without heat differences) in electric energy will be made in an average velocity model. This model has the following properties:

- The electrons achieve thermal equilibrium only through collisions. The velocity after a collision is appropriate to the temperature. So the electrons have the same average energy, there is no energy distribution.
- Collisions are characterized by a relaxation time τ, i.e. the average time between two collisions of an electron.
- Only negative charges are considered.
- There are no boundary effects taken into account and the cyclotron radius must be small compared to the size of the device.

According to the preconditions, there are only a few kinds of media in which the paradox would work. Firstly a static electric field from outside should have an effect inside the medium. Since metals build up a strong surface charge under the influence of an electric field, there is no field inside and therefore not feasible. However in a vacuum and in small layers of semiconductors (space charge region) the electric field can partly influence the electrons inside the media.

Secondly there only should be considered negative charges, thus the majority charges must be electrons. That is the case in a vacuum, and this is also possible with n-type semiconductors with a negative charge.

Lorentz force

The effect of a magnet field **B** on a moving charge q with velocity **v** is given by $q\mathbf{v} \times \mathbf{B}$ and is known as Lorentz force (e.g. [1]-[3]). This force causes an electron to move in a circular orbit in the plane orthogonal to B, i.e. in the xy plane for B_z. The angular frequency is known as cyclotron frequency ω_c, important is also the cyclotron radius r_c:

$$\omega_c = -eB_z / m_e^*, \quad r_c = -m_e^* v / (eB_z) \quad . \tag{1}$$

If there is an additional electric field **E**, the force **F** on an electron is given by:

$$\mathbf{F} = -e\mathbf{E} - e\mathbf{v} \times \mathbf{B} \ . \tag{2}$$

For $\mathbf{E}=(0,E_y,0)$, $\mathbf{B}=(0,0,B_z)$ and $\mathbf{v}(t=0) = (v_{x0}, v_{y0}, 0)$ the velocities are ([1])

$$v_x(t) = \quad -(v_{y0} - v_0)\sin(\omega_c t) + v_{x0}\cos(\omega_c t) \tag{3}$$

$$v_y(t) = v_0 + (v_{y0} - v_0)\cos(\omega_c t) + v_{x0}\sin(\omega_c t) \tag{4}$$

Independent of the initial velocity and direction, the electron drifts in *cycloid curves* with the velocity

$$v_0 = E_y / B_z \tag{5}$$

orthogonal to **E** and **B**, see Fig. 1. The initial speed and direction only influence the type of cycloid, but not the overall direction nor the overall velocity v_0.

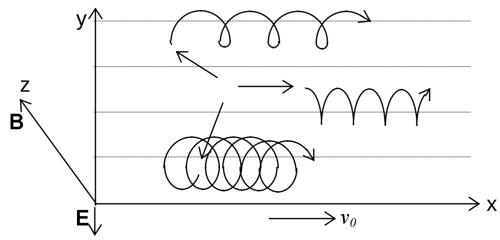

Fig. 1: Regardless of its initial speed and direction, in a crossed electric and magnetic field the electrons move in cycloids in the same direction.

For the paradox described in this paper there are two facts important:

- *Without* a magnetic field, the electron will be attracted by an electric field. The electron will be accelerated in the y-axis and gains kinetic energy from the electric field. However *with* a magnetic field, the cycloid movement of the electron is *normal* to the electric force i.e. on the same electric potential (marked as dotted lines in the figures). So in this case they are not gaining energy from the electric field.
- Regardless of its initial directions all electrons drift parallel the x-axis. Even if a collision occurs, the electron would return immediately to a movement along the x-axis.

The idea of paradox

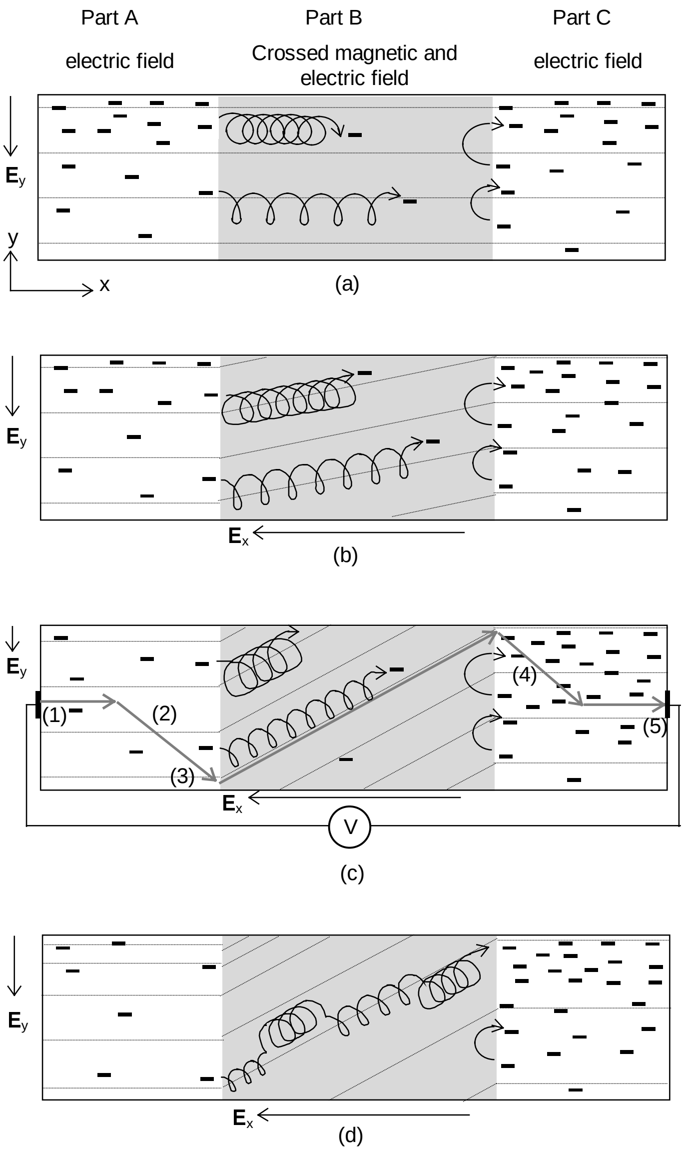

Fig.2: (a) Electrons from part A drift in cycloids through part B into C. Electrons from part C remains there. (b) In part C electrons are accumulated, therefore a field E_x occurs. (c) When the field E_x is high enough, no electrons can cross part B, thus an equilibrium occurs. (d) If the relaxation time τ is high enough, collisions do not effect that an electric potential occurs.

Fig. 2 shows a medium with an external electric field in negative y-direction. Only at the middle part B there is an additional magnetic field in z-direction. Except of Fig. 2(d) no collisions are considered.

The external electric field causes an electric field inside the medium (every dotted line marks a certain electric potential). Electrons are drawn as black rectangles.

In Fig. 2(a) the situation in the beginning is shown, that there is no potential difference between part A and C. However part B behaves like a one-way street: Electrons which move from part A into part B will divert in cycloids in x-direction through B into part C. Electrons from part C which come into part B will likewise divert in the x-direction, but this time this means that the electrons drift back to part C. So the electrons can only move from part A into C but not in the reverse direction.

Fig. 2(b) shows the situation after a certain time. The concentration of electrons in part C is higher than in part A, thus there will be built up an additional electric field $\mathbf{E}_x$ along the x-direction. So the electric potential is in part A higher than in part C, in B is the adjustment. In this Figure this is indicated with rotated dotted lines in part B. Since electrons in part B follow in cycloid movements the same potential, they also drift along the dotted lines skewed through part B. However this also means that only electrons in part A which have high potential energy (at the lower part of A) can get into part C.

Some times later, the additional electric field $\mathbf{E}_x$ is so high that the difference of the potential energies prevents that more electrons move from A to C, so an equilibrium is established, see Fig. 2(c). At the points 1 and 5 there is connected a voltmeter. Since the external electric field in y-direction has the same effect of both points, we do not have to consider it. However it remains the internal electric field $\mathbf{E}_x$ in the x-axis because of the concentration difference in part A and C. This produces an electric potential, which can be measured.

In Fig. 2(d) we also consider collisions of electrons. If the relaxation time τ is high enough, the electrons can make some cycloid movements between two collisions, so the overall drift remains along the same electric potential through part B. Even the produced electric potential remains the same, however it will last longer to achieve this value, since the drift velocity in part B is lower because of the collisions.

Energy considerations

In Fig. 2 it will be shown that a static electromagnetic field can build up an electric potential. If we connect at the outer points of this device an electric machine (like in Fig. 2(c)) an electric current will flow. But where does the energy for current come from? The answer can be given, if we consider the way of an electron through the device.

In Fig. 2(c) at point (1) the electron moves into the device. Since from point (3) electrons move into part C, electrons from A will move to this region. As long as the electron moves from (1) at the same potential, no energy will be needed. At (2) however the electron must convert kinetic into potential energy in order to move towards (3). The electron has a lower than the average kinetic energy and at the collisions with the lattice it will absorb kinetic energy. So at (2) heat energy will be converted to potential energy for electrons. While moving from (3) through part B into C in average no energy will be absorbed or radiated since the electron moves at the same electric potential. However at point (4) again the electron has to go up the potential hill in order to move towards point (5). So again kinetic energy will be converted into potential and the electrons will absorb kinetic energy from the lattice. So in part A and C heat energy will be converted into electric energy by the electrons which move against the potential. The higher the device is loaded up, the higher is the potential difference and thus the electrons have to convert more kinetic energy into potential to move from part A into C.

Proof

In this section, the effect is proved for the model described in the introduction.

Theorem Given is a device as shown in Fig. 2. There exists an external electric field in y direction that produces *inside* the device an electric field $\mathbf{E}=(0,E_y,0)$. Moreover there is a magnetic field $\mathbf{B}=(0,0,B_z)$ inside part B and the relaxation time $\tau \geq 4m_e^* v_e / (eE_y)$. In this case between point 1 and 5 an electric potential from the amount E_y occurs.

Proof: Between two collisions, an electron in part B in the crossed magnetic and electric field moves in cycloids in x direction with the average velocity $v_0 = E_y / B_z$. If we want to guarantee that electrons move in x direction in spite of collisions, the relaxation time must be sufficiently high.

The worst case is that after the collision the electron begins to drift in negative x-direction. The electron therefore drifts in maximum two times the cyclotron radius r_c in the wrong direction. Then it starts to go in the positive x-direction. At the next collision, the same can occur. Therefore the electron must move between two collisions at least four times the cyclotron radius in the positive direction. The relaxation time τ becomes therefore:

$$\tau = 4r_c / v_0 = 4m_e^* v_e / (eE_y). \tag{6}$$

With this relaxation time we can guarantee that in part B electrons only drift from the left to right. Since no electron can therefore move from C to A, the only possibility for an equilibrium is that no electrons can move from A to C neither. Because of the asymmetric flux of electrons, a different electron concentration in part A and C occurs. Thus an electric field will be built up ($\mathbf{E}_x$) which makes it more difficult for an electron to get from A into C. Only electrons in A which have a high potential energy can move through B into C. In B the electrons can not gain potential energy because they have to move in cycloids along the same potential. The only potential difference that can use an electron to move against $\mathbf{E}_x$ is the potential from the external field $\mathbf{E}_y$. Therefore electrons in A with a high potential energy from $\mathbf{E}_y$ can move into part C and increase $\mathbf{E}_x$ until $|\mathbf{E}_x| = |\mathbf{E}_y|$. □

Remarks

The restriction for the relaxation time τ is done for the worst case. The relaxation time can be smaller if the direction of electrons after a collision is randomly directed.

The electric potential between 1 and 5 can be used for an electric machine. In this case an electric current will flow and so the potential will decrease. The useable current depends also on the relaxation time, how fast electrons can move through the device. A possible application is a small n-type semiconductor layer. The external electric field can be produced statically with the Volta potential of two different conductors, which gives about 1 Volt. If the semiconductor layer is small enough there is a space charge region, so that a part of the external field remains inside the layer, a realistic value is 10 percent. So it should be possible to measure 0.1 Volt. Moreover, more such arrangements can be put together to increase the potential.

This effect can not be calculated in the Drude Model. The reason is that inside the device is an electric field but there is no average velocity in one direction. In the Drude Model one calculates with this average velocity direction vector, which is zero and therefore the Lorentz force in this model is zero. However the electrons have an average velocity and there is an electric field therefore the Lorentz force have an effect of drifting electrons in one direction.

Conclusion

The effect described in this paper uses a magnetic field and an electric field in right angles to produce an electric field in the third orthogonal direction. This effect can therefore be seen as a "static hall effect". It can only operate in special environments e.g. in vacuum tubes or in small semiconductor layers. In this case the Lorentz force will be used to produce an electric potential and electric current[1]. As a result heat energy will be converted into electric energy. This is proved in an average velocity electron model.

The effect does not contradict the 1st law of thermodynamics, since the whole energy will be conserved, only the distribution will be changed. However it contradicts the 2nd law of thermodynamics, since heat energy (and not only heat difference) will be converted into electric energy.

References

[1] P. Grosse, *Freie Elektronen in Festkörpern*, Springer-Verlag, Berlin, 1979.

[2] I. M. Lifshitz, M. Ya. Azbel and M. I. Kaganov, *Electron Theory of Metals*, Consultants Bureau, New York, 1973.

[3] B. Sapoval and C. Hermann, *Physics of Semiconductors*, Springer-Verlag, New York, 1995.

[4] H. Heffner (unpublished).

[1] There may be also other methods using the Lorentz force. Horace Heffner [4] describes in the Usenet News a method using a decreasing magnetic field, but without an electric field.