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ONE PROPERTY OF CONTACTS

By Ya. B. Zel'dovich and Yu. B Khariton

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FOREWORD

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/Following is the translation of an article by Ya. B. Zel'dovich and Yu. B. Khariton entitled "Ob Odnom Svoystve Kontaktov" (English version above) in Zhurnal Eksperimental'noy i Teoreticheskoy Fiziki (Journal of Experimental and Theoretical Physics) Vol. 10, No. 12, 1940, pp 1422 -- 1423./

When alternating current flows through the junction of two conductors, there are two reasons causing the occurrence of a dc component of current:

1) The thermal emf of the contact, connected with the heating of the contact by Joule heat (temf).

2) Change in the resistance of the contact, connected with the release of Peltier heat at the point of contact.

In the absence of temf and Peltier heat (which are connected by a well known thermodynamic relation) no causes (such as the change in the contact resistance due to liberation of Joule heat, which is a even function of the current) can yield a dc component.

Let us show that the indicated second reason has the same order in the current as the first. The Joule heating, and consequently the temf, are proportional to the square of the current.

The liberation (or absorption) of Peltier heat is proportional to the current; the change in resistance due to the Peltier heat is also proportional to the current. The additional emf (we shall call it pemf henceforth) is proportional to the product of the current by the change in the resistance, i.e., it is again proportional to the square of the current. It is essential that the pemf does not reverse its sign when the direction of the current changes. Let us note finally that pemf is essentially a fictitious emf, existing only to the extent that the main current exists. For bodies whose resistance increases with increasing temperature, the pemf has a sign opposite to the temf.

Under the very simple assumptions a) of low heating, b) of two metals of equal heat conduction $\varkappa$, c) of equal specific resistance ρ proportional to the absolute temperature, d) symmetrical one-dimensional problem with a specified temperature on a definite distance l, and e) the possibility of calculating the heating in accordance with the laws of the steady-state heat flow, an elementary calculation gives the heating due to Joule heat as

$$\vartheta_J = \frac{\rho i^2 l^2}{2\varkappa} \qquad (1)$$

$$\mathrm{temf} = \gamma\theta_J = \frac{\gamma\varrho i^2}{2\varkappa} l^2. \qquad (2)$$

Taking into account the thermodynamic expression for the Peltier coefficient, we obtain

$$\theta_P = -\frac{\gamma i T}{2\varkappa} |l - x|. \qquad (3)$$

Here x is the (running) distance from the plane of the contact. According to proposition c)

$$\frac{\Delta\varrho}{\varrho} = \frac{\theta}{T}, \qquad (4)$$

so that, finally integrating from - l to + l, we obtain

$$\mathrm{pemf} = -\frac{\gamma\varrho i^2}{2\varkappa} l^2 = -\mathrm{temf} \qquad (5)$$

The different expressions obtained for θ_P and θ_J as functions of the coordinates are connected with the fact that the Peltier heat is liberated only at the point of contact, while the Joule heat is liberated along the entire conductor.

It is easy to see that in the case of a contact with an alloy that has a considerable resistance with little dependence on the temperature, the pemf will be less in absolute value than the temf. In the case of a contact with a similar conductor, whose resistance diminishes rapidly with increasing temperature, the pemf can be considerably greater than the temf, but their sign will be the same. We disregard here the examination of inherently rectifying effects, in the usual sense of the word. These effects, which do not reduce to a thermal action, give, for a constant coefficient of rectification, an emf which is proportional to the amplitude of the alternating current, whereas the temf and pemf considered here, as already indicated, are proportional to the square of the amplitude of the current.

Let us stop on assumption e) relative to the possibility of calculation by the laws of steady-state flow.

For this purpose it is necessary that the effect of distance l from the contact to the region of the constant (specified) temperature be less than the free propagation of heat during the time on the order of half a cycle of alternating current, τ

$$l^2 < \frac{\varkappa\tau}{C}, \qquad (6)$$

where C is the bulk specific heat of the conductor. In the case ~~mf~~ investigated in detail by Holm (published in a series of articles in the scientific communications of the Siemens Company) of poor contacts and 50 cycle current, relation (6) is always satisfied.

To the contrary, in the case of a good contact (soldered) between two long wires with diameter 0.3 -- 1 mm and 50 cycle current, the Joule heat, which is of constant sign, is dissipated by heat transfer by the lateral surface of the wires to the surrounding medium. Here we have

$$l'_{\underset{\text{eff}}{\text{эфф.}}} = \sqrt{\frac{\varkappa d}{4\alpha}} = \frac{d}{2\sqrt{\mathrm{Nu}}},$$

where a is the coefficient of heat transfer, Nu is the Nusselt number;

the Peltier heat which pulsates with the current propagates in accordance with the laws of heat waves. As a result, since (6) is not satisfied, we obtain instead of (5)

$$pemf \leqslant temf \qquad (7)$$

In the case of sliding contacts, to be able to calculate the temperature field and the heating of the contact points due to the passage of current (Holm) er due to the liberation of the friction heat (Bowden and Ridler, Proceedings Royal Society [A] 154, 640, 1936), using formulas pertaining to the contact at rest, it is necessary that the following condition be satisfied

$$\mathrm{Pe} = \frac{udc}{x} < 1, \qquad (8)$$

where Pe is the Peclet number; d is the decisive dimension of the contact.

Finally, if condition a) is not satisfied, namely that the heating be small, there will appear, in addition to terms quadratic in the current, also terms of higher order (fourth, sixth, etc.).

Institute of Chemical Physics
Laboratory of Explosive Substances
and Combustion.

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