Thermoelectric power and nonstationary Josephson effect in S–N–S structures

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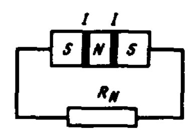
It is shown that if a temperature difference is produced on an S–N–S structure, then an ac component of current appears in a circuit containing this structure; its frequency is proportional to the absolute differential thermoelectric power of the normal metal and to the temperature difference on the junction.

The purpose of the present article is to show that if a temperature difference $T_2 - T_1$ is produced on an S_1-N-S_2 tunnel structure, then an alternating current is produced in a circuit containing this structure, with a frequency

$$\omega_0 = \frac{2e}{\hbar}\alpha(T_2 - T_1), \tag{1}$$

where α is the absolute differential thermoelectric power of the normal metal. In the presence of a temperature difference, a quasipartial thermoelectric current appears in the normal layer, and produces across the load resistance a voltage drop $V \sim \alpha(T_2 - T_1)$. Therefore, if the thermoelectric current exceeds the critical current of the Josephson junction, an ac current component of frequency ω_0 is produced.

At the present time the easiest structures to produce experimentally are apparently of the SINIS type, for which the theory of the Josephson effect has been developed in the paper of Aslamazov, Larkin, and Ovchinnikov.[1] In such structures, the superconducting current is described by the Josephson equation. Let us consider a series circuit consisting of an SINIS structure and a load resistance R_N (figure). The current j through the normal layer consists of the quasiparticle current J_N and the superconducting current J_S ($J = J_N + J_S$)[2]



$$J_N = -S_j \eta \nabla T - \frac{V}{R_i}, \tag{2}$$

where S_j is the area of the junction, η is the thermoelectric coefficient of the normal metal (see, e.g., [3]), V is the voltage drop on the Josephson junction, R_i is the internal resistance of the junction and consists of the resistances of the insulating layers R_I and of the resistance of the normal layer $R^* = d/\sigma S_j$:

$$R_i = 2R_I + R^* . \tag{3}$$

According to [1] we have

$$J_S = J_c \sin[\delta\phi + \frac{2e}{\hbar}\int_0^t V dt'] \equiv J_c \sin\phi, \tag{4}$$

where J_c is the critical current of the junction and $\delta\phi$ is the phase discontinuity at the junction.

Using (2) and (4) and equating the total current to V/R_N, we obtain an equation for the phase:

$$\frac{\hbar}{2e}\frac{\partial\phi}{\partial t} = -\alpha f(T_2 - T_1) + J_c R^* f \sin\phi, \tag{5}$$

where

$$f = \frac{1 + \frac{2R_I}{R^*}}{1 + 2R_I/R_N + R^*/R_N} .$$

As is well known, [2] Eq. (5) describes oscillations of the current in the circuit if

$$\alpha(T_2 - T_1) > J_c R^* . \tag{6}$$

When this inequality is strongly satisfied, the frequency of these oscillations is

$$\omega_0 = \frac{2e}{\hbar}\alpha(T_2 - T_1) f. \tag{7}$$

Let us estimate the possibility of observing the effect. If $\alpha \sim 1$ μV/°K and $f \sim 1$, then $\omega_0 \sim 3 \times 10^9 (T_2 - T_1)$ °K, and at a temperature difference 10^{-6} °K we have $\omega_0 \sim 3 \times 10^3$ sec^{-1}. As already noted above, to obtain an alternating current it is necessary to satisfy the condition (6). If this condition cannot be satisfied at the given temperature difference, it is possible to include in the circuit a dc voltage source V_0 and determine a frequency shift amounting to (7) from the reference frequency $2eV_0 f R^*/R_N/\hbar$.

We note one important circumstance. Since the presence of a temperature difference does not produce a thermoelectric field in the superconductor, it suffices, to make the effect observable, to produce the temperature drop only in the immediate vicinity of the junction. This may facilitate the measurement of small temperature drops localized in a region of small dimensions.

[1] L. G. Aslamazov, A. I. Larkin, and Yu. N. Ovchinnikov, Zh. Eksp. Teor. Fiz. 55, 323 (1968) [Sov. Phys.-JETP 28, 171 (1969)].

[2] P. G. de Gennes, Superconductivity of Metals and Alloys, Benjamin, 1966. (Russ. Transl., Mir, 1968, p. 123).

[3] A. A. Abrikosov, Vvedenie v teoriyu normal'nykh metallov (Introduction to the Theory of Normal Metals), Nauka, 1972, p. 107.