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S.A.Sergeenkov

THERMOELECTRIC EFFECTS IN SUPERCONDUCTORS: THE ROLE OF FLUCTUATIONS AND WEAK LINKS

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There is an old problem of a thermal flux trapping inside a bimetallic loop (see,e.g.,[1]). Namely, the measured flux [2] is considerably larger than that obtained by theory [3]. As Ginzburg [4] has recently noted :"The phenomenon remains unexplained." Detail information on thermoelectric effects in superconductors the Reader could find in the above-mentioned paper [4] and references therein.

One more question (we are dealing with here) is devoted to an excess thermal flux due to a weak-links behaviour of ceramic samples (within the effective Josephson medium approximation [5]).

Remember [4] that the total magnetic flux Φ through a counter inside a bimetallic loop (where both conductors I and II are in the superconducting state) is :

$$\Phi = n\,\Phi_0 + \Phi_T \;,\; \Phi_0 = hc/2e \;,\; n = 0,1,2,.... \tag{1}$$

The thermal flux contribution Φ_T has a form [2,4] :

$$\Phi_T = \int_{T_2}^{T_1} dT(\Omega_{II}(T) - \Omega_I(T)) \;, \tag{2}$$

where

$$\Omega(T) = mcb/e^2 n_s \;,\; b = \sigma s \;. \tag{3}$$

Here, σ is the conductivity, s is the Seebeck coefficient or thermoelectric power (TEP), n_s is the "concentration" of the superconductive electrons.

According to theory (see,e.g.,[1,3]), $b(T) \approx b(T_c)$ near T_c, while the measurements [2] lead to the following dependence:

$$b(T) \approx b(T_c)(1-T/T_c)^{-1/2} \;. \tag{4}$$

Numerous explanations of such a divergence (see,e.g.,[3] for discussions) have been suggested, but here we restrict ourselves to fluctuation-induced effects only. They are rather strong, in particular, for high-T_c superconductors

(HTS) [6]. So, if this is the case, one needs to assume that the samples (Van Harlingen [2] dealt with) show a strong three-dimensional (3-D) fluctuation behaviour. In other words, it means that an excess conductivity $\Delta\sigma = \sigma - \sigma_n$ behaves as :

$$\Delta\sigma_{3D} \sim \sigma_n \varepsilon^{-1/2} \quad , \tag{5}$$

where

$$\varepsilon = | T - T_c | / T_c \ .$$

In view of Eq.(3), from Eq.(5) one obtains :

$$b_{3D}(T) = s(T)\sigma(T) \approx b(T_c) + b(T_c)\varepsilon^{-1/2} \quad , \tag{6}$$

in, at least, qualitative agreement with that measured (cf. Eq.(4)).

In HTS fluctuation effects have, mainly, a 2-D character [7]. In this case the following singularity should be observed :

$$b_{2D}(T) \sim b(T_c)\varepsilon^{-1} \quad . \tag{7}$$

It will be interesting to check this behaviour in thermal flux experiments with HTS.

Let us now turn to the second question announced above, and consider an excess thermal flux trapping via Josephson junction medium. It should be noted that thermoelectric effects in superconducting loops with a single junction have already been studied (see,e.g.,[8] and references therein). The main point of the Josephson effective medium approximation (JEMA) [5] (not confuse with the ordinary effective medium approximation [9] which is used for the description of thermoelectric effects in granular superconductors) is the effective stiffness g of a superfluid condensate. Namely, for a uniform superconductor $g = \hbar^2 n_s / 2m$, while for the Josephson weak-link medium $g \approx E_J d \ll \hbar^2 n_s / 2m$, where E_J is the energy of weak links per unit area, and d is the size of a grain. Thus, in the frame of JEMA instead of Eq.(3) we have :

$$\Omega_J(T) = \hbar^2 c b_J / 2e^2 g \quad , \tag{8}$$

where

$$g^{-1} = 2m/\hbar^2 n_s + 1/E_J d \quad .$$

Usually [5,7,9], $b_J \ll b$ (where b(T) is defined by Eq.(3)). Let us calculate the enhancement of the thermal flux $\Delta\Phi_T = \Phi_T^J - \Phi_T$ (Φ_T is the thermal flux for a uniform superconductor, see Eqs.(2) and (3)) due to weak links. From Eqs.(2),(3) and (8) it follows that :

$$\Delta\Phi_T/\Phi_T \sim \Delta\Omega/\Omega = (b_J/b - 1) + (b_J/b)(\hbar^2 n_s / 2m E_J d) \quad . \tag{9}$$

Using typical values of HTS [5] : $T_c \sim 100$ K, $d \sim 10^{-4}$cm, $E_J d \sim T_c/d \sim 10^{-13}$J/cm, $\hbar^2 n_s/2m \sim 10^{-8}$J/cm, and $b_J \approx 10^{-3}$ b, one gets $\Delta\Phi_T/\Phi_T \sim 10^2$. It seems to us, that such a prediction looks like a challenge to the experimenters (remind [1-3] that for uniform superconductor $\Phi_T/\Delta T \sim 10^{-4}\Phi_0$ per 1K). We do hope it will be accepted.

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