RESISTIVE PHENOMENA IN THE INTERMEDIATE STATE

V.A. Shukhman and L.M. Kano
Physics Institute, Georgian Academy of Sciences
Submitted 26 January 1971
ZhETF Pis. Red. 13, No. 6, 277 - 280 (20 March 1971)

Several recent papers [1 - 4] lead to the conclusion that the transition of a superconductor of the first kind to the intermediate state begins with the appearance of isolated normal regions in the superconducting matrix, and the intermediate state assumes a layered character only in stronger fields. These facts enable us to speak, in principle, of the possible existence of resistive effects in superconductors of the first kind in the initial stage of the intermediate state[1)], such that the motion of the normal region in the presence of the transport current is governed by the Lorentz force and by the "dry friction" forces exerted by the structural inhomogeneities of the sample, i.e., such that the critical fields and current obey a law of the Anderson type, $j_c(H - B_0) = \alpha_c$.

To determine the $j_c = f(H)$ relation, we deemed it most advantageous to measure the current in a closed superconducting circuit, one section of which was the investigated sample in the intermediate state, i.e., to estimate the value of j_c directly by determining the start of current damping in such a circuit, and to reduce the loss measurement to a measurement of the relaxation time of such a damping. The sample was connected in a superconducting circuit consisting of a lead coil w_1.

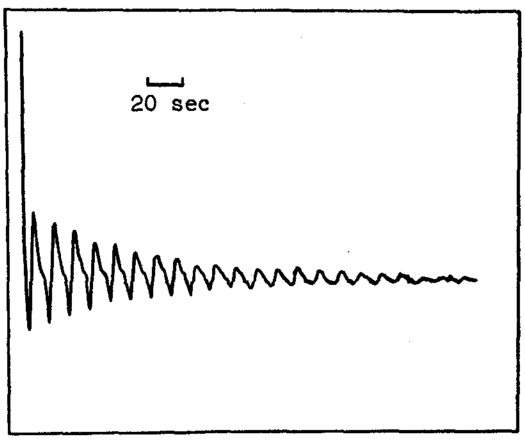

Fig. 1. Decrease of the current in a tin plate at T = 2.51°K, from an equilibrium value I = 300 mA at H = 122 G to another equilibrium value I = 0 at H = 123 G.

The current in the circuit was determined from the emf induced in a measuring coil w_2, which vibrated near w_1. The applied magnetic field H was perpendicular to the sample surface. The procedure permitted measurement of currents from 30 mA to several times 10 A and to register a relative change of current up to 5%. Polycrystalline tin samples of two types were prepared: cold-rolled foils 22 × 6 × 0.09 mm and annealed plates 22 × 6 × 1.5 mm. (Γ = R(293°K)/R(4.2°K) = 560, $\rho_n = (2.4 \pm 0.4) \times 10^{-8}$ ohm-cm, Ginzburg-Landau parameter χ = 0.33). The control samples were made of superconducting alloy of the second kind, In + 2.5 at% Bi (χ = 1.25, T_c = 4.1°K), in the form of annealed plates 22 × 6 × 1.5 mm. The behavior of the current in the circuit with increasing field exhibits a number of similar features for all the investigated samples. At a

[1)]The resistivity should appear also in the specific case of motion of n-phase layers elongated along the direction of the transport current (the Gorter model [5]). Such a motion was observed by Yu.V. Sharvin [6] in single-crystal samples in an oblique magnetic field.

Copyright © by American Institute of Physics 1971

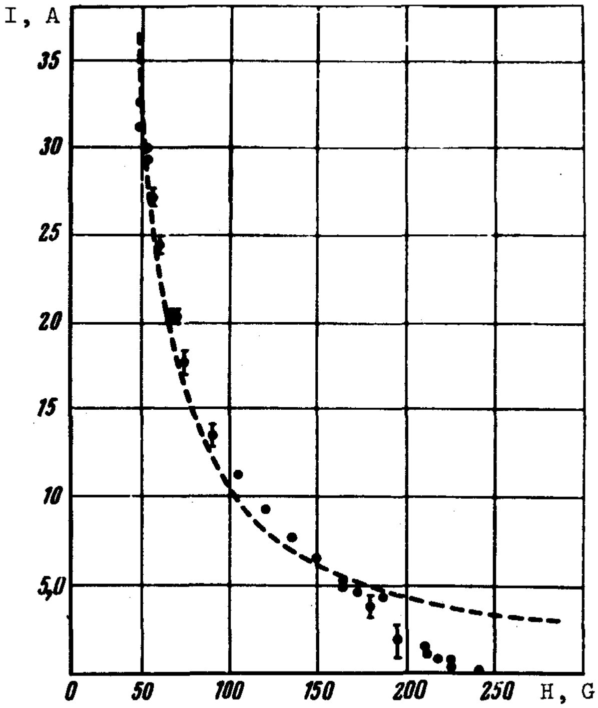

Fig. 2

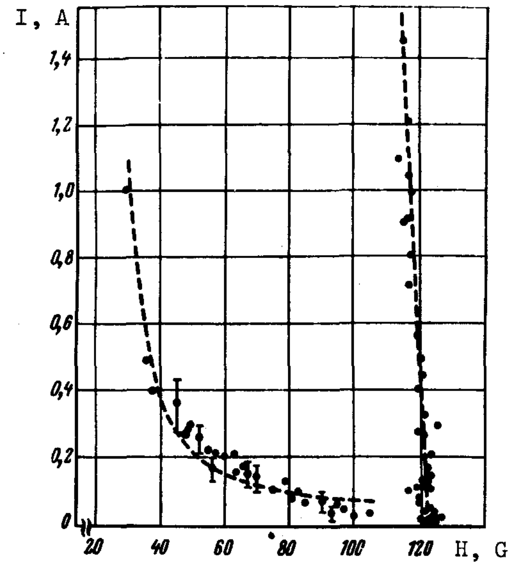

Fig. 3

Fig. 2. Critical current vs. field for a plate of thickness d = 1.5 mm made of the alloy In + 2.5 at.% Bi, T = 3.11°K. The dashed curve is a plot of the type $j_c(H - B_0) = \alpha_c$, where $\alpha_c = (83 \pm 5) \times 10^2$ G-A/cm^2 and $B_0 = (28 \pm 4)$ G.

Fig. 3. Field dependence of the critical current in tin samples. Left - foil sample of thickness d = 0.09 mm, right - plate of thickness d = 1.5 mm. The dashed curve on the left shows a plot of the type $j_c(H - B_0) = \alpha_c$, $\alpha_c = (9.7 \pm 0.7) \times 10^2$ G-A/cm^2, $B_0 = (26 \pm 3)$ G.

certain value of the field, the current in the circuit begins to decrease and tends to a certain value I that is in equilibrium for a given H. Figure 1 shows an example of such a process in a tin plate. Measurement of the equilibrium values of the current I at the corresponding values of the field H yields the plots of the critical current against the field. Examples of such plots for different objects are shown in Figs. 2 and 3.

As seen from the figures, the picture, at least for a foil, coincides qualitatively with that obtained for a superconductor of the second kind in the resistive state. The only difference is in the parameters α_c and B_0. In the temperature interval $(0.93 - 0.75)T_0$, the parameter α_c changes from 4×10^2 to 8×10^3 G-A/cm^2 for the alloy and from 4×10^2 to 1×10^3 G-A/cm^2 for the tin foil.

The constant B_0 has the meaning of the field at which the losses begin. For the alloy, B_0 coincides, within the limits of errors, with the values of the first critical field H_{c1} at the corresponding temperatures. For the tin samples, B_0 exceeds noticeably in all cases the value of the field $(1 - n)H_c$ at which the intermediate state appears, i.e., the resistive losses do not occur simultaneously with the nucleation of the intermediate state, but during a later stage of its development. This indicates that at fields close to $(1 - n)H_c$ there is produced at the edges of the sample an n-phase layer, from which normal regions begin to break away in strong fields; motion of these normal regions under the influence of the transport current is the reason for the observed losses.

The minimal effective resistance of these losses lies in the interval $6 \times 10^{-9} - 1 \times 10^{-7}$ ohm for the plates and $4 \times 10^{-9} - 1 \times 10^{-8}$ ohm for the foil samples; this is much less than the values obtained under our conditions when a layered intermediate-state structure perpendicular to the current is produced.

Our experimental data, as well as experiments on the induced motion of magnetic-flux tubes in tin plates [1], allow us to assume that in the case of a plate (see Fig. 3) we are dealing with resistive losses, but the parameter α_c is in this case much smaller than for the foil or for the alloy ($\alpha_c \lesssim 10^{-1}$ G-A/cm^2). This difference is natural for two reasons. First, a cold-deformed foil is an object having many structural defects, and this makes the pinning appreciable. Second, an important role is played by the characteristic dimensions a_n of the normal regions themselves, which increase with increasing sample thickness, thereby decreasing the efficiency of the pinning in thicker samples. (An estimate under our conditions yields $a_n \lesssim 10^{-3}$ cm for the foil and $a_n \lesssim 10^{-2}$ cm for tin plates.)

We note that the resistive state in all tin samples was observed up to external field values $H \simeq 0.7H_c$; the field values did not vary noticeably with either the sample thickness or the temperature.

[1] P.R. Solomon, Phys. Rev. Lett. 16, 50 (1966).
[2] P.R. Solomon and F.A. Otter, Phys. Rev. 164, 608 (1967).
[3] G.J. Van Gurp, Phys. Lett. 24A, 528 (1967).
[4] H. Trauble and U. Essmann, Phys. Status Solidi 18, 813 (1966).
[5] C.J. Groter, Physica 23, 45 (1957).
[6] Yu.V. Sharvin, ZhETF Pis. Red. 2, 287 (1965) [JETP Lett. 2, 183 (1965)].

HEAVY LEPTONS AND NEUTRINO ASTRONOMY

B. Pontecorvo
Joint Institute for Nuclear Research

Submitted 8 February 1971
ZhETF Pis. Red. 13, No. 6, 281 - 283 (20 March 1971)

The possible existence of heavy leptons, i.e., of charged leptons heavier than $e^{\pm}$ and $\mu^{\pm}$, has been discussed recently a number of times [1 - 6], as well as the question of realizability of experiments intended for their observation [4 - 6]. Searches for a "heavy charged electron e'" in the reaction ep → e'p were made [7 - 9] with electron accelerators, and the negative results say nothing concerning the existence of different charged leptons that might not be produced only via electromagnetic interactions. In analogy with the known laws, it can be assumed that these heavy charged leptons, if they exist, take part together with the neutrino in weak interactions. Through a gracious communication from Yu.D. Prokoshkin and I.V. Chuvilo, I learned that experiments aimed at observing the formation of heavy leptons by high-energy electrons had been initiated by Schwartz's group with the SLAC, using a method proposed independently by Schwartz [4] and by myself [10], consisting of finding events produced in a neutrino detector by neutrinolike decay products of short-lived particles (heavy leptons), when the flux of "ordinary" neutrinos from the decay of long-lived particles (pions, kaons) is purposely suppressed.