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ELECTRON TUNNELING IN SUPERCONDUCTORS WITH NONEQUILIBRIUM OCCUPATION OF QUASIPARTICLE STATES

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Résumé.- La décroissance de la conduction électrique de jonctions tunnel de plomb hors d'équilibre a été mesurée pour eV > 2Δ. Nous avons étudié en détail l'effet de la température, du courant superfluide, de l'excitation des quasiparticules et des conditions de transfert de chaleur sur la fonction de distribution hors d'équilibre de l'énergie des quasiparticules. Nous comparons les résultats expérimentaux aux résultats calculés en utilisant une fonction de distribution hors d'équilibre.

Abstract.- The decrease in electrical conductivity of nonequilibrium tunnel junctions of lead has been measured at eV > 2Δ. The effect of ambient temperature, superfluid current, methods of quasiparticle excitation and heat transfer conditions on the nonequilibrium part of quasiparticle energy distribution function has been studied in detail. The experimental data are compared to the results calculated using the model nonequilibrium distribution function.

A decrease in conductivity of tunnel junctions between similar superconductors at eV > 2Δ caused by a nonequilibrium occupancy of quasiparticle states under laser irradiation (the blocking effect) was first found in papers /1,2/. The present paper deals with the detailed study of small deviations of conductivity at eV > 2Δ in nonequilibrium Pb-junctions. The effect of temperature, superfluid current, excitation and heat transfer conditions on the nonequilibrium part of quasiparticle energy distribution function was studied. Nonequilibrium excitations in a junction were produced both under direct irradiation with laser light of λ = 0.63 μm and under irradiation with nonequilibrium phonons, excited with light in superconducting or normal intermediate screen. The measurements were made on specimens of different configuration in which the tunnel junction or one of its films was in contact directly with the liquid helium, the crystalline sapphire substrate or the metal screen.

Figure 1 shows a comparison between the experimental data on the minimum conduction depth ΔV₀(T) at eV > 2Δ normalized to a relative change in energy gap and the theoretical values of the quantity, denoted as J(V₀,T) and calculated for a tunnel junction with a model nonequilibrium part of the energy distribution function exp[-(e-Δ)/kT]. The values of the quantities under question are taken at the same temperatures plotted on the right-hand scale.

Fig. 1: Comparison between the observed and calculated values of the minimum conduction depth.

A good agreement between the theory and the experiment (solid line) is observed at high temperatures. The calculations assumed that nonequilibrium excitations were concentrated only in one
film of the junction and did not involve a real smearing of quasiparticle current jump at \( eV = 2\Delta \) resulting in the constant amplitude shift of \( J(V_o,T) \) by \( \frac{2}{15} \) mV. As the temperature decreases, the number of nonequilibrium excitations, \( N_0 \), begins to exceed a number of thermally equilibrium ones, \( N_t \), and a sharp disagreement appears (dotted line). The temperature value determining the condition \( N\sqrt{N_t} = 1 \), is dependent on heat transfer and hence on the uniformity of nonequilibrium quasiparticle distribution between the junction films.

The same cause results in a difference in the maximum values of \( \delta V_o \) displayed by vertical dotted lines.

The influence of a transport superconducting current across one of the film on the blocking is shown in Figure 2. The increase in the transport current density leads to a smoothing of the square-root singularity in the quasi-particle density of states near the upper edge of the energy gap, where the nonequilibrium excitations are localized; this, in turn causes the smearing and decrease of the minimum conduction depth, \( \delta V_o \), due to laser irradiation. Curve 1 in Figure 2 corresponds to \( I_{tr} = 0 \), and curve 2 to \( I_{tr} \geq I_c \). The extent of the transport current effect is determined by the relation between \( N \) and \( N_t \) and is maximum at low temperatures when \( N > N_t \). There were observed no further deviation from the equilibrium due to a shift of the distribution function in momentum space by \( \mathbf{P} \) and to a corresponding increase in the recombination time of quasi-particles. This seems to be explained by the dirtiness of our films \( (\xi < \xi_0) \) and by the fact that the tunnel current is contributed only by the quasi-particles, the wave vector of which is perpendicular to the barrier plane and therefore to \( \mathbf{P} \).

Fig. 2 : The influence of the transport superconducting current on the blocking effect: 
(1) \( I_{tr} = 0 \); (2) \( I_{tr} \geq I_c \).