QUANTUM INTERFERENCE IN THE RESISTIVE STATE OF SUPERCONDUCTORS

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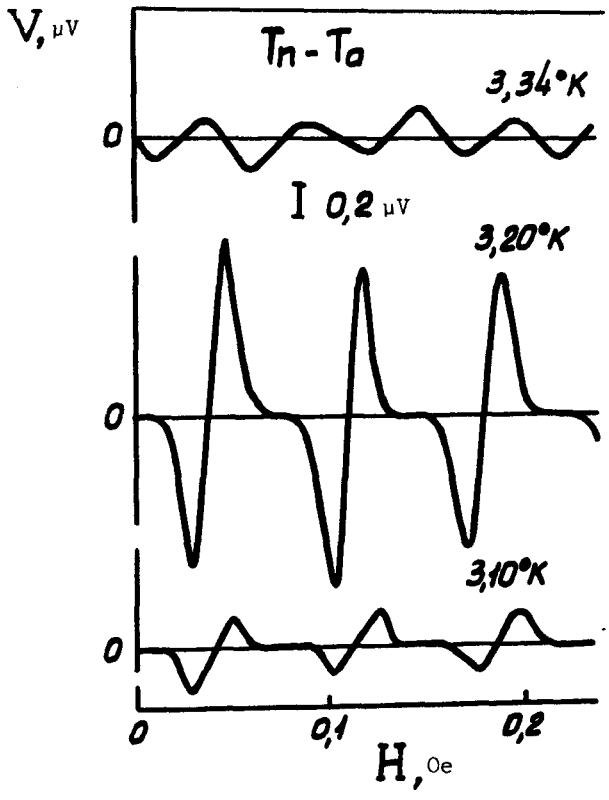
A number of recent communications (see, e.g., [1]) report observation of oscillations of the critical current flowing through parallel-connected tunnel or point contacts (superconducting interferometer) when the external magnetic field is varied. There are also reports of an experimental observation of voltage oscillations in a superconducting interferometer whose poor connections were brought back to the resistive state with the aid of a sufficiently large transport current flowing through the interferometer [2]. Observation of the quantum voltage oscillations means that the phase coherence and the quantum interference remain in force in the resistive state of the superconductor. Such a conclusion does not contradict the existing notions concerning the resistive (dynamic-mixed or intermediate) state of the superconductor. Yet the question of quantization of the London fluxoid [3] in the resistive state of superconductors remains quite open, and the presence of transport current in experiments with interferometers [2] masks certain specific features of such quantization.

Using superconducting interferometers constructed by Clarke's method [4], we observed, besides the already known voltage oscillations in the presence of transport current, also a time-invariant voltage oscillating in the magnetic field with the same periodicity, but in the absence of transport current through the interferometer. In this case there was no voltage component independent of the magnetic field and connected with the transport current.

A small drop of indium (or Sn-Pb eutectic) was placed on a closed ring of tantalum wire ~1 cm diameter; the solidified bead and the tantalum formed two or more point contacts through the oxide layer [4]. Current and potential leads were connected to the bead and to the ring, making it possible to pass transport current through the point contacts and to measure the potential difference between the bead and the ring. The interferometer was placed inside a solenoid shielded by a system of superconducting and magnetic screens. When the magnetic field of the solenoid was turned on and the temperature reduced below the critical point T_c of the tantalum, an undamped current was excited in the ring and its magnetic field penetrated directly the interferometer quantizing loops containing the poor connections (point contacts). Under such conditions, in a definite temperature interval below T_c of the indium, a voltage V of approximately 1 μV appeared across the potential leads, oscillating about zero when the solenoid field (the current in the tantalum ring) was varied when the current loop of the interferometer was open. The voltage was measured with a battery-powered photoelectric microvoltmeter (type F116/1) and recorded with an x-y plotter. When the temperature was lowered, the amplitude of the oscillations increased, passed through a maximum, and decreased to zero at a temperature 0.2 - 0.3° below critical. At lower temperatures, oscillations with the same period were produced by the flow of the transport current; the current needed for the appearance of the oscillations increased monotonically from zero with decreasing temperature. The figure shows the observed oscillations of the voltage



Voltage oscillations in a superconducting interferometer in the resistive state with variation of the external magnetic field in the absence of transport current through the interferometer.

V as a function of the magnetic field H of the solenoid. In all cases the V(H) oscillations were reversible as functions of the field and reproducible. The resistance of the bead-ring junctions on which the oscillations of V(H) were observed without the transport current was approximately 1 ohm at T = 77°K. Lower-resistance junctions revealed V(H) oscillations only in the presence of transport current. With decreasing temperature, the period of the oscillations increased somewhat with decreasing depth of penetration of the magnetic field. At the quantizing-loop inductances characteristic of our interferometer, $L \sim 10^{-11}$ H, the total circulating current i_c in the static condition of the fluxoid quantization [3] reaches 10^{-4} A (from the estimate $Li_c \sim \Phi_0/2$). At this value of the current, the poor connections are in a resistive state. Therefore the circulating current should attenuate and the state with the quantized fluxoid should decay within a time on the order of 10^{-7} - 10^{-9} sec (on the order of the ratio $Li_c^2/(Vi_c)$). Experiment revealed, however, a time-invariant voltage. We are now working on the question of the energy balance in interferometers with resistive poor connections.

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OPTICAL BREAKDOWN OF MERCURY VAPOR

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Experiments on laser breakdown of gases with high ionization potential and with low excitation-band width are satisfactorily explained by the cascade theory proposed by Ya. B. Zel'dovich and Yu. P. Raizer [1]. The definition of the threshold electric field intensity in the light wave contains the quantity α - the probability that the electron will jump through the excitation-loss band - which is determined by solving the average stationary kinetic equation for a level with a certain average energy $\bar{\epsilon}$ in the excitation-loss band. However, in the case of atoms with small ionization potential and a broad excitation band, $\Delta \sim I_i$ (alkali metals, mercury [5]), an estimate of the probability α obviously calls for a detailed analysis of the energy levels of the atoms and for a solution of the complete quantum-kinetic equation in each band that is determined by the arrangement of the energy levels. For example, in the spectrum of the mercury atoms we can separate four bands: band I corresponds to the energy interval from the ground state level (I_0) to the first excited one (I_1^*), band II corresponds to the interval between levels 6^3P_1 and 6^1P_1, band III to the interval between levels 6^1P_1 and 7^1P_1, and band IV to the interval between the levels 7^1P_1 and the boundary of the continuum. The width of this band is $\Delta_4 = I_1 - I_3^* \sim \hbar\omega$, i.e., of the order of the ruby-laser quantum. This choice of the width of band IV is explained by the fact that the loss to the excitation level in this band will not influence the rate of development of the cascade, owing to the large probability of one-photon ionization.

The quantum-kinetic equation for the distribution function of the electrons $n(\epsilon)$, under the same assumptions as in [1], can be written in each band in the form

$$2\epsilon u \frac{d^2 n_k}{d\epsilon^2} + u \frac{d n_k}{d\epsilon} - \frac{n_k}{\theta_k} = 0, \qquad (1)$$

where k = 1, 2, 3, and 4 are the numbers of the bands, u is the "macroscopic" particle velocity along the energy axis, θ_1 is the time constant of the cascade development: $n(t) = n_0 \exp(t/\theta_1)$,

$$\frac{1}{\theta_2} = \frac{1}{\theta_1} + \frac{1}{\tau_1^*}$$

(τ_1^* - lifetime of the electron with respect to the excitation of the level I_1^*),

$$\frac{1}{\theta_3} = \frac{1}{\theta_1} + \frac{1}{\tau_{2i}^*} + \frac{1}{\tau_{21}^*}$$