Superconductivity and Electron Tunneling

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Abstract

Tunnel effect between metal layers is analyzed here. A potential difference imposed between two metal layers creates an electron tunneling current, and its relation with the potential depends on the state of the layers. Here is presented the case when one of the metals, Lead, is in the superconducting state and the other, Aluminum, in the normal state. By analysis of the data the gap of the Lead and other consequences can be inferred.

1 Introduction

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2 Theoretical Approach

A LITTLE BIT OF MATHEMATICS FOR ELECTRON TUNNELING... FROM GIAEVER'S PAPER AND ANDRES' SOLID IV COURSE NOTES

The transition rate W for an electron from an occupied state in the layer 1 with momentum $\mathbf{p_1}$ to a free state in the layer 2 with momentum $\mathbf{p_2}$ can be calculated by means of the Fermi Golden Rule like follows:

$$W^{1e}_{1\to 2} = \frac{2\pi}{\hbar}|T_{21}|^2 f(\epsilon_{\mathbf{p_1}})[1-f(\epsilon_{\mathbf{p_2}})]\delta(\epsilon_{\mathbf{p_1}}-\epsilon_{\mathbf{p_2}})\delta_{s_1 s_2}, \tag{1}$$

where T_{21} is the transition amplitud, $f(\epsilon_{\mathbf{p_1}})$ the probability that the state $\mathbf{p_1}$ is occupied and $[1 - f(\epsilon_{\mathbf{p_2}})]$ the probability that the state $\mathbf{p_f}$ is empty, and the conservation of the energy and spin in the transition are assumed.

The total transition rate from the electrode 1 to the electrode 2 will be

$$W_{1\to 2} = \frac{2\pi}{\hbar}\sum_{\substack{s_1,s_2\\ \mathbf{p_1},\mathbf{p_2}}} |T_{21}|^2 f(\epsilon_{\mathbf{p_1}})[1-f(\epsilon_{\mathbf{p_2}})]\delta(\epsilon_{\mathbf{p_1}}-\epsilon_{\mathbf{p_2}})\delta_{s_1 s_2}. \tag{2}$$

If the transition hamiltonian does not depend on the spin and couples weakly the electrodes when the applied voltage is small (a valid approximation for the voltages used in this experiment), we can simplify the expression (2):

$$W_{1\to 2} = \frac{4\pi}{\hbar}|T|^2 \sum_{\mathbf{p_1},\mathbf{p_2}} f(\epsilon_{\mathbf{p_1}})[1-f(\epsilon_{\mathbf{p_2}})]\delta(\epsilon_{\mathbf{p_1}}-\epsilon_{\mathbf{p_2}}). \tag{3}$$

The transition rate in the opposite way is analogous.

Now we can write explicitly the expression for the current in the $1\to 2$ direction:

$$I = e\ (W_{1\to 2} - W_{2\to 1}), \tag{4}$$

that is

$$I = \frac{4\pi e}{\hbar}|T|^2 \sum_{\mathbf{p_1},\mathbf{p_2}} [f(\epsilon_{\mathbf{p_1}}) - f(\epsilon_{\mathbf{p_2}})]\delta(\epsilon_{\mathbf{p_1}} - \epsilon_{\mathbf{p_2}}).. \tag{5}$$

If we replace the summatories by integrals, considering that the momentums configure a quasicontinuum, and assuming a voltage difference V between the electrodes that makes $\mu_2 - \mu_1 = eV$, we get

$$\begin{aligned} I &= \frac{4\pi e}{\hbar}|T|^2 \times \\ &\times \int_{-\infty}^{\infty} d\epsilon \; N_1(\epsilon - eV) \; N_2(\epsilon)[f(\epsilon - eV) - f(\epsilon)]. \end{aligned} \tag{6}$$

3 Experimental Method

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4 Experimental Results

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