ELECTRON EVOLUTION IN SINGLE-ELECTRON TUNNELING

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Abstract

In single-electron tunneling the behaviour of the charges on the plates is that of two fluids flowing in opposite directions.

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In DC-current biased junctions, elementary charging results in the correlation of the quasicontinuous accumulation of electrical charge on the metallic plates of the junction with the discrete transfer of electrical charge across the barrier with mean frequency

$$\tau_i^{-1} = \overline{I}/e \text{ and/or } \tau_B^{-1} = \overline{I}/2e$$

for "single-electron tunneling" or "Bloch" oscillations respectively. In the above notation I is the average current through the junction. It is also understood that during a tunneling event the junction capacitor charge Q changes discontinuously by an elementary charge e. The object of the present study is the discussion of the possible way in which this charge evolves. In this work it is considered that as the charge is deposited on the plates 1 (positive) and 2 (negative) its distribution on them is such, that its value is not $Q = ne$ sharp, where n is an integer, but $Q + x_{1,2}e$, where $0 \leq x_{1,2} \leq 1$ is a time dependent function. Accordingly, the tunneling event may occur if and when the sum of both charges $q_{1,2} = x_{1,2}e$ exceeds the threshold value e, that is if $x_1 + x_2 \geq 1$. Hence

a) In the tunneling effect the quasicontinuous transfer of electrical charge on the plates turns to a continuous distribution during the tunneling time.

b) In this time interval each charge $q_1 = x_1 e$ and $q_2 = x_2 e$ may acquire any value which is a fraction of the elementary charge e. This charge will be referred to as a "clasmatron" after the Greek word "clasma" for fraction.

c) For the tunneling effect to occur it must be $x_1 + x_2 \geq 1$.

The variation of x_1, and x_2 is continuous so that we can argue that the evolution of the clasmatrons q_1, and q_2 is that of two fluids flowing in the same channel but in

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opposite directions and with different, in general, speeds. When the two fronts meet, the flow becomes unidirectional and this is the moment at which the fluid character of the charge is suppressed and it transforms to an electron that is transferred from plate to plate. The time interval of the flow corresponds to the duration of the tunneling event. The evolution of the clasmatrons q_1, and q_2 is described by the corresponding wave functions Ψ and Y. Let $\Psi_1 = \exp i \left(\underset{-1}{k} \cdot \underset{-1}{r} - \omega t \right)$ and $Y_2 = \exp i \left(\underset{-2}{k} \cdot \underset{-2}{r} - \omega t \right)$ be two waves that are incident, the first at a point $A_1 \left(\underset{-1}{r} \right)$ on plate 1 and the second at a point $A_2 \left(\underset{-2}{r} \right)$ on plate 2, propagating in opposite directions. At a point $\sum \left(\underset{-}{r} \right)$ between the two plates, the wave functions are determined by Green's theorem

$$\Psi = \frac{1}{2\pi} \int \mathcal{I}_1 \Psi_1 \frac{\partial G_i}{\partial n_i} dS_i,$$

$$Y = \frac{1}{2\pi} \int \mathcal{I}_2 Y_2 \frac{\partial G_i}{\partial n_2} dS_2.$$

In the above notation $\mathcal{I}_1 \left(\underset{-1}{k} \cdot \underset{-1}{r} \right)$ and $\mathcal{I}_2 \left(\underset{-2}{k} \cdot \underset{-2}{r} \right)$ are the transmission coefficients at the left and right interface, $G_i = [\exp(k_i R_i)] / R$, where $R_i = \| r_i -_i r_i \|, (i = 1, 2)$ and K_i^{-1} is the decay length of the wave function in the insulator. Since the position probability for each clasmatron's front to be at the point $\sum$ is

$$P_1(x,t) = \int_0^{x_1} |\Psi|^2 \, dx,$$

$$P_2(x,t) = \int_0^{x_2} |Y|^2 \, dx,$$

the total probability is $P = P_1 + P_2 = 1$ and this is an equation relating x_1, and x_2 with time. The other is $x_1 + x_2 = 1$.

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