AHARONOV–BOHM EFFECT INDUCED BY LIGHT

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The quantum interferometry of normal metallic loops based on the Aharonov-Bohm effect is usually applied to measurements at low temperatures in the case of static or slowly time-varying magnetic fields (e.g., see [1]). Recently, an important case of an *ac* field of high frequency $\omega \gg v_F/R$ (v_F is the Fermi velocity and R is the radius of the metallic ring) has been considered [2]. This consideration is based on the assumption that the position dependent time-varying electromagnetic field produces the static electron energy minibands in the ring which appear due to electron motion in a time-averaged electrostatic potential periodic with coordinate along the ring circumference, produced by the square of an *ac* electric field [3]. It should be noted that, in the quantum case, an electron reflection from an oscillating potential causes a time-dependent phase shift, resulting in an effective chaotization of the phase of electron wave function, except at energy multiples of $\hbar\omega$.

The case of much higher frequency $\omega > \Delta E/\hbar$ has been considered in [4]. Here ΔE is the width of the electron conduction band of the metal. Thus, it corresponds to the optical frequencies.This high-frequency Aharonov-Bohm effect can take place in the system, consisting of an optical fiber surrounded by a small metallic ring. Under the above condition, the elastic scattering of electrons in the metal is prohibited if the separation between the conduction band and higher nonoccupied band of the metal is larger than $\hbar\omega$. In this case, the the phase shift of the electron wave function is mainly due to the magnetic component of the electromagnetic field, propagating through the fiber. Among the modes of the fiber field TE_{01} modes produces the largest contribution to the oscillation of conductance. It is important to use an inhomogeneous ring to provide the concentration of the *ac* electric field near the narrowings (points A, B) of the ring. Hopping of electrons near these points is influenced by a phase factor emerging from the vector potential $\mathbf{A}(\mathbf{r}, t)$ of the *ac* field.

The model has been used for the description of the effect under consideration [4] considers a one-dimensional loop in the tight-binding approximation with two transmittance amplitudes t_1, t_2 at the points A, B which are much smaller than the hopping amplitude t_0 between the nearest points inside upper and lower parts

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of the ring. The system is described by the Hamiltonian

$$H = -t_0 \sum_n (a_n^+ a_{n+1} + b_n^+ b_{n+1}) + h.c. + H_{int},$$
$$H_{int} = -t_1 a_{n_1}^+ b_{n_1} e^{i\alpha_1} - t_2 a_{n_2}^+ b_{n_2} e^{i\alpha_2} + h.c. \tag{1}$$

Here index n enumerates the sites along the ring and a_n, b_n are the electron annihilation operators. The phases of transmission amplitudes at the contraction points n_1, n_2 are

$$\alpha_i = \alpha_i^0 + A_i \sin(\omega t + \delta), \quad \alpha_1^0 - \alpha_2^0 = \frac{2\pi\Phi_{dc}}{\Phi_0}$$

where a_i is $\Phi_{dc} = \int \mathbf{B} \cdot d\mathbf{S}$ and $\Phi_0 = hc/e$. Hamiltonian (1) is Fourier-transformed into the following

$$H_{int} = \sum_{n=-\infty}^{\infty} H_{int}^{(n)} e^{in\omega t}, \quad H_{int}^{(n)} = -\sum_{j=1}^{2} t_j e^{i\alpha_j^0} J_n(A_j) a_{n_j}^+ b_{n_j} \tag{2}$$

where $J_n(\cdot)$ is the Bessel function. Since the scattering events are forbidden under the condition $4t_0 < \hbar\omega$, the contribution of $H_{int}^{(n)}$ at $n = 0$ can be omitted. By perturbation, the forward (+) and backward (−) scattering probabilities between the plane-wave states are $W_{\pm k}$ where

$$W_k = |\frac{\partial \epsilon_k}{\partial k}|^{-1} \sum_{j=1}^{2} [(t_j J_0(A_j))^2 + 2t_j J_0(A_j)\cos(\alpha + 2kL)]. \tag{3}$$

Here L is the total length of the loop, the phase $\alpha = 2\pi\Phi_{dc}/\Phi_0$, and $\epsilon_k = -2t_0 \cos k$.

Taking into account that, in the steady state, the populations of electron states are obtained from the kinetic equation, describing emerging of the electrons from two thermal reservoirs [4] one can find the contribution into conductance due to the interchange scattering as follows

$$G = \frac{e^2(t_1^2 + t_2^2)W_0}{2ht} \int_0^\pi \frac{W_0[W_k + W_{-k} + 2W_k W_{-k}}{[W_0 + W_k][W_0 + W_{-k}]} \times \frac{dk}{|\partial\epsilon_k/\partial k| \cosh^2[(\epsilon_k - \mu)/2T}. \tag{4}$$

This equation (4) is equivalent, in some sense, to the Landauer formula for the conductance at transmission probability $|t|$ [5].

The largest contribution to the conductance oscillations in (4) with the typical magnitude of change of the order of $2e^2/h$ corresponds to the mode TE_{01} of the fiber field under consideration. To observe the effect, the size of the loop should be of the order of a few wavelengths of light. It follows from (3) and (4) that the dependence of G on phase α of the electromagnetic field leads to two different effects. First, the oscillatory dependence $G(\Phi_{dc})$ is the standard mesoscopic effect similar to that in the static electron interferometer [1]. In addition, we have oscillations of the type $G(A_{ac})$ arise from the Bessel function in (2). Let us turn to quantitative estimation of the effects. If we choose $L = 1m\mu$ the estimation of the magnitude of the magnetic field from (4) gives $H_{ac} \sim 10^{-7}T$ which corresponds to a quite reasonable power of the optical field of the order of $P \sim 10^{-3}w$. We can also estimate the minimum number of photons, passing through the ring and producing the necessary shift of the phase, as $N_{\omega} \sim \hbar c/e^2$. It corresponds to the case of optical soliton propagating through the fiber.

References

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