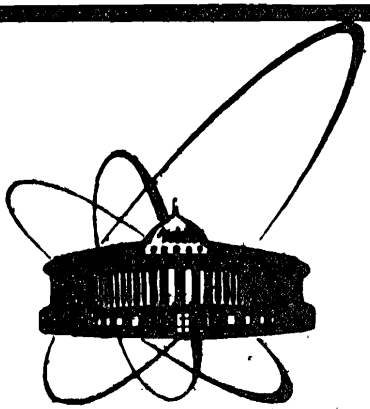

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QUANTUM INTERFERENCE ON GRAPHS CONTROLLED BY AN EXTERNAL ELECTRIC FIELD

1987

1. Introduction

The rapid development of the techniques of fabricating small metallic or semiconductor structures has opened an entirely new field of research which is sometimes dubbed mesoscopic physics. The term expresses the fact that while the structures involved are designed by an experimentalist (that is, in a macroscopic way), they are small enough to exhibit typical quantum effects. Conductivity measurements have been performed on various structures ; rings, squares and their sequences, honeycomb networks, etc. [5,7,30,39-41]. Most attention has been paid to the Aharonov-Bohm effect manifested by magnetoresistance oscillations which represents a suitable object for experimental investigation being stable with respect to variations of the pattern geometry.

There are other interesting situations, however. It is natural to ask, e.g., what happens if the structure is placed into an electric field, in particular, how its resistance depends on the field intensity. The possibility is technically attractive, because it might open way to a new type of switching devices. In order to decide whether such a prospect is realistic, a careful analysis is needed. In this paper, we address ourselves with this problem.

From the microscopic point of view, the system under consideration is complicated enough to make its complete description very difficult. We shall not attempt to do it. Instead, we are going to construct a model which, as we believe, reproduces the essential features of the system, and at the same time it is solvable. It is based on the assumption that the "wires" which are building elements of the structure are infinitely thin. Actually they represent a band of atoms whose width can be made as small as 200 Å by the technologies mentioned above. Once we replace them by lines, our problem reduces to the analysis of motion of a quantum particle which is confined to an appropriate planar graph and subjected to the electric field. We limit ourselves to the simplest non-trivial case when the graph consists of a loop with

two external leads. We shall assume also that the external field is weak enough so that the semiclassical approximation may be used. The results of the present analysis have been announced in Ref.22 .

Let us describe briefly the contents of the paper. In the next section we show, how and under which assumptions the conductivity can be calculated. The key element of the model is to describe how the electron wavefuction "splits" at the junctions. This is discussed in Section 3 ; it allows us to choose the Hamiltonian for a charged particle whose motion is confined to a planar curve in presence of an external field. In the next section, the transmission coefficient is calculated. Its evaluation requires the knowledge of transfer matrices for the corresponding Schrödinger equations ; we calculate them in Section 5 using the semiclassical approximation. In conclusion, we give some examples of conductivity vs. field intensity plots which show that the prospect of constructing the above-mentioned switching devices is fully realistic.

2. The physical background

As we have said, our model is intended to describe a charged quantum particle (an electron) moving on a loop with two external leads under influence of (a) a voltage U applied to the leads and (b) a homogeneous electric field of intensity parallel to the graph plane and perpendicular to the leads. The motion on the loop is assumed to be ballistic, i.e., both the elastic and inelastic scattering is negligible.

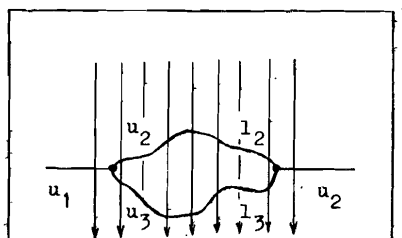

Fig.1. Scheme of the model

Let us first say a few words about the ways in which such systems can be prepared. The metallic rings and similar stuctures are usually produced lithographically, by an atomic beam drawing a required graph on a substrate (cf. the references quoted in the introduction). The technique is fairly elaborated at present ; its appealing feature is that in principle an arbitrary planar graph can be drawn.

The situation is not so simple with semiconductors. For them, too, interference experiments have been proposed and performed, but in distinction to the above named ones, they employed heterostructures grown by the epitaxial technique[12]. It was even suggested to use the

interference in heterostructures in switching devices[11] ; our analysis shows, however, that the "graphs" are more suitable for that purpose. Let us remark in this connection that though our model is not applicable to the heterostructures, since the channel thickness cannot be neglected in this case, there is a way how this difficulty might be overcome. It is connected with a solution to the so-called injection problem[27] which we are going to discuss in a separate paper.

Very recently a new technique has been reported which opens way to fabricating semiconductor graph structures[38]. In a sense, it combines the procedures mentioned above. One prepares first a semiconductor layer on a substrate and draws lithographically metallic lines on it. The graph is afterwards used as a mask when the layer is removed by ion bombarding.

The essential assumption of our model is that the electrons move ballistically on the loop. It can be fulfilled if the electron mean free path is much longer than the loop size. In semiconductors this quantity depends heavily on how much the material is doped. It can be made as long as $\lesssim 1\mu m$ so the assumption can be justified in this case. The situation is not so good in metals, but even here experiments with ballistic electrons could be expected in the nearest future[41].

Under this assumption, one is able to solve the one-particle problem, i.e., to deduce the transmission coefficient $T(E)$ for an electron moving towards the loop with an energy E . It allows us further to calculate the conductivity. For a bulk metal, the current corresponding to the apllied voltage U is given by[29]

$$I = \frac{e}{\pi\hbar} \int_0^\infty \left[f(E+eU) - f(E)\right] \frac{T(E)}{1-T(E)}\, dE \quad , \tag{2.1a}$$

where f denotes the Fermi-Dirac distribution,

$$f(E) = \left(1 + \exp\left(\frac{E - E_F}{kT}\right)\right)^{-1} \quad . \tag{2.1b}$$

A typical Fermi energy in metals is a few eV so $kT \ll E_F$ (recall that 1 eV corresponds to the temperature $11605^\circ K$). The voltage U in the above quoted experiments was of order of microvolts so $eU \ll E_F$ too. If the transmission coefficient is a slowly varying function of energy in this scale, we get for the conductivity $G = I/U$ from (2.1a) the following approximative expression

$$G = \frac{e^2}{\pi\hbar} \frac{T(E)}{1-T(E)} \quad , \tag{2.2}$$

where $E \approx E_F$. Notice that in fact the distribution of electrons in the conductivity band is not given by (2.1b), since the wire does not represent a bulk metal, and therefore E_F should be replaced by another value. However, the correction again does not exceed kT .

In semiconductors the situation is completely different. There are much less electrons in the conductivity band. On the other hand, they have typically a small effective mass (for GaAs , e.g., we have $m^* = 0.067\, m_e$), and therefore only a few transversal modes are contained in the conductivity band[24]. The conductivity will be then calculated from the formula (2.2) again, but now E will be the lowest-transversal mode energy. It depends not only on the material, but also on the shape of the wire ; for 200 Å thick wires, it is of order of 10^{-2}eV.

3. The mathematical backgroud

For the sake of simplicity, the electrons will be assumed to be spinless. The state Hilbert space of our problem is then of the form

$$\mathcal{H} = L^2(0,\infty) \oplus L^2(0,l_2) \oplus L^2(0,l_3) \oplus L^2(-\infty,0) \quad , \tag{3.1}$$

where the orientation of axes is chosen in a way that allows to describe the two junction in a similar fashion. The central problem is how to choose the Hamiltonian H of the model. Two requirements must be fulfilled :

(a) . H is self-adjoint,

(b) if the wavefunction has a support separated from the junctions, then H describes the appropriate motion on the halfline or on the loop.

Such an operator can be constructed by taking first a suitable pre-Hamiltonian H_0 which is non-selfadjoint, the branching points of the graph being removed from its domain. The admissible Hamiltonians are then obtained as self-adjoint extensions of H_0 . The same method has been applied recently in different contexts[1-4,13,16-22,28,31-36].

The Hamiltonians describing a free motion on a branching graph have been studied in Refs.20,21 . In particular, we derived there boundary conditions which specify the self-adjoint extensions of the pre-Hamiltonian H_0 .They can be used obviously for an electron moving under influence of an external field as long as the interaction remains bounded. This is true in our case : we shall show a little later that the starting operator H_0 may be chosen as

$$H_0 = \bigoplus_{j=1}^{4} H_{0,j} \tag{3.2a}$$

with

$$H_{0,j} = \left(-\frac{\hbar^2}{2m^*} \frac{d^2}{dx_j^2} + V_j(x_j) \right) \restriction C_0^\infty(M_j) \quad , \tag{3.2b}$$

where M_j is the appropriate part of the configuration manifold, m^* is the effective mass ; furthermore, V_j is a bounded function on the loop, $j = 2,3$, while $V_j = 0$ on the leads, $j = 1,4$.

In general, the deficiency indices of H_0 are (18,18) so it has a vast family of self-adjoint extensions.We adopt the following restrictions on the Hamiltonian H :

(c) H is local in the sense that supp $Hu \subset$ supp u for all $u \in D(H)$,

(d) H is locally permutation-invariant at each junction : if the support of u is sufficiently concentrated around one of the junctions, and P_{jk} is the operator permuting the j-th and k-th wire at the junction, then $P_{jk}u \in D(H)$ and $P_{jk}Hu = HP_{jk}u$.

The last condition means that if the electric field is switched off, the electron whose motion is governed by H does not distinguish the wires provided it is close enough to the juction.

Under the conditions (c) and (d), the self-adjoint extensions H are characterized by two pairs of real parameters, each of them referring to one junction. Most of the extensions can be expressed by the following boundary conditions

$$\begin{aligned} u_1(0) &= A_1 u_1'(0) + B_1 u_2'(0) + B_1 u_3'(0) \quad , \\ u_2(0) &= B_1 u_1'(0) + A_1 u_2'(0) + B_1 u_3'(0) \quad , \\ u_3(0) &= B_1 u_1'(0) + B_1 u_2'(0) + A_1 u_3'(0) \end{aligned} \tag{3.3a}$$

and

$$\begin{aligned} u_2(l_2) &= A_2 u_2'(l_2) + B_2 u_3'(l_3) + B_2 u_4'(0) \quad , \\ u_3(l_3) &= B_2 u_2'(l_2) + A_2 u_3'(l_3) + B_2 u_4'(0) \quad , \\ u_4(0) &= B_2 u_2'(l_2) + B_2 u_3'(l_3) + A_2 u_4'(0) \quad , \end{aligned} \tag{3.3b}$$

where $u_j(0)$, $u_j'(0)$, $u_j(l_j)$ and $u_j'(l_j)$ are understood as the limits from the appropriate side. With the chosen orientation of the axes, the two junctions are the same if

$$A_1 = -A_2 \quad , \quad B_1 = -B_2 \quad . \tag{3.4}$$

The conditions (3.3) do not exhaust all the operators H fulfilling the requirements (a)-(d). There are two additional one-parameter classes of boundary conditions at each junction that also lead to a self-adjoint H - cf.Ref.21 . However, the considerations presented below are adapted easily to these exceptional cases, and we shall not treat them explicitly in the following.

The last thing we must fix are the potentials V_j appearing in (3.2b). A natural guess which can be supported by the standard quantization procedure[14,37] is

$$V_j(x_j) = -e\mathcal{E}y_j(x_j) \quad , \tag{3.5}$$

where $y_j(x_j)$ marks the distance from a fixed equipotential line ; conventionally, we choose zero value of the potential on the leads. Unfortunately, the problem is more complicated. The graph lines in our model substitute thin stripes, and therefore the potentials should contain curvature-dependent terms[8-10,25,26]. Simple estimates show, however, that for the ring structures mentioned in the introduction, the ansatz (3.5) represents a good approximation. We shall use it therefore in the present paper leaving the analysis of the curvature effects to a subsequent publication.

4. The transmission coefficient

Now we are ready to solve the scattering problem for the loop. We shall use the time-independent framework ; then one has to find the function $u = (u_1, u_2, u_3, u_4)$ that belongs locally to the domain of the extension H chosen to play the role of Hamiltonian, and fulfils

$$u_1(x_1) = e^{-ikx_1} + a\, e^{ikx_1} \quad , \tag{4.1a}$$

$$u_2(x_2) = c_1 f_1(x_2) + c_2 f_2(x_2) \quad , \tag{4.1b}$$

$$u_3(x_3) = d_1 g_1(x_3) + d_2 g_2(x_3) \quad , \tag{4.1c}$$

$$u_4(x_4) = b\, e^{-ikx_4} \quad , \tag{4.1d}$$

where f_1, f_2 are the solutions to the Schrödinger equation

$$-\frac{\hbar^2}{2m^*} f_k''(x_2) + V_2(x_2) f_k(x_2) = E f_k(x_2) \tag{4.2a}$$

with $E = \hbar^2 k^2/2m$ fulfilling the boundary conditions

$$f_1(0) = f_2'(0) = 1 \quad , \quad f_1'(0) = f_2(0) = 0 \quad , \tag{4.3a}$$

and similarly, g_1, g_2 are the solutions of

$$-\frac{\hbar^2}{2m^*} g_k''(x_3) + V_3(x_3) g_k(x_3) = E g_k(x_3) \tag{4.2b}$$

corresponding to the boundary conditions

$$g_1(0) = g_2'(0) = 1 \quad , \quad g_1'(0) = g_2(0) = 0 \quad ; \tag{4.3b}$$

the potentials V_2, V_3 are given by (3.5) as mentioned above. We shall need also the transfer matrices $\Pi_j \equiv \Pi_j(l_j)$, $j = 2,3$,

$$\begin{pmatrix} u_j(l_j) \\ u_j'(l_j) \end{pmatrix} = \Pi_j \begin{pmatrix} u_j(0) \\ u_j'(0) \end{pmatrix} \quad . \tag{4.4a}$$

Using the above mentioned solutions to the eqs.(4.2), we may express them as

$$\Pi_2 = \begin{pmatrix} f_1(l_2) & f_2(l_2) \\ f_1'(l_2) & f_2'(l_2) \end{pmatrix} \quad , \quad \Pi_3 = \begin{pmatrix} g_1(l_3) & g_2(l_3) \\ g_1'(l_3) & g_2'(l_3) \end{pmatrix} \quad . \tag{4.4b}$$

Our aim is to find the coefficient b assuming that the functions (4.1) fulfil the boundary conditions (3.3). To solve this problem, we express first the coefficients c_1, c_2 with the help of d_1, d_2 . The boundary conditions for the first junction yield the equations

$$1 + a = -ikA_1(1-a) + c_2 B_1 + d_2 B_1 \quad ,$$

$$c_1 = -ikB_1(1-a) + c_2 A_1 + d_2 B_1 \quad ,$$

$$d_1 = -ikB_1(1-a) + c_2 B_1 + d_2 A_1 \quad .$$

Excluding a from here, we get a system of two linear equations for c_1, c_2 which is solved by

$$\begin{pmatrix} c_1 \\ c_2 \end{pmatrix} = \begin{pmatrix} z_1(k) \\ z_2(k) \end{pmatrix} + C_1(k) \begin{pmatrix} d_1 \\ d_2 \end{pmatrix} \quad , \tag{4.5}$$

where

$$z_2(k) = (A_1-B_1)z_1(k) \quad , \quad z_1(k) = \frac{2ik}{1+ik(B_1-A_1)} \tag{4.6a}$$

and

$$C_1(k) = \frac{1}{B_1[1+ik(B_1-A_1)]} \times$$

$$\times \begin{pmatrix} A_1+ik(B_1^2-A_1^2) & (B_1-A_1)[(A_1+B_1)(1-ikA_1)+2ikB_1^2] \\ 1-ikA_1 & -A_1-ik(B_1^2-A_1^2) \end{pmatrix} . \tag{4.6b}$$

- The boundary conditions at the second junction yield the equations

$$\tilde{c}_1 = \tilde{c}_2 A_2 + \tilde{d}_2 B_2 - ikbB_2 \quad ,$$

$$\tilde{d}_1 = \tilde{c}_2 B_2 + \tilde{d}_2 A_2 - ikbB_2 \quad ,$$

$$b = \tilde{c}_2 B_2 + \tilde{d}_2 B_2 - ikbA_2 \quad ,$$

where we have introduced

$$\begin{pmatrix} \tilde{c}_1 \\ \tilde{c}_2 \end{pmatrix} = \Pi_2 \begin{pmatrix} c_1 \\ c_2 \end{pmatrix} = \begin{pmatrix} u_2(l_2) \\ u_2'(l_2) \end{pmatrix} \tag{4.7a}$$

and

$$\begin{pmatrix} \tilde{d}_1 \\ \tilde{d}_2 \end{pmatrix} = \Pi_3 \begin{pmatrix} d_1 \\ d_2 \end{pmatrix} = \begin{pmatrix} u_3(l_3) \\ u_3'(l_3) \end{pmatrix} . \tag{4.7b}$$

Excluding b from the above system,

$$b = \frac{B_2}{1+ikA_2}(\tilde{c}_2 + \tilde{d}_2) \quad , \tag{4.8}$$

we arrive at equations for $\tilde{c}_1, \tilde{c}_2$. They are solved by

$$\begin{pmatrix} \tilde{c}_1 \\ \tilde{c}_2 \end{pmatrix} = C_2(-k) \begin{pmatrix} \tilde{d}_1 \\ \tilde{d}_2 \end{pmatrix} \quad , \tag{4.9}$$

where $C_2(k)$ is given by (4.6b) with A_1, B_1 replaced by A_2, B_2 .

Now we are in position to find the coefficients in (4.1b,c). Notice that the matrices appearing in the above relations are non-singular ; one finds easily that $\det C_j(k) = -1$, and furthermore, $\det \Pi_j$ is the Wronskian of the corresponding solutions, and therefore non-zero. The relations (4.5),(4.7) and (4.9) give

$$\Pi_2^{-1} C_2(-k) \Pi_3 \begin{pmatrix} d_1 \\ d_2 \end{pmatrix} = \begin{pmatrix} z_1(k) \\ z_2(k) \end{pmatrix} + C_1(k) \begin{pmatrix} d_1 \\ d_2 \end{pmatrix} .$$

From here the coefficients d_1, d_2 may be found ; the other three pairs of coefficients are then obtained from (4.7) and (4.9). In particular, we have

$$\begin{pmatrix} \tilde{c}_1 \\ \tilde{c}_2 \end{pmatrix} = \left[\Pi_2^{-1} - C_1(k)\Pi_3^{-1} C_2(-k)^{-1}\right]^{-1} \begin{pmatrix} z_1(k) \\ z_2(k) \end{pmatrix} \quad , \tag{4.10a}$$

$$\begin{pmatrix} \tilde{d}_1 \\ \tilde{d}_2 \end{pmatrix} = \left[\Pi_2^{-1} C_2(-k) - C_1(k)\Pi_3^{-1}\right]^{-1} \begin{pmatrix} z_1(k) \\ z_2(k) \end{pmatrix} \quad , \tag{4.10b}$$

provided the matrices in the square brackets are non-singular (it is sufficient that one of them is non-singular). Combining now the relations (4.8) and (4.10), we get the sought transmission coefficient

$$T(E) = |b|^2 = \frac{B_2^2}{1+k^2A_2^2} |\tilde{c}_2 + \tilde{d}_2|^2 \quad , \tag{4.11}$$

where $E = \hbar^2k^2/2m^*$. In a similar way, the reflection coefficient at energy E is given by

$$R(E) = |a|^2 = \frac{|2 - B_1(c_2+d_2)|^2}{1+k^2A_1^2} \quad . \tag{4.12}$$

5. Semiclassical expressions for the transfer matrices

The relations (2.2) and (4.11) represent the solution to our problem. In order to calculate the conductivity, however, one must know the transfer matrices (4.4). They can be written down analytically for very few potentials, so one must look for another way. One possibility is to solve the eqs.(4.2) numerically ; it will be done in a separate paper[15].

Instead of that, we shall use here an analytically expressed but approximative solution. In fact, the WKB-approximation is applicable to nearly all situations in our model with the exception of those when the energy is near the top of the potential barrier or a plateau in the "upper" branch of the loop. We restrict our attention, however, to the simplest situation represented by the weak-field case when no tunneling occurs (Fig.2). This is true if

$$\mathcal{E} \lesssim \frac{E}{2ae} \quad , \tag{5.1}$$

where a is a characteristic size of the "upper" branch, say, the radius of the ring. Taking $a \approx 2\cdot10^{-5}$ cm and a typical Fermi energy for metals, we get $\mathcal{E} \lesssim 10^5 \text{ V cm}^{-1}$. For semiconductors, this bound is correspondingly lower, $\mathcal{E} \lesssim 10^3 \text{ V cm}^{-1}$, but still it is possible to obtain interference minima before the tunneling regime takes place.

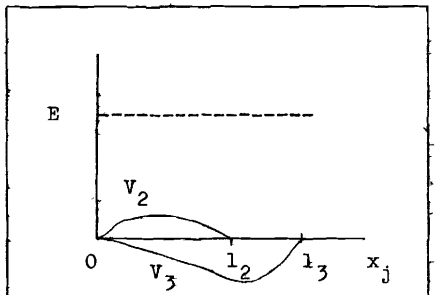

Fig.2. To the solution of eqs.(5.2)

The WKB-approximation may be applied if $|(\hbar/p_j(x_j))'| \ll 1$, where

$$p_j(x_j) = (2m^*(E - V_j(x_j)))^{1/2} \quad . \tag{5.2}$$

Since $p_j(x) \approx \sqrt{2m^*E}$ in the weak-field case, it yields the condition

$$\mathcal{E} \ll \frac{(2m^*E)^{3/2}}{m^*e\hbar} \quad . \tag{5.3}$$

In metals, this leads to the requirement $\mathcal{E} \ll 10^9 \text{ V cm}^{-1}$. In semiconductors, we get $\mathcal{E} \ll 10^5 \text{ V cm}^{-1}$ which is still fine.

The general WKB-solution to eq.(4.2a) is well-known[23]; it is only necessary to select the two solutions that fulfil the boundary conditions (4.3a). We obtain

$$f_1(x_2) = \left(\frac{p_2(0)}{p_2(x_2)}\right)^{1/2} \cos\left(\frac{1}{\hbar}\int_0^{x_2} p_2(y)\,dy\right) - \frac{m^*\hbar V_2'(0)}{2p_2(0)^{5/2}p_2(x_2)^{1/2}} \sin\left(\frac{1}{\hbar}\int_0^{x_2} p_2(y)\,dy\right) \quad , \tag{5.4a}$$

$$f_1'(x_2) = m^* \frac{V_2'(x_2)p_2(0)^3 - V_2'(0)p_2(x_2)^3}{2(p_2(0)p_2(x_2))^{5/2}} \cos\left(\frac{1}{\hbar}\int_0^{x_2} p_2(y)\,dy\right) - \frac{(m\hbar)^2 V_2'(0)V_2'(x_2) + 4(p_2(0)p_2(x_2))^3}{4\hbar(p_2(0)p_2(x_2))^{5/2}} \sin\left(\frac{1}{\hbar}\int_0^{x_2} p_2(y)\,dy\right) , \tag{5.4b}$$

$$f_2(x_2) = \frac{\hbar}{(p_2(0)p_2(x_2))^{1/2}} \sin\left(\frac{1}{\hbar}\int_0^{x_2} p_2(y)\,dy\right) \quad , \tag{5.4c}$$

$$f_2'(x_2) = -\left(\frac{p_2(x_2)}{p_2(0)}\right)^{1/2} \cos\left(\frac{1}{\hbar}\int_0^{x_2} p_2(y)\,dy\right) + \frac{m^*\hbar V_2'(x_2)}{2p_2(0)^{1/2}p_2(x_2)^{5/2}} \sin\left(\frac{1}{\hbar}\int_0^{x_2} p_2(y)\,dy\right) \quad ; \tag{5.4d}$$

substituting $x_2 = l_2$ and using (4.4b), we get the sought expression of Π_2. The transfer matrix Π_3 expresses in quite the same way by means of p_3, V_3 and V_3'.

6. Conclusions

On the following pages, we present a few examples of conductivity plots calculated in the above described way. The shape of the loop is sketched on each graph ; the junctions are supposed to be the same and such that $A_1 = B_1 = -A_2 = -B_2 = 1$. The first three plots are calculated for gold ($E_F = 5.49$ eV), while the remaining ones refer to a GaAs - wire ; in that case we choose $E = 0.05$ eV , in accord with the results of Ref.24 . Variating the parameters that characterize the junctions, the loop shape and the energy E, we obtain other curves. The qualitative character does not change, however. The conductivity always exhibits large oscillations with well-distinguished minima at reasonably low field intensities.

Let us add a few comments. The results of our model for metals have only an academic meaning because the applied field is screened in this case. For a bulk-metal wire, the screening would be complete. For ultrathin wires whose cross section contains $\sim 10^2$ atoms, however, at least the electrons near the surface feel the field and the effect survives, though the conductivity plot is expected to be smeared. In order to find it on the basis of the above considerations, one has to solve the corresponding electrostatic problem and to calculate the (appropriately weighted) average over the potentials V_j.

In semiconductors, a similar smearing effect might be caused by self-screening if sufficiently many electrons were injected into the structure. However, taking into account typical currents (μA to nA region) and velocities (10^6-10^7 cm/s) in these experiments, we see that typically a single conductivity electron is present on the loop.

Hence we can conclude that the prospect of constructing a new type of switching device (quantum interference transistors, if you like) based on the ultrathin semiconductor wires is fully realistic. They would have two attractive features. For one, the values of field intensities corresponding to interference minima show that such a device could operate at very low switching voltages, since the electrodes generating the external field can be placed very close to the loop. Even more appealing is the possibility of tailoring the conductance plot by choosing an appropriate shape of the loop.

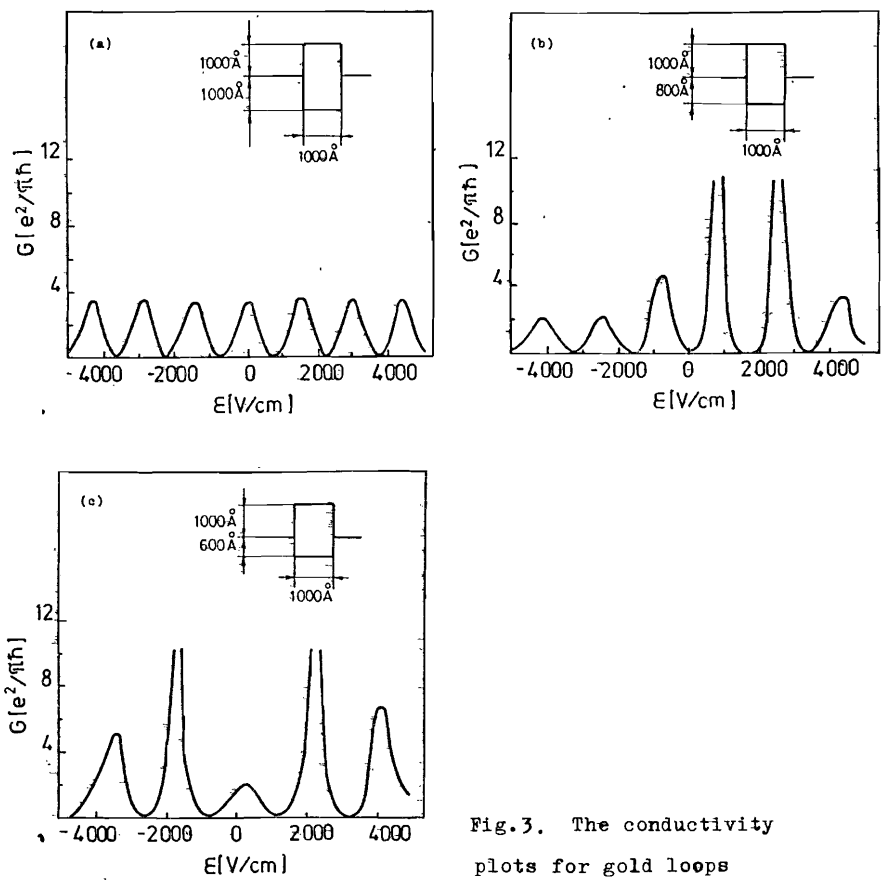

Fig.3. The conductivity plots for gold loops

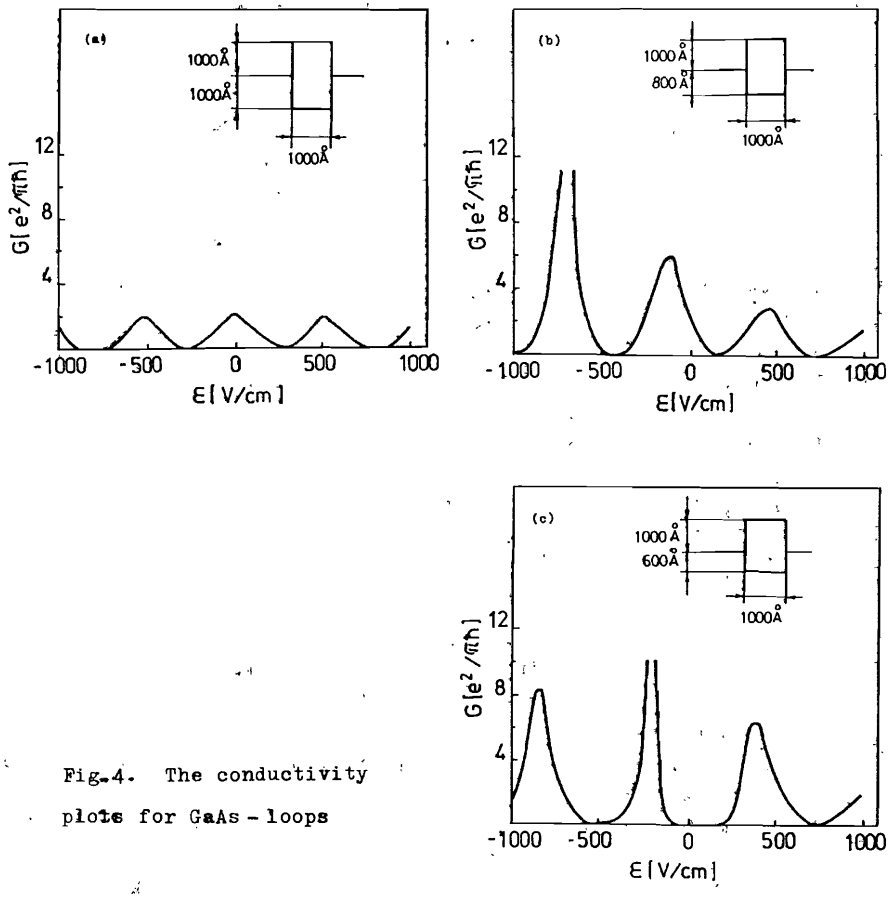

Fig.4. The conductivity plots for GaAs - loops

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Экснер П., Шеба П., Штовичек П. E2-87-707

Квантовая интерференция на графиках, управляемая внешним электрическим полем

Рассматривается движение заряженной квантовой частицы на петле с двумя внешними приводами, помещенной в электростатическое поле. Гамильтониан петли выбирается простейшим образом; чтобы связать его с гамильтонианами приводов, используется метод, основывающийся на самосопряженных расширениях. Накладывая условие симметрии, мы получаем полный гамильтониан, зависящий от четырех свободных параметров; каждый контакт характеризуется одной парой. Рассматриваемая система представляет собой модель металлической или полупроводниковой структуры, которые могут производиться при помощи доступных сегодня технологий. В предположении баллистического режима для электронов вычислено сопротивление такой структуры в зависимости от интенсивности внешнего поля. Результаты показывают возможность создания квантовых интерференционных транзисторов, у которых размеры и выключающее напряжение могут быть намного меньше чем в применяемых сегодня микросхемах.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна 1987

Exner P., Šeba P., Šťovíček P. E2-87-707

Quantum Interference on Graphs Controlled by an External Electric Field

We consider motion of a charged quantum particle on a loop with two external leads which is placed into an electrostatic field. The loop Hamiltonian is chosen in the simplest possible way; in order to join it to the free Hamiltonians describing the leads, we employ a method based on self-adjoint extensions. Under a symmetry requirement, the resulting full Hamiltonian contains four free parameters; each junction is characterized by a pair of them. The system under consideration represents a model of metallic or semiconductor structures that can be fabricated by presently available technologies. Assuming the ballistic regime for electrons in such a structure, we calculate the resistance dependence on intensity of the external field. The results suggest the possibility of constructing quantum interference transistors whose size and switching voltage would be much smaller than in the presently used microchips.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna 1987