THE HOPPING MODEL OF ZERO-BIAS TUNNELLING ANOMALIES: MAGNETIC FIELD EFFECT

T. Ivezić

To cite this version:


HAL Id: jpa-00217848
https://hal.archives-ouvertes.fr/jpa-00217848

Submitted on 1 Jan 1978

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.
THE HOPPING MODEL OF ZERO-BIAS TUNNELLING ANOMALIES : MAGNETIC FIELD EFFECT

T. Ivezic

Institute of Physics of the University, P.O.B. 304, Zagreb, Yugoslavia

Résumé.- Le modèle des liaisons fortes pour l'effet tunnel, proposé par Caroli et al./1/, est utilisé dans l'étude de la diffusion des électrons par les impuretés dans une jonction métal-isolant-métal, avec les impuretés magnétiques situées soit dans les électrodes soit dans l'isolant. Les caractéristiques de la conductivité en présence d'un champ magnétique sont obtenues et leur différence par rapport à la théorie d'Appelbaum /2,3/ discutée. La dépendance des différentes contributions à la conductivité sur la position des impuretés magnétiques est étudiée.

Abstract.— A hopping model of tunnelling proposed by Caroli et al./1/ is used to study electron-impurity scattering in metal-insulator-metal junctions with magnetic impurities in either the insulator or the electrodes. The conductance characteristics in magnetic field are obtained and their differences with respect to Appelbaum's theory /2,3/ are discussed. The dependence of the different contributions to the conductance on the position of the magnetic impurities is considered.

Expressions for the conductance of a magnetically doped tunnel junction are derived in our earlier paper /4/, using the hopping model of zero bias tunnelling anomalies. Here, we consider the same type of junction and obtain the junction conductance characteristics in a magnetic field. As shown in our earlier paper the Appelbaum theory /2,3/ does not include all the important contributions to the conductance. This is also true for the tunnel junctions in the magnetic field.

Due to the freezing out of some spin-flip processes in the presence of the magnetic field \( \vec{H} \) there appear a well in the conductance characteristic \( G(V) \) for \( |V| < g_H \). In Appelbaum's theory the total conductance near zero voltage even falls below the background for large enough field. However, Wallis and Wyatt /5/ showed experimentally that there is only a local minimum in conductance at zero bias, and in this respect their results did not agree with the Appelbaum theory.

We present general results for the conductance in a magnetic field and simplify these results to the case of impurities not far from the interface. Instead of Appelbaum's undetermined phenomenological parameters we have explicit expressions in which the dependence of the conductance on the position of the impurities is taken into account. It is shown that some new terms appear in our theory. These terms may be important when the impurities are near the interface, which is the usual experimental situation.

Our Hamiltonian is /4/
\[
H = H_{MIN} - J \sum_{\alpha \beta} C^\dagger_{\alpha} a_{\beta} C_{\beta} \vec{S} + g_H \vec{S} \cdot \vec{H}
\]
(1)

The first term \( H_{MIN} \) is the pure contact Hamiltonian in the hopping model of tunnelling, the second term is the Kondo type exchange coupling and the third term describes the local spin coupling to the magnetic field. We have calculated \( \Sigma_1^1 \) and \( \Sigma_1^2 \) self energy matrix elements up to order \( J^2 \) and \( J^3 \), using the Keldysh technique, for the impurities confined to the barrier region and to the electrodes. The second order contribution to the conductance in the magnetic field is the most important term. In contrast to the zero field case it shows the strong temperature and voltage dependence. When the impurities are in the barrier it has the following form
\[
\frac{G(0)}{G(0) = 1 + 2 \cos 2 \phi} \quad \frac{G(0)}{G(0) = 1 + 2 \cos 2 \phi}
\]

where \( F(Q) = \int_0^\infty df \left( e^{-f} - 1 \right) \rho_0(e) \) is average spin polarization in the field \( H \).

\[
G_{2i} = R \left| e^{i\phi} \right|^2 K = 2 \left( 1 + 2 \cos 2 \phi \right) ^2 \left( 1 + 2 \cos 2 \phi \right) ^2
\]

(see /4/)

Article published online by EDP Sciences and available at http://dx.doi.org/10.1051/jphyscol:19786380
\[ \gamma(x) = \frac{e^{2x-2xe^{-x}}}{1-\exp^x} \] and \( 6G^{(2)}(H=0) \) is the second order contribution to the conductance in the zero field case

\[ \frac{6G^{(2)}(H=0)}{6G(0)} = |\xi_1^0|^2 J^2 g(S+1) \]  

(4)

\( G(o) \) is the conductance for an undoped junction.

The sum of all terms without the \( d \) function corresponds to Appelbaum's result. The magnetic field does not affect the first two terms in (2), which are none other than the second order conductance in the absence of magnetic field \( G^{(2)}(H=0) \). It affects \( \delta G^{(2)} \) through the terms proportional to \( <M> \). One of them (which does not contain \( d \)) is due to the \( \Sigma \) self-energy and corresponds to Appelbaum's theory. It always decreases \( \delta G^{(2)} \) near zero voltage. On the other hand, the term proportional to \( <M> \sin \phi \), which is due to \( \text{Im} \Sigma_{\text{F}1a}^{1a} \) does not appear in Appelbaum's theory. This term contains the explicit dependence on the position of the impurities in the barrier. For the impurity near the interface, the angular bracket in (2) can be written as \( 1 - 2 \sin^2 \phi \). In that case, the impurities which are approximately one atomic distance from the interface /4/ can increase the second order conductance.

The term proportional to \( <M> \cos \phi \), which is due to \( \text{Re} \Sigma_{\text{F}1a}^{1a} \) is an odd function of bias in the magnetic field. (All other terms are even in \( V \)). If the impurities were symmetrically positioned in the junction, this term would vanish identically. However, if the impurities are associated specifically with one side of the junction, it can not be neglected. It becomes proportional to \( <M> \sin 2\phi \) for the impurity near the interface. Appelbaum /2,3/ obtained a similar term and interpreted it as an interference term involving simultaneous potential and exchange tunnelling. Our considerations show that such a term arises from the pure exchange scattering process in the second order of the exchange coupling constant.

The third order contribution to the conductance can be written as a sum of even and odd parts.

\[ \delta G^{(3)} = (1 - 2 \sin^2 \phi ) \delta G^{(3)} (H=V,T) \]  

(5)

where \( \delta G^{(3)} (H=V,T) \) corresponds to Appelbaum's result /2,3/ \( \delta G^{(3)} \) even is the sum of the contributions coming from \( \Sigma^{1a}(3) \) and \( \text{Im} \Sigma_{\text{F}1a}^{1a}(3) \). The expression (5) is already written for the usual case of the impurity near to one of the electrodes. The odd part, which is due to \( \text{Re} \Sigma^{1a}(3) \), for the same position of the impurity, can be written as

\[ \delta G^{(3)} \text{Re} \Sigma^{1a} = - \frac{2}{\pi S(S+1)} J \sin 2\phi <M> \int \left[ F(Q+eV) - F(Q-eV) \right] \]  

\[ - \ln^2 \max \left( \frac{Q+eV}{kT}, \frac{Q-eV}{kT} \right) \]  

(6)

In (6) we approximated the double integrals over the Fermi functions by \( \ln^2 \) terms (\( E_o \) is the cut-off in the integrals).

For the impurities in the electrode we obtained the same functional form for zero bias anomalies as for the impurities in the barrier. However, the sign of zero bias anomalies due to impurities in the electrode is random. Because of that the barrier impurities will give the main contribution to the conductance.

Writing the propagators in the continuous representation /4/ and for the square barrier potential model we are able to compare our theory with available experimental result. This will be reported elsewhere.

We see that exchange contribution does not always give a conductance in parallel with the normal tunnelling as in Appelbaum's theory. In fact, the exchange contribution has a rather complicated dependence on the position of the impurity in the barrier.

The explicit form of the position dependence of the conductance is our main result.

References