The hopping model of zero-bias tunnelling anomalies: Magnetic field effect

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Recently various theories (Appelbaum 1967, Sólyom and Zawadowski 1968a,b) have been proposed to explain zero-bias anomalies in the dynamical conductance-voltage characteris tics of metal-metal oxide metal tunnel junctions, which contain magnetic impurities in the vicinity of one of the electrode-barrier interfaces.

These anomalies are caused by the Kondo-type impurity scattering.

In order to treat the effect of exchange scattering of tunnelling electrons on magnetic impurities in a tunnel junction, we have used (Ivezić 1975) the hopping model of tunnelling proposed by Caroli et. al. (1971, 1972) and Keldysh nonequilibrium technique.

Here, we consider the same type of junction and obtain the junction conductance characteristics in a magnetic field. The magnetic field splits the spins into their Zeeman levels and therefore the spin-flip scattering proc -esses become inelastic. Some of these processes become energetically unfavourable. According to Appelbaum's theory the freezing out of spin-flip processes affects the conduc -tance at low voltages and temperatures and causes a well in the conductance characteristics G(V) for $e|V| \leq g\mu_B H$ where g is the g-value of the impurity, μ_B is the Bohr magneton and H is the applied field. Appelbaum's theory predicts this well in G(V) might be so large that the total conductance falls below the background - the part of the co -nductance which is not temperature and voltage dependent -near zero voltage for large enough fields. Experimentaly it appeares that there is only a local minimum in conduct -ance at zero bias.

As we have shown (Ivezić 1975) the Appelbaum theory does not include all the important contributions to the conductivity. The position dependence of different contributions to the conductivity which was not considered in Appelbaum's theory and the occurence of some new terms cause relatively smaller change in conductance by the field ΔG_H which makes the agreement between theory and experiment much better.

Our Hamiltonian is

$$H = H_{MIM} - J \sum_{\alpha,\beta} C^{+}_{i\alpha} \sigma_{\alpha\beta} C_{i\beta} \vec{S}_i + g \mu_B \vec{S} \vec{H} \qquad (1)$$

The first term H_{MIM} 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 the $\Sigma^{\pm}$ and $\Sigma^{r,a}$ self-energy matrix elements up to the 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 is the most important term since it is already strongly temperature and voltage dependent. Here the main contribution comes from the region inside the barrier and close to the interface :

$$\frac{\delta G^{(2)}(H,V,T)}{\delta G^{(2)}_{\Sigma^{\pm}}(H=0)} = 1 + 2\cos 2\phi - \frac{\langle M \rangle}{2S(S+1)}(1 - 2\sin^2\phi)\left[\gamma\left(\frac{Q+eV}{kT}\right) + \gamma\left(\frac{Q-eV}{kT}\right)\right] + \frac{1}{\pi}\frac{\langle M \rangle}{S(S+1)} \sin 2\phi \left(F(eV-Q) - F(eV+Q) \right) \qquad (2)$$

Here: $\gamma(x) = \frac{e^{2x} - 2x e^{x} - 1}{(1-e^{x})^2}$ (3), $F(eV,T) \approx -\ln\left(\frac{e|V| + nkT}{E_0}\right)$ (4), $g\mu_B \vec{S}\vec{H} = QS^z$ (5)

$\phi(\omega)$ is the argument of the retarded Green function of the pure contact on the place of the impurity "i" $- G^{r0}_{ii}$, and $\langle M \rangle$ is the average spin polarization in the field H.

The terms without ϕ function correspond to Appelbaum's result. The other terms which contain the explicit dependence on the position of the impurities in the barrier come from the $\Sigma^{r,a}$ self energy elements and change Appelbaum's result. The third order contribution to the conductance which for nonzero $\vec{H}$ gives only a small correction to (2) has a complicated form and will not be quoted here.

References

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