Tomography of bistable scatterers in mesoscopic wire

V. I. Fal'ko and D. E. Khmel'nitskiĭ
Institute of Solid State Physics, Academy of Sciences of the USSR

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A method is proposed for determining the position of a bistable scatterer in a mesoscopic wire from fluctuations of its magnetoresistance.

There have been several recent reports of observations of a bistable behavior of the resistance of samples of small dimensions (see the review by Kirton and Uren[1]). The resistance assumes one of several fixed values as a function of the time (in the simplest case, this would be one of two values). Such phenomena are interpreted theoretically[2] as a sensitivity of the resistance of a mesoscopic sample to the state of an individual scatterer (to its charge state, to its position, etc.). It has been established experimentally that the mesoscopic magnetoresistance differs slightly from state to state.[3] Our purpose in the present letter is to show how one can determine the position of a bistable scatterer (i.e., carry out magnetic tomography of a sample) by studying the mutual correlations of the magnetoresistance values.

Some of the samples which have been studied experimentally have had dimensions L smaller than the mean free path l (a ballistic contact). In other cases the relation $L \gg l$ has held (a diffusion contact). For definiteness we will treat the case of a diffusion contact in the present letter. We assume that the contact is a long (quasi-1D) bridge of length L and width $L_\perp \ll L$ between massive banks. We put the bistable scatterer at a distance x_0 from the left edge of the bridge. As a result of a change in the state of the scatterer, the conductance G in a magnetic field H takes on the values $G_{1,2}(H)$. Information required for the tomography of the sample is embodied in the correlation function

$$K(\Delta H) = \langle G_1(H + \Delta H/2) G_2(H - \Delta H/2) \rangle - \langle G_1(H + \Delta H/2) G_1(H - \Delta H/2) \rangle. \quad (1)$$

The angle brackets in (1) mean an average over realizations of the random potential of all impurities except the bistable scatterer under study. According to the ergodic theorem, an averaging of this sort in a theoretical calculation is equivalent to a determination of a mutual autocorrelation function of the experimental curves of $G_{1,2}(H + \Delta H/2)$ (an averaging over H). The correlation function $K(\Delta H)$ can be written in the form

$$K(\Delta H) = 6(e^2/\hbar)^2 (D^2/L^4) \int dx dx' P^d(x, x', \Omega = 0) P^d(x, x', \Omega = 0), \quad (2)$$

where in the quasi-1D case and in magnetic fields $\Delta H < \Phi_0 / L_\perp^2$ the two-particle Green's function P^d satisfies the equation

$$\{-i\Omega - D\nabla^2 + (L_\perp \Delta H e/\hbar c)^2/2 + v\delta(x - x_0)\} P^d(x, x', \Omega) = \delta(x - x') \quad (3)$$

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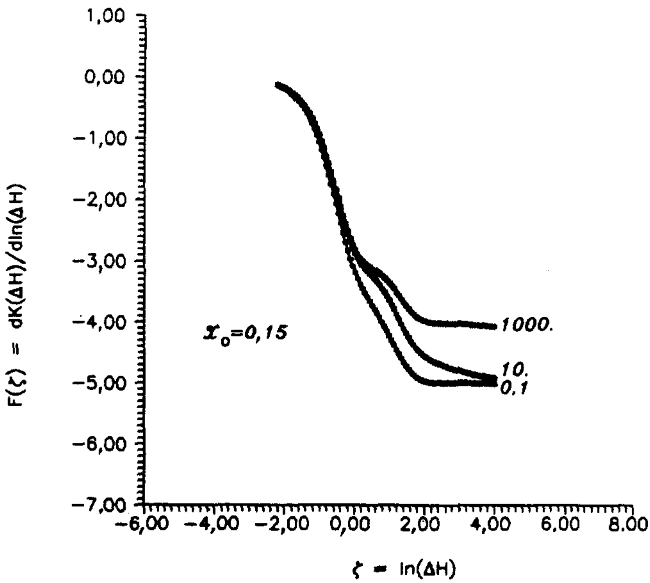

FIG. 1. Logarithmic derivative of the correlation function in (1) versus $\xi = \ln \Delta H$.

with the boundary conditions $P^d(x=0) = P^d(x=L) = 0$. In this equation

$$v = (2\pi\nu\tau)^{-1} \int dp_1 dp_2 \,|G^R(p_1)G^R(p_2)|^2 \,|u_1(p_1 - p_2) - u_2(p_1 - p_2)|^2$$

is determined by the change in the potential of the bistable scatterer, $u_{1,2}(r)$. If the parameter v is small (so that the relation $w = vL/D\pi^2 \ll 1$ holds), a solution of Eq. (3) can be found by perturbation theory, and the correlation function $K(\Delta H)$ takes the form

$$K(\Delta H, x_0) = (9/2\pi^3)\, w (e^2/h)^2 A^{-5} \{1 - [1 + \alpha A + (\alpha A)^2/3] \exp(-\alpha A)]\}, \tag{4}$$

where $A = 2^{1/2} gDHS/\Phi_0$, $S = LL_\perp$, and $\alpha = 2\pi x_0/L$ Expression (4) applies to a fairly large difference in magnetic fields, $\Delta H > \Phi_0/S$, and has two distinct types of asymptotic behavior, $K(\Delta H) \sim \Delta H^{-3}$ and $K(\Delta H)! \sim \Delta H^{-5}$ at $\Delta H \langle (L/x_0)\Phi_0/S$ and $\Delta H \rangle (L/x_0)\Phi_0/S$, respectively. If the parameter v is not small, i.e., if $w \ll 1$, the perturbation in Eq. (3) partitions the segment $[0,L]$ into two weakly coupled parts, and $K(\Delta H)$ takes the form

$$K(\Delta H, x_0) = 6\pi^{-2}(e^2/h)^2 \{A^{-4}/2 + \phi(1,A) - \phi(x_0/L, A) - \phi(1 - x_0/L, A)\},$$

$$\phi(x, A) = (\pi x/A^3)\,\mathrm{cth}(\pi x A) + (\pi x/A)^2 \,\mathrm{cosech}(\pi x A). \tag{5}$$

From (5) we find the asymptotic behavior $K(\Delta H) \sim (\Delta H)^{-3}$ and $K(\Delta H) \sim (\Delta H)^{-4}$ in the regions specified above.

The position of the bistable scatterer, x_0, can be found from the value of ΔH at which the change in asymptotic regime occurs. In analyzing the experimental data, the most convenient approach is to work from the shape of the curve of the logarithmic derivative $F = d \ln K(\Delta H)/d \ln \Delta H$. Figure 1 shows the results of a numerical calculation of the function $F(\xi)$, $\xi = \ln \Delta H$, for $x_0/L = 0.15$ and for the three values $w = 0.1$, 10, and 1000. It can be seen from this figure that although the shape of the $F(\xi)$ curve changes as v is varied, the value of ξ at which the change is asymptotic regime occurs remains essentially the same.

In the case of a charge exchange or a displacement d of an individual point scatterer we would expect the relation $w \ll 1$ to hold [$w \sim (L/l)^2/N_i$, if $p_F dh \ll 1$ and $w \sim (L/l)^2 (p_F d/h)^2/N_i$ if $p_F d/h \ll 1$, where N_i is the total number of scatterers in the sample]. Large values of v might arise in the motion of extended defects, e.g., dislocations.

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