Comment on “Quantum Decoherence in Disordered Mesoscopic Systems”

In a recent letter [1], Golubev and Zaikin (GZ) found that “zero-point fluctuations of electrons” contribute to the dephasing rate $1/\tau_\varphi$ extracted from the magnetoresistance. As a result, $1/\tau_\varphi$ remains finite at zero temperature, $T$. GZ claimed that their results “agree well with the experimental data”.

We point out that the GZ results are incompatible with (i) conventional perturbation theory of the effects of interaction on weak localization (WL), and (ii) with the available experimental data. More detailed criticism of Ref. [1] can be found in Ref. [2].

According to Ref. [1], as $T \to 0$ in all dimensions

$$\frac{\hbar}{\tau_\varphi} = \frac{\hbar}{\tau g[L^*]} = \sqrt{D\tau}, \quad L^* = \min \left(\sqrt{D\tau_H}, \sqrt{D\tau}, \frac{T}{g[L^*]}\right), \quad (1)$$

where $\tau$ is the elastic time, $D$ is the diffusion constant, and $g[L] \propto L^{d-2}$ is the conductance [in units of $e^2/(2\pi h)$]

$$\delta\sigma_{1\times WL} = \frac{e^2}{\pi\hbar} \frac{e^2}{h} \left\{ D\tau_H \left[ \frac{T \tau_H}{4\hbar} \right] \left[ 1 + \zeta \left( \frac{1}{2} \right) \right. \right.$$ $\left. \left. \sqrt{\frac{2\hbar}{\pi T \tau_H}} + \frac{\zeta \left( \frac{1}{2} \right) h D^2 \tau_H}{2\pi T^3} \right\}, \quad d = 1,$

$$\delta\sigma_{1\times WL} = \frac{e^2}{2\pi^2 \hbar} \frac{R_{\parallel}}{2\pi^2 \hbar} \left[ \frac{\pi T \tau_H}{\hbar} \ln \left( \frac{T \tau_H}{\hbar} \right) + 1 \right] + \frac{3}{2} \ln \left( \frac{T \tau_H}{\hbar} \right) + O \left[ \ln \left( \frac{T \tau_H}{\hbar} \right) \right], \quad d = 2 \quad (4)$$

where $\sigma_1$ is the conductivity per unit length of a one-dimensional conductor, $R_{\parallel}$ is the sheet resistance of a two-dimensional film, $\zeta(1/2) = -1.461 \ldots, \zeta(3/2) = 2.612 \ldots$.

Comparison of Eqs. (1) with Eq. (3) shows that $\tau_\varphi$ is given by Eq. (1) rather than by Eq. (3). The procedure of Ref. [1] is nothing but a perturbative expansion. Since it disagrees parametrically with the diagrammatic expansion already in the first order, it is simply wrong. The errors of Ref. [1] stem from the uncontrollable procedure of the semiclassical averages; as a result, some contributions were lost (Sec. 6.1 of Ref. [3]).

The results of Ref. [1] are in contradiction with the experiments. It is well known that the magnetoresistance in 2d and 3d systems (quasi-2d and 3d metal films, metal glasses, 3d doped semiconductors, 2DEG in heterostructures, etc.) depends substantially on the temperature. Such a dependence is impossible according to Ref. [1]. Indeed, for disordered metals with $\tau = 10^{-16} \ldots 10^{-14}$ s, Eq. (1) predicts a $T$-independent dephasing rate for any conceivable temperature. The experimental values of $\tau_\varphi$ exceed by far the estimates Eq. (1): e.g., by $10^5$ for the 3d Cu films [4] (for a more detailed comparison of the experimental data on $\tau_\varphi$ with Eq. (1) see Sec. 6.2 of Ref. [3]). The statement [5] that the interactions preclude the crossover into the insulating regime in low-dimensional conductors, is also at odds with experiment. The weak-to-strong localization crossover has been observed for both 1d and 2d cases (see e.g. Refs. [6,7]). It has been shown [8] that the 1d samples are driven into the insulating state by both the WL and interaction effects.

1. D.S. Golubev and A.D. Zaikin, Phys. Rev. Lett., 81, 1074 (1998).
2. I.L. Aleiner, B.L. Altshuler, and M.E. Gershenson, cond-mat/9808053.
3. B.L. Altshuler, A.G. Aronov, and D.E. Khmelnitskii, J. Phys. C 15, 7367 (1982).
4. B.L. Altshuler and A.G. Aronov, in Electron-Electron Interaction in Disordered Systems, edited by A.L. Efros and M. Pollak (North-Holland, Amsterdam, 1985).
5. A.G. Aronov, M.E. Gershenson, and Yu. E. Zhuravlev, Sov. Phys. - JETP 60, 554 (1984).
6. B. J. F. Lin et al., Phys. Rev. B 29, 927 (1984).
7. S.-Y. Hsu and J. M. Valles, Phys. Rev. Lett. 74, 2331 (1995) and references therein.
8. M. E. Gershenson et al., Phys. Rev. Lett. 79, 725 (1997).