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. Golubev and Zaikin 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,

$$\frac{\hbar}{\tau_\varphi} = \frac{\hbar}{\tau g[L^*]}, \qquad L^* = \sqrt{D\tau}, \tag{1}$$

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

This result differs from the conventional one [3,4],

$$\frac{\hbar}{\tau_\varphi} \simeq \frac{T}{g[L^*]}, \qquad L^* = \min(\sqrt{D\tau_\varphi}, \sqrt{D\tau_H}), \tag{2}$$

where τ_H is the scale due to the breaking of the time-reversal invariance by the magnetic field H [4].

The idea of the zero-T dephasing can be rejected using qualitative arguments (sections 2 and 3 of Ref. [2]). Here we provide the result of the formal calculation. The dephasing contribution for $\tau_\varphi \gtrsim \tau_H$ can be found from the expansion of the WL correction to the conductivity

$$\frac{\delta\sigma}{\sigma} \simeq -\frac{1}{g(\sqrt{D\tau_H})} + \frac{1}{g(\sqrt{D\tau_H})}\frac{\tau_H}{\tau_\varphi} + \cdots, \tag{3}$$

and the second term on the right-hand side appears in the first-order perturbation theory in the interaction propagator. The calculation which takes into account *all of the diagrams* of the order of $1/g^2$ (sections 4 and 5 of Ref. [2]) leads to

$$\begin{aligned} \delta\sigma_{I\times\mathrm{WL}} &= \frac{e^2}{\pi\hbar}\frac{e^2}{\hbar\sigma_1}\left\{D\tau_H\left(\frac{T\tau_H}{4\hbar}\right)\left[1+\zeta\left(\frac{1}{2}\right)\sqrt{\frac{2\hbar}{\pi T\tau_H}}\right] + \frac{\zeta(\frac{3}{2})}{\pi}\sqrt{\frac{\hbar D^2\tau_H}{2\pi T}}\right\}, \qquad d=1, \\ \delta\sigma_{I\times\mathrm{WL}} &= \frac{e^2}{2\pi^2\hbar}\frac{R_\square e^2}{2\pi^2\hbar}\left\{\frac{\pi T\tau_H}{\hbar}\left[\ln\left(\frac{T\tau_H}{\hbar}\right)+1\right] + \frac{3}{2}\ln\left(\frac{\tau_H}{\tau}\right) + \mathcal{O}[\ln(T\tau/\hbar)]\right\}, \qquad d=2, \end{aligned} \tag{4}$$

where σ_1 is the conductivity per unit length of a one-dimensional conductor, $R_\square$ is the sheet resistance of a two-dimensional film, $\zeta(1/2) = -1.461\ldots$, $\zeta(3/2) = 2.162\ldots$. Comparison of Eqs. (4) with Eq. (3) shows that τ_φ is given by Eq. (2) rather than by Eq. (1). 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 (section 6.1 of Ref. [2]).

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, 2D electron gas in heterostructures, etc.) depends substantially on the temperature. Such a dependence is impossible according to Ref. [1]. Indeed, for disordered metals with $\tau = 10^{-16}$–10^{-14} s, Eq. (1) predicts a T-independent dephasing rate for any conceivable temperature. The experimental values of τ_φ exceed by far the estimates of Eq. (1); e.g., by 10^5 for the 3D Cu films [5] (for a more detailed comparison of the experimental data on τ_φ with Eq. (1) see section 6.2 of Ref. [2]). The statement [1] 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 [7] that the 1D samples are driven into the insulating state by *both* the WL and interaction effects.

I. L. Aleiner,[1] B. L. Altshuler,[2,3] and M. E. Gershenson[4]
[1]SUNY at Stony Brook, Stony Brook, New York 11794
[2]Princeton University, Princeton, New Jersey 08544
[3]NEC Research Institute, Princeton, New Jersey 08540
[4]Rutgers University, Piscataway, New Jersey 08544-8019

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