Comment on “Magnetic-Field-Tuned Quantum Phase Transition in the Insulating Regime of Ultrathin Amorphous Bi Films”

A recent Letter by Lin and Goldman [1] presented experimental data for the relative magnetoresistance (MR) in disordered thin films, which were interpreted as evidence of a quantum phase transition. Such films are known to exhibit a superconductor (SC)-insulator transition as a function of disorder [2], and a huge peak in the resistance $R(B)$ with magnetic field $B$ [3,4]. These highly disordered samples were insulating at zero $B$. The experimental results supporting the quantum phase transition scenario are: (a) the relative magnetoresistance, $MR(B,B_0)=(R(B)-R(B_0))/R(B_0)$, at $B_0=0$ was temperature independent at a specific, non-universal, field $B_C$, and (b) near this point all the different-$T$ curves collapsed upon rescaling $R=R_0F(|B-B_C|/T^{1/\nu_z})$, where $\nu$ and $z$ were interpreted as the critical exponents of the transition. In this comment we present an alternative interpretation based on activated transport in a disordered landscape. We first present numerical simulations, and then support them by simple analytic arguments.

Our numerical simulations were performed using a new ab initio technique, based on the disordered negative-$U$ Hubbard model, that fully captures the effects of thermal phase fluctuations [5]. The results of this method describe the observed phenomenology of transport through thin disordered SC films, including the origin of the magnetoresistance peak [6]. Here we report results for more disordered systems, which, as in the experiment, are resistive at zero $B$ (we used an onsite energy standard deviation of $W=6t$, where $t$ is the lattice hopping integral, onsite interaction $U=1.6t$, and 0.37 filling). The inset of Fig. 1(b) depicts $R(B)$ for several temperatures, with the resulting MR shown in Fig. 1(a), where the main experimental result is reproduced — following a peak, the MR isotherms cross at a constant magnetic field. Near that point, all the curves collapse (Fig. 1(c)), using the same scaling analysis as in [1], with $\nu_z=0.89$. The sample displays no notable phenomenon in the local currents and chemical potential at $B_C$.

Since our numerical calculations neglect quantum fluctuations, the source of our crossing point $B_C$ cannot be the putative quantum phase transition [1]. To understand the crossing we note that both in the theory and in the experiment, the resistance is activated, $R(B,T)=R_0(B)e^{T_A(B)/T}$, with $T_A(B)$ the activation temperature at field $B$, and $R_0(B)\approx\hbar/4e^2$ is the high temperature resistance. Fig. 1(a) shows that $T_A(B)$, in agreement with experiment, is a non-monotonic function, and, in fact, $B_C$ corresponds to $T_A(B_C)=T_A(0)$. If $R(B,T)$ obeys the activated behavior above, $MR(B,0)$ becomes $T$-independent at $B=B_C$. Moreover, expanding $T_A(B)$ around $B=B_C$, we find that the scaling function

$$MR(B,B_0) = \frac{R_0(B)}{R_0(B_0)} \left(1 + \frac{T_A(B_C)(B-B_C)}{T} \right)^{-1},$$

is in agreement with the experimental fitted form with $\nu_z=1$. (The deviations from perfect scaling come from the weak dependence of $R_0(B)$ on $B$, and from the deviations, both experimentally and numerically, from simple activation at lower temperatures.)

If our interpretation is correct, and $B_C$ was only determined by $T_A(B_C)=T_A(0)$, the same behavior should be observed in less disordered samples for $MR(B,B_0)$, where $T_A(B_C)=T_A(B_0)$ and $B_0>0$. Indeed in Fig. 1(c,d) we present results for a sample with lower disorder $W=t$ that is SC at $B=0$. Again the MR isotherms all cross at $B=B_C$, with a reasonable collapse. Moreover the inset of Fig. 1(d) depicts the excellent collapse of the experimental data published in Ref. [3] for a lower disorder sample, with $B_0=4T$ and $B_C=12.8T$, supporting our scenario.

In summary, using ab initio simulations and analytic arguments, we have demonstrated an alternative explanation of the experimental results of Ref. [1]. The crossing of the MR curves can be understood entirely in terms of activated transport, which our previous analysis attributed to transport through Coulomb blockade islands [6]. Finally, we have made a specific prediction to test our analysis.

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FIG. 1: (Color online) (a,c) The MR curves (solid) and activation temperature (dotted) with magnetic field. The upper plots were taken at disorder $W=6t$ and the lower at $W=t$. The blue curve (lowest at large fields) is at low temperature $T=0.02t$, and red high temperature $T=0.07t$. (b,d) The MR with scaled magnetic field. The inset (b) shows the variation of resistance with magnetic field and (d) the MR for the experimental data from Ref. [3].

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