Comment on "Measurement of the Intrinsic Dissipation of a Macroscopic System in the Quantum Regime"

Recently, Cosmelli *et al.* (hereafter the authors) [1] measured the escape rate (Γ) vs normalized flux bias ($X \equiv \Phi_x/\Phi_0$) of an rf SQUID from a metastable fluxoid state at a temperature below 50 mK. The data were compared to calculations from which an effective damping resistance $R = 4\ \mathrm{M}\Omega$ was extracted. However, in the following discussion we show that, in Ref. [1], (i) the energy level structure used to calculate the escape rate was significantly incorrect, and (ii) treating system temperature as a free fitting parameter could not be justified. Therefore, the value of R inferred from the data is unreliable.

In Ref. [1], the measured escape rate $\Gamma(X)$ was compared to the solution of the master equation. Using the SQUID parameters given in Ref. [1], we found the number of levels in the well is $N \simeq 11$ to 13; that is in a stark contrast to the value of 20 to 30 estimated by the authors. Furthermore, we found the parameter η, which is completely set by $Z_0 \equiv \sqrt{L/C}$, $\beta_L \equiv 2\pi L I_c/\Phi_0$, and X, varies smoothly from 660 to 700 for $-0.505 < X < -0.485$. Thus, the value $\eta \approx 900$ obtained by the authors is $\sim$30% ($\sim 6\sigma$) greater than the independently determined value. The calculated barrier height ΔU, small oscillation frequency ω_0, $\Delta U/\hbar\omega_0$, and $\eta \equiv 2\pi d(\Delta U/\hbar\omega_0)/dX$ vs X are shown in Fig. 1. Obviously, the result of rate calculation depends crucially on the level structure. Hence, the use of incorrect values of N and η is sufficient to raise question about the validity of the $\Gamma(X)$ calculations in Ref. [1].

The observed oscillations in $\Gamma(X)$ have been attributed to a depletion of the highest active level, denoted as the nth excited level with energy E_n, that contributes the most to escape. Roughly speaking, the amplitude of oscillations in $\Gamma(X)$ can be taken as a measure of how fast the level n is being repopulated from below. Since the nth level couples most strongly to its nearest neighbors, a good approximation on the rate of repopulating it is given by

$$\begin{aligned} W_{n-1,n} &= W_{n,n-1} \exp[(E_{n-1} - E_n)/k_B T] \\ &\approx n(RC)^{-1} \exp(-\hbar\omega/k_B T), \end{aligned} \tag{1}$$

where $W_{n-1,n}$ is the transition rate from the $(n-1)$th to the nth level, and ω is the level spacing [2,3]. The last equation is valid at $T \ll \hbar\omega/k_B$. The rate is expressed explicitly in R to emphasize that $W_{n-1,n}$ depends *exponentially* on T but only linearly on R. Thus, a very small overestimate of T could result in a huge increase in the extracted value of R. For this reason, in order to obtain R from the fit unambiguously, it is necessary to have T independently verified.

It is well known that an effective system temperature significantly higher than the bath temperature T_b often indicates serious problems in shielding the sample from extrinsic electromagnetic noise. Therefore, treating T as an adjustable fitting parameter, especially in a range well above T_b, requires justification. The fact that the system was observed to follow Kramers' thermal activation behavior down to $T_b \approx 1$ K [1] strongly suggests that the effective system temperature was, in fact, much less than 0.5 K, especially at $T_b < 50$ mK.

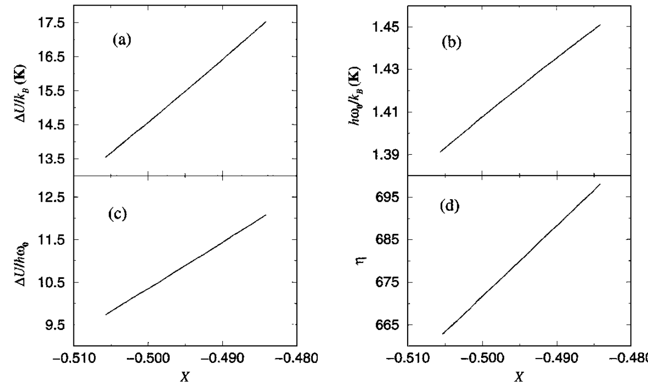

FIG. 1. Several key system parameters vs the normalized external flux calculated using SQUID parameters given in Ref. [1]. Note, the number of levels in the well is $N \approx \mathrm{round}(\Delta U/\hbar\omega_0 + 0.5)$.

In summary, in Ref. [1] the energy level structure seems to have been miscalculated, which would entirely invalidate the escape rate calculations. More importantly, the rate of repopulating the upper level depends exponentially on T so that the escape rate of a system with low damping resistance at low temperature mimics that of a system with a slightly higher temperature and a much larger R. Since the experimental evidence strongly indicates $T < 0.5$ K, we conclude that the authors have significantly overestimated the effective damping resistance due to their inadequate data analysis procedure.

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Siyuan Han
Department of Physics and Astronomy,
University of Kansas, Lawrence, Kansas 66045

R. Rouse
Sun Microsystems, Sunnyvale, California 94086

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