# Comment on "Probabilities for Quantum Tunneling through a Barrier with Linear Passive Dissipation"

In a recent Letter,[1] Caldeira and Leggett gave a theory of the decay of a metastable state by quantum tunneling in the presence of dissipation, with particular reference to tunneling on the macroscopic scale. Very recently, Widom and Clark (WC)[2] have published a Letter which is apparently intended in effect as a comment on our work. Having derived a formal result for transmission through a parabolic barrier, they claim a "qualitative difference" between this result and ours and attribute the alleged discrepancy to an "incorrect treatment of renormalizations which lead to divergences" in our theory. While WC's comments call for immediate rebuttal, all the points raised below are discussed in exhaustive detail in a lengthy paper[3] currently in the last stages of preparation.

We believe that WC's criticism of our work rests entirely on a (presumably unconscious) verbal sleight of hand. Consider two possible statements: (A) that if we compare two systems described by our Eq. (5) with the same "bare" potential $V(q)$ but coupling coefficients $c_\alpha$ zero in the first case and nonzero in the second, then the second system tunnels more slowly; (B) that if we compare two systems whose quasiclassical motion is described by our Eq. (1), with the same *phenomenological* (experimentally observable) potential $V(q)$ but friction coefficient $\eta$ zero in the first case and nonzero in the second, then the second tunnels more slowly. The reason that (A) and (B) are not equivalent has nothing to do with quantum tunneling as such, but is simply that linear coordinate-coordinate coupling (only) of a system to its environment will not only produce dissipation but also change the effective potential in which the system moves: see Ref. 1, p. 213, second paragraph. As this paragraph and the context makes clear, the claim we are making is (B), which we abbreviate, in the abstract and conclusion of our Letter only, as the statement that *dissipation* ("linear friction") decreases quantum tunneling. WC's counter argument relies on first giving a subtly distorting paraphrase ("The principal conclusion of Caldeira and Leggett is that *dissipative oscillator-bath couplings* decrease the quantum-mechanical tunneling probability": emphasis supplied) and then producing a result which is a counter example to this statement *if (and only if) it is interpreted as statement (A)*—a statement which we do not make, do not imply and, as a general claim, do not believe. Indeed, for the Lagrangian of our Eq. (5) by itself, our Eqs. (6)–(8), plus the observation that $q(t) \geq 0$ for a bounce in our geometry, imply the negative of (A) so that WC's formal result for the less physical case of an infinite parabolic barrier, so far from exhibiting a "qualitative difference" with our work, is actually a variant of results implicit in it.

The principal (though not the only) reason why, in the context of macroscopic tunneling, we regard (B) as the question of physical relevance and (A) as of academic interest is given in our footnote 12, which WC ignore. The relevant point of elementary electrodynamics,[3] when transposed to WC's Hamiltonian formalism, means that for certain types of electromagnetic coupling their Eq. (4) must be replaced, for example, by one in which the coupling is introduced through a term of the form $\sum_k (P_k - \lambda_k' x)^2$. For such a coupling WC's argument fails, so that the claim apparently implied in their work that *any* coupling to the environment which produces "linear passive dissipation" increases the barrier transmission probability is unsubstantiated.

Finally, WC claim that there is a "divergence in the oscillator-strength sum rule implicit in (our) calculational method". Since they offer no supporting evidence whatsoever [nothing in our method is in any way inconsistent with a Drude form of $J(\omega)$], this claim defies useful comment.

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[1]A. O. Caldeira and A. J. Leggett, Phys. Rev. Lett. 46, 211 (1981).

[2]A. Widom and T. D. Clark, Phys. Rev. Lett. 48, 63 (1982): hereafter referred to as WC.

[3]A. O. Caldeira and A. J. Leggett, to be published.