Editorial Note: At the time of acceptance of a Comment article [L. A. Openov, Phys. Rev. Lett. **93**, 158901 (2004)], the author of the Letter being commented on [E. M. Chudnovsky, Phys. Rev. Lett. **92**, 120405 (2004)] was inadvertently not given the opportunity to submit a formal Reply, which is contrary to the normal practice. The Comment was subsequently published without any response from this author. To rectify this oversight, we are now publishing Chudnovsky's Reply to this Comment. For the convenience of the reader, the text of the original Comment is also being reprinted in the end pages of the print journal.

Chudnovsky Replies: The Comment of Openov [1] on my Physical Review Letter [2] does not affect the universality of the decoherence mechanism, described in the Letter [2]. The Letter addressed the question of decoherence of quantum oscillations of a two-state system in a solid when the oscillation frequency ω_0 is below the Debye frequency $\omega_D \sim 10^{13}\ \mathrm{s}^{-1}$. I have shown that conservation laws (that is, symmetry) mandate parameter-free interaction of the tunneling variable with the phonon displacement field $\mathbf{u}$. For, e.g., a particle of mass m, oscillating between degenerate minima, $\mathbf{R} = \pm\mathbf{R}_0$, of a potential $U(\mathbf{R})$, conservation of the total linear momentum (particle + solid) results in a decohering interaction:

$$\mathrm{m}\,\dot{\mathbf{R}} \cdot \dot{\mathbf{u}}. \tag{1}$$

In quantum theory

$$\dot{\mathbf{R}} = \frac{i}{\hbar}[\mathcal{H}, \mathbf{R}], \tag{2}$$

where $\mathcal{H}$ is the Hamiltonian of the system, while

$$\dot{\mathbf{u}} = \frac{\Pi}{\rho} = \frac{-i}{\sqrt{V}}\sum_{\mathbf{k},i}\sqrt{\frac{\hbar\omega_{\mathbf{k}i}}{2\rho}}(a_{\mathbf{k}i}e^{i\mathbf{k}\mathbf{r}} - a^{\dagger}_{\mathbf{k}i}e^{-i\mathbf{k}\mathbf{r}})\mathbf{e}_i, \tag{3}$$

where Π is the momentum density of phonons, canonically conjugate to $\mathbf{u}$. Here V and ρ are the volume and the mass density of the system, $a^{\dagger}_{\mathbf{k}i}$ and $a_{\mathbf{k}i}$ are operators of creation and annihilation of phonons, $\omega_{\mathbf{k}i}$ is the frequency of the phonon of wave vector $\mathbf{k}$ and polarization i, and $\mathbf{e}_i$ are unit vectors of polarization of the phonons.

For an orbital moment or a spin, $\mathbf{I}$, oscillating, e.g., between $\pm I$ projections onto a quantization axis, conservation of the total angular momentum ($\mathbf{I}$ + angular momentum of a solid) results in a decohering interaction:

$$\frac{1}{2}\mathbf{I} \cdot (\nabla \times \dot{\mathbf{u}}), \tag{4}$$

with $\dot{\mathbf{u}}$ given by Eq. (3).

Equations (1) and (4) were used in my Letter [2] to obtain universal lower bound on the decoherence of solid-state qubits. Parameter-free decoherence rates were computed within perturbation theory, making use of the Fermi golden rule. It gives accurate results for, e.g., tunneling of electron or tunneling of a spin, and applies to all solid-state systems that fit the definition of a qubit. At low temperature, $k_B T \ll \hbar\omega_0$, the decoherence occurs due to spontaneous resonant emission of a phonon of frequency ω_0. Openov observed [1] that for a heavy particle oscillating at a high frequency, the decoherence due to Eq. (1) may become so strong that standard perturbation theory and the Fermi golden rule may no longer apply. I would like to stress that this observation in no way affects the universality of the mechanism of decoherence pointed out in my Letter. Parameter-free equations (1) and (4) describe an unavoidable decohering effect of the elastic environment, which is mandated by the conservation laws regardless of the strength of decoherence. They apply to all problems of quantum tunneling of a particle in a solid [2], to transitions between quantum states of a spin in a crystal field [2–4], and to tunneling between macroscopic quantum states of a superconducting current [5].

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