From the adiabatic to the anti-adiabtic regime of phonon-assisted tunneling

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The promise of molecular electronics has generated intense interest in the interplay of molecular vibrations and resonant electronic transport. Two customary limits of phonon-assisted tunneling are the anti-adiabatic and adiabatic regimes, where the phonon frequency is either sufficiently large or sufficiently small as compared to the bare electronic hopping rate. In the former case the phonon can efficiently respond to hopping events by forming a polaron, thus suppressing the bare tunneling rate. In the latter case the phonon is too slow to track the electronic motion, having little effect on its rate. While each of these extreme limits is rather well controlled theoretically, the crossover between them is far less understood as it lacks a small parameter.

We conducted a systematic study of the crossover between the two regimes in the framework of the resonant-level model in order (1) to reveal the physical parameters governing the transition, (2) to expose its manifestations in linear transport, and (3) to track the evolution of the low-energy scale corresponding to the renormalized resonance width. In particular, focusing on strong electron-phonon coupling we find an extended regime where the bare electronic tunneling rate is large as compared to the phonon frequency and yet the physics is essentially that of the anti-adiabatic limit. The effective low-energy Hamiltonian in this regime is found to be the interacting resonant-level model, whose parameters we extract numerically.