Modeling dissipation and decoherence in qubit systems via the spin-boson model

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The usual approach to studying the dynamics of an open quantum system is to use a quantum master equation (QME) with Markovian evolution and weak coupling, leading to the Redfield or Lindblad equations [1]. However, in the presence of strong coupling or a strong driving field, the Markovian time evolution may no longer be valid.

We model a qubit coupled to an environment using the spin-boson model and examine the effects of strong coupling and driving pulses on the system's dynamics. The pulses represent laser pulses used in the implementation of gate operations between qubits in quantum computers [2]. We investigate how strong system-bath coupling influences both the adiabatic preparation of the coupled equilibrium state and the subsequent nonequilibrium dynamics after the two-level system is driven out of equilibrium. We find that the adiabatic preparation time depends on the specific observable used to assess convergence: when the ground-state energy is the target, the required switching time increases monotonically with coupling strength, whereas for local observables such as Pauli matrix expectation values, the behavior can appear non-monotonic. Starting from this prepared coupled state, we then track the system's nonequilibrium evolution and relaxation under driving, highlighting how strong coupling controls the post-drive dynamics [3].

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