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Rapid charging of a two-qubit quantum battery by transverse field amplitude and phase control

We consider a quantum battery composed of a pair of qubits coupled with an Ising interaction in the usual NMR framework, where the longitudinal applied field is constant and the time-dependent variables controlling the system are the amplitude and phase of the transverse field, and use optimal control to derive fast charging protocols. We study both the cases where the Ising coupling is weaker and stronger than the longitudinal field. In the first case, where the lowest-energy state of the system is the spin-down state, the optimal charging protocol stipulates the transverse field amplitude to be constant and equal to its maximum allowed value, while the minimum time for full charging of the battery tends to zero as this maximum bound increases. In the second case, where the lowest-energy state is a maximally entangled Bell state, the optimal charging protocol includes a time interval where the transverse field amplitude is zero and its phase is immaterial, corresponding to singular control. In this case, the quantum battery can be charged with higher levels of stored energy, while the minimum time for full charging tends to a nonzero limit proportional to the inverse Ising interaction, as the maximum bound of the control amplitude increases. We analyze intuitively and quantitatively the distinct behavior of the two cases and additionally use the dynamical Lie algebra of the system to elucidate the presence of a singular arc in the optimal pulse-sequence in the second case. The discovered interplay between the quantum battery parameters, the stored energy and the minimum time for full charging, provides great flexibility for optimizing the performance of the device according to the operating constraints. The valuable insights gained regarding the design of quantum batteries is expected to find immediate applications in modern quantum science and technology, while we aim to extend the proposed methods to larger spin chains.

Theme

Theme 3. Theoretical and experimental methods for quantum effects in energy processes

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