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Energy level renormalization in strongly coupled open quantum systems

When a quantum system interacts strongly with a general environment, the interaction energy they share can be of the same magnitude as the expectation value of the bare system Hamiltonian, and can no longer be neglected. Is it then justified to still consider the bare system Hamiltonian as the operator determining the energy levels of the system? What happens if the environment is non-Markovian or finite? We argue that the energy levels the system undergo a renormalization due to the strong coupling with the environment, in accordance with our recent proposal for a theory of open system quantum thermodynamics [1]. This energy level shift, which is in general time-dependent, is determined by the coupling strength and by the initial state of the environment. We show experimental validation of this time-dependent shift in the electronic degrees of freedom of a trapped ion [2], recovering the well known Lamb-shift when the ion's motional mode is in the vacuum, and in the limit of large detuning.

[1] A. Colla and H.-P. Breuer, Phys. Rev. A 105, 052216 (2022).
[2] A. Colla, F. Hasse, D. Palani, T. Schaetz, H.-P. Breuer, and U. Warring, arXiv:2408.15928 [quant-ph] (2024).

Theme

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

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