Quantum Control Tools for Quantum Simulation and Sensing with NV Centers in Diamond

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In my PhD I will use spin control techniques for single nitrogen-vacancy centers (NV centers) in diamond to create a simulation platform for investigation of energy exchange mechanisms in open quantum system dynamics and quantum thermodynamics. The NV center is an outstanding defect in the diamond lattice composed by a substitutional nitrogen atom with an adjacent lattice vacancy. It is of particular interest in quantum sensing, computation and communication. I will follow a different route and employ the NV center as a promising platform for investigation of quantum thermodynamics in open quantum systems. The NV center offers excellent control of its electronic ground state (spin $S = 1$) and spin pumping under optical irradiation allows to simulate coupling to a thermal bath.
Recently at LENS quantum fluctuation theorems have been tested with a single NV center described by an effective two-level system [1]. The idea for my work is to extend the setting to a three-level system using all three spin levels of the electronic ground state. Unlike the simple two-level case, an arbitrary superposition state in higher dimensions cannot be attributed to an effective thermal state in general. The aim is to study experimentally quantum fluctuation relations in non-equilibrium conditions, i.e. with non-thermal final states.
Secondarily, it is planned to study the operation of a fully quantum thermal machine with the NV center as effective two-level system as the working medium. Accessibility of different working regimes [2] in the Otto cycle will be studied with particular interest in the regimes of the heat engine and refrigeration. These regimes are accessed depending on the sign of the exchanged heat between the hot and cold thermal baths and of the work exerted on the NV center, which are parameters that can be controlled externally.
A further project for the following years of my PhD course include optimal control techniques for sensing purposes using the NV center as quantum probe [3]. The goal here is to optimize the sensing protocol for an unknown magnetic signal reducing the influence of environmental noise, which is mostly dephasing due to paramagnetic impurities in the diamond lattice. Having no knowledge of the spectral composition and amplitude of the signal, an adaptive approach has to be adopted. For that it is necessary to employ a feedback loop for the optimization algorithm to calculate the best sensing protocol relying on previous measurement outcomes.

References

[1] S. Hernández-Gómez et al., Experimental test of exchange fluctuation relations in an open quantum system, arXiv:1907.08240, 2019.

[2] M. Campisi et al., Nonequilibrium fluctuations in quantum heat engines: theory, example, and possible solid state experiments, *New J. Phys*, **17**:035012, 2015.

[3] F. Poggiali et al., Optimal Control for One-Qubit Quantum Sensing, *Phys. Rev. X*, **8**:021059, 2018.