MASTER INTERNSHIP M2 PPN (5 months)

2022-2023

Title of the project: Optimization of autonomous quantum engines and refrigerators

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Laboratory / Department / Team : ICB lab/ Quantum interaction and control (ICQ)/ Quantum dynamics and technologies (DyTeQ)

Collaborations: Cyril Elouard (Université de Lorraine)

Summary:

Scientific context

Quantum engines and quantum refrigerators, the quantum counterpart of our familiar engines and refrigerators, whose aims are respectively to produce useful energy – work extraction – and refrigerate a target system, have been receiving a lot of attention during the past decade [1–3]. One reason for this interest is to understand how quantum properties such as quantum coherence and quantum correlations can enhance the performances of such fundamental thermodynamic tasks. A second reason relies on the fact that upcoming quantum technologies will most likely need nano-scale energy suppliers and heat managing devices able to refrigerate or reset quantum systems without the invasive character of classical solutions –in other words, quantum devices realizing useful thermodynamic tasks for quantum technologies. Such ambitious applications are slowly become a reality [4].

Central problem

A promising type of quantum devices are the ones referred to as autonomous quantum devices: devices which do not require external control from an agent or from an auxiliary (classical) system. This is actually the kind of device realized in [4] and the kind of devices mentioned for useful applications in quantum technologies [5]. In this context, a recent paper introduces a thermodynamic framework [6] allowing to design autonomous quantum devices exploiting resources (in the form of non-thermal characteristics) contained in arbitrary quantum systems. As illustrative application, one can design an autonomous quantum refrigerator composed of a qubit and of a quantum harmonic oscillator (for instance a cavity mode), and where their interaction is enough to refrigerate the qubit (to lower its entropy), without need of thermal baths and external controls. Such autonomous refrigerator is powered by non-thermal resources initially present in the harmonic oscillator, like for instance quantum coherences. This was already confirmed by numerical simulations. For information, such mechanism is being realized experimentally with supraconductors circuits (in Lyon). However, many open questions need to be investigated. In particular, it is not known what is the minimal entropy of the qubit one can reach, whether the maximal efficiency (similar to Carnot efficiency) can be reached, and whether the minimal time (given by the quantum speed limit) required to reach a target entropy can be saturated. More generally, the exploration and optimization of the trade-off energetic cost versus performances (in term of efficiency, velocity, targeted final entropy) needs also to be addressed. The aim of the project would to answer the above open questions. Theorems from quantum thermodynamics will provide some guiding lines (Quantun Speed Limit, Thermodynamic Uncertainty Relations), and techniques of optimization similar to the one used in optimal quantum control will be developed and applied. Realism and experimental feasibility of the designed setups will be a constant objective.

Additional information

Students with a background in quantum information and with knowledge in basic programming could be appreciated. This project is part of a recently established Junior Professor Chair on Quantum Technologies at Université de Bourgogne. It can potentially be followed by a fully funded PhD thesis.

References

[1] R. Kosloff, Quantum Thermodynamics: A Dynamical Viewpoint, Entropy 15, 2100 (2013).

[2] M. T. Mitchison, Quantum thermal absorption machines: refrigerators, engines and clocks, Contemp. Phys. , 164 (2019).

[3] C. L. Latune, I. Sinayskiy, and F. Petruccione, Roles of quantum coherences in thermal machines, Eur. Phys. J. Spec. Top. 230, 841 (2021).

[4] M. A. Aamir, P. J. Suria, J. A. M. Guzmán, C. Castillo-Moreno, J. M. Epstein, N. Y. Halpern, and S. Gasparinetti, Thermally driven quantum refrigerator autonomously resets superconducting qubit, arXiv (2023), 2305.16710.

[5] J. A. M. Guzmán, P. Erker, S. Gasparinetti, M. Huber, and N. Y. Halpern, DiVincenzo-like criteria for autonomous quantum machines, arXiv (2023), 2307.08739.

[6] C. Elouard and C. Lombard Latune, Extending the Laws of Thermodynamics for Arbitrary Autonomous Quantum Systems, PRX Quantum 4, 020309 (2023).

Type of project (theory / experiment): Theory

Required skills: Students with a background in quantum information and with knowledge in basic programming could be appreciated.