Annual PhD report - 2nd year

Giulia Gemme

XXXVIII cycle

Supervisor: Prof. Dario Ferraro

1 Research activity

During the second year of my PhD, I have continued my research in the field of quantum thermodynamics, with a special focus on quantum batteries (QB)s, miniaturised devices exploiting non-classical features to efficiently store, transfer and release energy on-demand. My work has involved characterising the performances of these devices through a combination of theoretical analysis, simulations, and test on real quantum machines available via the IBM Quantum Lab.

This year, I have analysed a collection of N two-level systems coupled to photons trapped in a resonant cavity [1], expanding on research initiated during my first year. During this year, I also published my work on a three-level QB, which I had primarily worked on during my first year [2]. Additionally, I have worked on a cyclic QB model based on an interacting bipartite system weakly coupled to a thermal bath [3]. Furthermore, I have worked on a model of a harmonic oscillator strongly coupled to a highly non-Markovian thermal reservoir [4].

In the following I describe in further detail the three different lines of research which I carried forward this year.

- In my first work [1] of the second year I consider a QB in the so called Dicke configuration, it is made of N two-level systems embedded into a cavity which plays the role of charger. In this context I compare two different situations, namely: the resonant regime, where the energy of the two-level systems is the same as the one of the photons trapped in the cavity, and the off-resonant regime, where the photons are way more energetic. I observe that, while the energy stored per two-level system is comparable in the two cases, the average charging power, despite showing the same asymptotic super-extensive scaling $N\sqrt{N}$, is strongly suppressed in the latter. This analysis will help to orient future experimental implementations of these devices.
- The second work is the result of a collaboration with the group of Prof. Benenti from the University of Insubria (Como). We introduce a cyclic QB model, based on an interacting bipartite system, weakly coupled to a thermal bath. The working cycle of the battery consists of four strokes: system thermalization, disconnection of subsystems, ergotropy extraction, and reconnection. The ergotropy extraction is possible because the ensuing thermal state is no longer passive after the disconnection stroke. In the presence of non-trivial correlations between the qubits, we show that it is possible to reach working regimes with efficiency higher than 50% while providing finite ergotropy. I this context, I simulate the considered cycle on superconducting IBM quantum machines. The good agreement between the theoretical and simulated results strongly suggests that our scheme for cyclic QBs can be successfully realised in superconducting quantum hardware.
- In the last work, I focused on a harmonic oscillator strongly coupled to a highly non-Markovian thermal reservoir. At short times, a *dynamical blockade* of the reservoir prevents the leakage of energy towards its degrees of freedom, promoting a significant accumulation of energy in the battery with high efficiency.

2 Courses and exams

I have attended the following course:

- **Fundamentals of quantum mechanics**, Prof. Paolo Solinas, Prof. Pierantonio Zanghì (PhD course)

3 Publications

[1] **G. Gemme**, M. Sassetti, and D. Ferraro, "Comparing different operating regimes of a dicke quantum battery," *International Journal of Quantum Information*, p. 2 450 024, 2024. DOI: 10.1142/S0219749924500242. eprint: https://doi.org/10.1142/S0219749924500242. [Online]. Available: https://doi.org/10.1142/S0219749924500242.

[2] **G. Gemme**, M. Grossi, S. Vallecorsa, M. Sassetti, and D. Ferraro, "Qutrit quantum battery: Comparing different charging protocols," *Phys. Rev. Res.*, vol. 6, p. 023 091, 2 Apr. 2024. DOI: 10.1103/PhysRevResearch.6.023091. [Online]. Available: https://link.aps.org/doi/10.1103/PhysRevResearch.6.023091.

[3] L. Razzoli, **G. Gemme**, I. Khomchenko, *et al.*, *Cyclic solid-state quantum battery: Thermodynamic characterization and quantum hardware simulation*, 2024. arXiv: 2407.07157 [quant-ph]. [Online]. Available: https://arxiv.org/abs/2407.07157.

[4] F. Cavaliere, **G. Gemme**, G. Benenti, D. Ferraro, and M. Sassetti, *Dynamical blockade of a reservoir for optimal performances of a quantum battery*, 2024. arXiv: 2407.16471 [quant-ph]. [Online]. Available: https://arxiv.org/abs/2407.16471.

4 Schools and conferences

- **Winter school on ultrafast thermodynamics**
  February 19-23, 2024, Chalmers University, Goteborg, Sweden
  https://www.chalmers.se/en/current/calendar/f-winter-school-on-ultrafast-thermodynamics/
  I presented a poster: "Qutrit quantum battery: sequential vs simultaneous charging"

- **Quantum Science Generation**
  May 6-10, 2024, Trento, Italy
  https://indico.ectstar.eu/event/204/
  I presented a poster: "Qutrit quantum battery: sequential vs simultaneous charging"

- **Workshop on Classical and Quantum Machine Learning for Condensed Matter Physics**
  June 19-21, 2024, Online by ICTP
  https://indico.ictp.it/event/10486

- **Non-equilibrium quantum many-body systems. From superconductors to quantum devices**
  July 10-12, 2024, Genova, Italy
  https://www.difi.unige.it/en/events/2024/07/10/non-equilibrium-quantum-many-body-systems
  I participated in organizing and I chaired the session on "Quantum Thermodynamics".

- **CMD-General Conference of the Condensed Matter Division**
  September 2-6, 2024, Braga, Portugal
  https://cmd31.sci-meet.net/
  I presented an oral contribution: "Thermodynamics of a rechargeable Josephson quantum battery"

- **Quantum Thermodynamics meets Quantum Computation**
  To be held - October 7-10, 2024, Pisa, Italy
  https://indico.sns.it/event/72/abstracts/
  Oral contribution ("Cyclic solid-state quantum battery: Thermodynamic characterization and quantum hardware simulation") accepted.

5 Other activity

- **Didactic tutor** (project: A_SMFN_01).
  Tutor for the course Fisica Generale 1 of the bachelor's degree in Physics.

- **Didactic tutor** (supporto alla didattica).
  Tutor for the course Fisica Generale of the bachelor's degree in Civil and Environmental Engineering.

- Referee for several scientific journals.