Report - 2nd PhD year

Alba Crescente (XXXV cycle) Supervisor: Prof. Maura Sassetti

Research activity:

I focussed the second year of my PhD on studying realistic models for quantum batteries (QBs). Up to now there have been only few experimental proposals of QBs, based on the well known superconducting qubits or double quantum dots technology, inspired by quantum computation, where these systems can be modeled as two-level systems (TLSs), namely qubits. In this direction, in my research I proposed models for QBs based on TLSs. During this year I have studied the following open problems:

- How to achieve faster charging and better work extraction thanks to a two-photon interaction.
- How to improve the energy transfer between QBs, mediated by a cavity.

In the following I describe in more details these points:

- **Advantages of the two-photon interaction for QBs**

  Here the QB is modeled as a set of N TLSs embedded into a cavity described with a single photonic mode. Usually, in literature, the TLSs are coupled to the cavity thanks to a single-photon interaction (related to the conventional dipole coupling between the TLSs and the cavity). In my work I have considered regimes of parameters where this interaction becomes negliegable and the coupling is given by a two-photon interaction. In this context it is important to study the collective advantage of the QB, namely the possibility of reaching better performances in the charging times and charging power (energy stored in a given time interval) compared to the case where each TLS is coupled to a different photonic cavity. Using a two-photon coupling compared to the usual single-photon one, I demonstrated the possibility of achieving a collective advantage that scales with the number of TLSs as N, compared to the $\sqrt{N}$ advantage obtained in literature for the single-photon interaction. These results have been published in [1].

  In my research I have also studied the important open problem of how much of the stored energy in the QB can be extracted as usable work. Here I have considered the limiting case of $N = 1$ TLS and I compared three different initial states for the cavity, i.e. Fock, coherent and squeezed states. As a result I obtained that for all the different states it is possible to completely extract the stored energy in the QB for a given time interval. However only for Fock states the QB can be charged completely, making them the best choice to implement QBs. These results have been published in [2].

- **Cavity-mediated energy transfer and energy cost**

  This is presently the topic of my research. The main idea is to considered two QBs embedded in a cavity and to study how energy could be transferred between the two QBs thanks to the cavity. As a first result I observed that all the energy stored in the first QB can be transferred in the second thanks to the cavity, when the system is on resonance, i.e. when the frequencies of the two QBs and the cavity are the same. Moreover the time for which this occurs is shorter compared to the more simple case of energy transfer between two QBs without cavity, already studied in literature. Another important role is played by the number of photons n in the cavity. In literature it was demonstrated that, without cavity, when the energy separation between the two TLSs is different (off-resonant scenario), the energy transfer is not efficient (60% of the full charge when there is a 10% mismatch between the frequencies). However by adding the cavity and by increasing the number of photons inside it ($n = 6$), at equal interaction strength, I demonstrated that it is possible to improve the energy transfer by 50% even when the two TLSs are off-resonance.

  In the context of energy transfer it is also important to study how much work is required to switch on and off the interaction between the cavity and QBs. Here I obtained that when the TLSs and cavity are on resonance no work is needed, as also stated in literature for the energy transfer between two QBs without cavity. However when we consider the off-resonant regime there is a cost in switching on and off the interaction, that becomes larger the more the system gets off-resonance. The main result of this work is that it is convenient to perform energy transfer operation in presence of a photonic cavity.

Right now I'm also investigating the scenario where the energy transfer between the first and second QB is mediated by a third TLS to understand if it allows even better performances compared to the other two configurations. These results will be submitted soon [3].

Publications, time period 30/09/2020-15/09/2021:

[1] A. Crescente, M. Carrega, M. Sassetti, D. Ferraro, *Ultrafast charging in a two-photon Dicke quantum battery*, Phys. Rev. B **102**, 245407 (2020).

[2] A. Delmonte, A. Crescente, M. Carrega, D. Ferraro, M. Sassetti, *Characterization of a Two-Photon Quantum Battery: Initial Conditions, Stability and Work Extraction*, Entropy **23**, 612 (2021).

[3] A. Crescente, D. Ferraro, M. Carrega, M. Sassetti, *Cavity-mediated energy transfer between quantum batteries*, soon to be submitted.

Courses and Exams, time period 30/09/2020-15/09/2021:

I have attended and passed the last exam of my PhD course: **Topological phases of condensed matter** (Master course).

Conferences and Schools, time period 30/09/2020-15/09/2021:

I have attended the following online conferences and schools, where I either presented a poster or an oral talk:

[1] **Conference on quantum thermodynamics** (19-23 October 2020). Poster presentation: *Charging, energy fluctuations and dissipation of a two-level quantum battery.*

[2] **GDR "Physique quantique mesoscopique" - plenary session** (23-26 November 2020). Poster presentation: *Ultrafast charging in a two-photon Dicke quantum battery.*

[3] **Lake Como School of Advanced Studies: Thermodynamics of quantum systems and processes** (22-26 March 2021). Oral talk: *Ultrafast charging in a two-photon Dicke quantum battery.*

[4] **Frontiers of Quantum and Mesoscopic Thermodynamics** (18-24 July 2021). Poster presentation: *Ultrafast charging in a two-photon Dicke quantum battery.*

[5] **SIF National Congress** (13-17 September 2021). Oral Talk: *Advantages of two-photon processes in quantum batteries.*

Achievements, time period 30/09/2020-15/09/2021:

My article *Dissipative dynamics of an open quantum battery*, New J. Phys. **22**, 083085 (2020), was chosen as one of the Highlights 2020 of CNR-SPIN in the Activity F: **Electronic and thermal transport from the nanoscale to the macroscale**.

Other activities, time period 30/09/2020-15/09/2021:

- **Didactic tutor, project: A_SMFN_01**
  Tutor for the course *Istituzioni di Matematiche* of the bachelor's degree in *Scienze biologiche*. 50 hours (01 October 2020 - 30 January 2021).
- **Referee for international journals**: Physical Review A, Physical Review E, New Journal of Physics.