QI 10: Quantum Thermodynamics and Open Quantum Systems I

Time: Tuesday 11:00–13:00 Location: B302

Invited Talk QI 10.1 Tue 11:00 B302

Quantum information in minimal quantum thermal machines — •Géraldine Haack — University of Geneva, Switzerland

Minimal models for quantum thermal machines are central to understand energy exchanges at the quantum scale and the intimate connection between quantum thermodynamics and quantum information theory. In particular, one would like to determine whether quantum features, like entanglement, interactions and quantum statistics, can be beneficial to the efficiency of a thermal machine made of few quantum constituents. This research direction becomes even more fascinating in view of recent experimental progresses towards manipulating out-of-equilibrium multi-partite quantum systems, allowing for new designs and investigations of quantum thermal machines. In this talk, I will present some of our latest results concerning the advantages that open quantum systems can offer towards heat and quantum information management at the nanoscale, including storing energy, generation of quantum correlations and optimization of dissipative flows. References: Khandelwal et al., PRX Quantum 2, 040346 (2021) Seah et al., PRL 127, 100601 (2021) Brask et al., Quantum 6, 672 (2022)

QI 10.2 Tue 11:30 B302

Quantum optomechanical thermodynamics — •David Edward Bruschi — Institute for Quantum Computing Analytics (PGI-12), Forschungszentrum Jülich, Germany

Quantum Thermodynamics extends the notions from classical thermodynamics to the quantum regime. Novel features appear, and processes acquire intrinsic probabilistic nature, in the sense that classically forbidden processes can statistically occur at least in principle. Given the advances in quantum technologies, it remains an open question to develop and characterize quantum systems as potential quantum thermal machines.

We propose an extension of the concepts of quantum thermodynamics to optomechanical systems. We study their properties and characterize them as quantum thermal machines. Applications and extensions are discussed in light of quantum technological applications.

QI 10.3 Tue 11:45 B302

Catalytic Gaussian thermal operations — •Benjamin Yadin[1], Hyejung Jee[2], Carlo Sparaciari[2,3], Gerardo Adesso[4], and Alessio Serafini[3] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Straße 3, 57068 Siegen, Germany — [2]Department of Computing, Imperial College London, London SW7 2AZ, UK — [3]Department of Physics and Astronomy, University College London, Gower Street, London WC1E 6BT, UK — [4]School of Mathematical Sciences, University of Nottingham, University Park, Nottingham NG7 2RD, UK

We examine the problem of state transformations in the framework of Gaussian thermal resource theory in the presence of catalysts. To this end, we introduce an expedient parametrisation of covariance matrices in terms of principal mode temperatures and asymmetries, and consider both weak and strong catalytic scenarios. We show that strong catalysts (where final correlations with the system are forbidden) are useless for a single mode, in that they do not expand the set of states reachable from a given initial state. We then go on to prove that weak catalysts (where final correlations with the system are allowed) are capable of reaching more final system states, and determine exact conditions for state transformations of a single mode in their presence. Next, we derive necessary conditions for Gaussian thermal state transformations holding for any number of modes, for strong catalysts and approximate transformations, and for weak catalysts with and without the addition of a thermal bath. We discuss the implications of these results for devices operating with Gaussian elements.

QI 10.4 Tue 12:00 B302

Which Bath-Hamiltonians Matter for Thermal Operations? — •Frederik vom Ende — Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany

We explore the set of thermal operations from a mathematical and topological point of view. We introduce the concept of Hamiltonians with resonant spectrum with respect to some reference Hamiltonian, followed by proving that when defining thermal operations it suffices to only consider bath Hamiltonians which satisfy this resonance property. Moreover we find a semigroup representation of the (enhanced) thermal operations in two dimensions by characterizing any such operation via three real parameters, thus allowing for a visualization of this set. This allows us to specify all qubit thermal operations (without the closure). This talk is based on the article J. Math. Phys. 63, 112202 (2022)

QI 10.5 Tue 12:15 B302

Thermodynamics of a many-body three level maser — •Julia Boeyens, Benjamin Yadin, and Stefan Nimmrichter — Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Siegen 57068, Germany

Many-body systems that are invariant under permutation of particles display interesting effects like superradiance due to their collective dynamics. These effects are apparent even in systems of particles that are, in principle, distinguishable but are permutation invariant from the perspective of the bath. It was recently demonstrated that multi-level systems that are collectively coupled to a thermal environment have thermodynamic properties that are different from collective spin systems and collections of distinguishable particles [1]. The thermodynamic effects of interactions between the multi-level systems are, however, yet to be investigated. Interactions should heighten the differences observed between the non-thermal steady states obtained by multi-level systems and the already well studied spin systems. In this work we study a three level maser coupled collectively to two thermal reservoirs. The performance is compared to an equivalent engine that is made up of the same number of three level systems that are distinguishable from the perspective of the baths.

[1] B. Yadin, B. Morris, K. Brandner arXiv:2206.12639 (2022)

QI 10.6 Tue 12:30 B302

A Trapped Ion Anharmonic Oscillator — •Bo Deng, Moritz Göb, Max Masuhr, Daqing Wang, and Kilian Singer — Experimentalphysik I, Universität Kassel, Heinrich Plett Str. 40, 34132 Kassel, Germany

In a tapered trap used for the realization of a single ion heat engine, the coupling of radial and axial modes implements an anharmonic mechanical oscillator. In this talk, we show that this coupling can be approximately described by the radiation-pressure Hamiltonian in the context of optomechanics. We further characterize the nonlinearity of this oscillator and the resulting mechanical bi-stability. Finally, we will discuss possible applications for thermal machines in the quantum regime.

QI 10.7 Tue 12:45 B302

Probing coherent quantum thermodynamics using a trapped ion — •Oleksiy Onishchenko[1], Giacomo Guarnieri[2], Pablo Rosillo-Rodes[3], Daniël Pijn[1], Janine Hilder[1], Ulrich G. Poschinger[1], Martí Perarnau-Llobet[4], Jens Eisert[2], and Ferdinand Schmidt-Kaler[1] — [1]QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, Mainz, Germany — [2]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, Berlin, Germany — [3]Institute for Cross-Disciplinary Physics and Complex Systems, Campus Universitat de les Illes Balears, Palma, Spain — [4]Department of Applied Physics, University of Geneva, Geneva, Switzerland

We report an experimental measurement of the genuine quantum correction to the classical fluctuation-dissipation relation (FDR) [1] in a trapped ion platform. We employ a single qubit and perform thermalization and coherent drive via laser pulses to implement a quantum coherent work protocol [1]. Using the excellent degree of control of trapped ions, we find agreement with the theory of quantum FDR and violate any classical explanation by more than 10.9 standard deviations [2]. This work opens the path to further experimental exploration of quantum thermodynamics, in particular to measurements of non-Markovian evolution, where the state of the qubit would not be reset between single experiments.

[1] M. Scandi *et al.*, Phys. Rev. Research **2**, 023377 (2020).
[2] O. Onishchenko *et al.*, arXiv:2207.14325 (2022).