QI 11: Quantum Thermodynamics

Time: Tuesday 9:30–11:45 Location: HFT-TA 441

QI 11.1 Tue 9:30 HFT-TA 441

Fermionic one-body entanglement as a thermodynamic resource — •Krzysztof Ptaszyński[1,2] and Massimiliano Esposito[1] — [1]Complex Systems and Statistical Mechanics, Department of Physics and Materials Science, University of Luxembourg, L-1511 Luxembourg, Luxembourg — [2]Institute of Molecular Physics, Polish Academy of Sciences, Mariana Smoluchowskiego 17, 60-179 Poznań, Poland

There is a controversy about whether a pure state of a single fermion delocalized between two modes (e.g., quantum dots) should be regarded entangled or not, that is, whether the quantum correlations encoded in such a state are operationally accessible and useful as a resource. This has been questioned on the basis that such an entanglement cannot be accessed by local operations on individual modes due to the parity superselection rule which constrains the set of physical observables. In other words, one cannot observe violations of Bell's inequality.

Here we approach this issue from the perspective of quantum thermodynamics [1]. We show that a single-particle fermionic state can be used in open-system thermodynamic processes, enabling one to perform tasks forbidden for separable (non-entangled) states. Therefore, its entanglement is a genuine quantum resource with a clear physical manifestation. Our work thus shows that quantum thermodynamics may be a useful theoretical framework to shed light on unsolved problems of quantum information theory.

[1] Phys. Rev. Lett. 130, 150201 (2023)

QI 11.2 Tue 9:45 HFT-TA 441

Role of nonequilibrium fluctuations and feedback in a quantum dot thermal machine — •Juliette Monsel[1], Nicolas Chiabrando[1,2], Matteo Acciai[1], Robert Whitney[3], Rafael Sánchez[4], and Janine Splettstoesser[1] — [1]Dept. of Microtechnology and Nanoscience, Chalmers University of Technology, Göteborg, Sweden — [2]École Normale Supérieure de Lyon, Lyon, France — [3]Université Grenoble Alpes, CNRS, LPMMC, Grenoble, France — [4]Universidad Autónoma de Madrid, Madrid, Spain

Steady-state thermoelectric engines can be operated using various resources, including information and nonequilibrium resources, even without any average particle or energy flow from the resource into the working substance. In those cases, fluctuations in the currents clearly play a key role in the performance of the engine. We study a three-quantum dot setup in which one dot is coupled to two electronic reservoirs at different chemical potentials (the working substance) while the other two dots are in contact with a hot reservoir and a cold reservoir respectively (the resource). The temperature difference between these two reservoirs creates nonequilibrium conditions in the resource allowing for work production in the form of a steady-state current against the potential bias in the working substance. Simultaneously, the capacitive coupling between the dots creates an autonomous feedback mechanism which can participate in the work extraction and be interpreted as an autonomous Maxwell demon scheme. We investigate the respective roles of the information flow and nonthermal fluctuations in the performance of this engine.

QI 11.3 Tue 10:00 HFT-TA 441

Coherent effects in the path integral formulation of quantum work. — Nicolás Torres-Domínguez and •Carlos Viviescas — Departamento de Física, Universidad Nacional de Colombia, Bogotá, Colombia

A proper definition of work and heat remains a relevant issue in the framework of quantum thermodynamics. The usual approach to this problem is through the two-point measurement (TPM) scheme, which, despite its relevant role in the development of the actual understanding of work statistics in the quantum regime, has a fundamental limitation: Due to energy projective measurements it involves, the effects that the initial coherences may have on the energetics of the system are lost. The Margenau-Hill (MH) is an alternative scheme that offers a bypass to this problem and retains the coherences in the initial state. In this work we introduce a path integral formulation for work in the MH scheme, which provides further insight on the role of initial coherences in quantum thermodynamic setups, and paves the way for a semiclassical study of the quantum work distribution.

QI 11.4 Tue 10:15 HFT-TA 441

The Thermomajorization Polytope and its Degeneracies — Frederik vom Ende[1] and •Emanuel Malvetti[2,3] — [1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany — [2]School of Natural Sciences, Technische Universität München, 85737 Garching, Germany — [3]Munich Center for Quantum Science and Technology & Munich Quantum Valley, 80799 München, Germany

In quantum thermodynamics thermal operations are considered free. Our goal is to understand which states are reachable from a given initial state using thermal operations. In the quasi-classical case of diagonal states the problem reduces to understanding the thermomajorization polytope. By drawing a connection between the polytope of Gibbs-stochastic matrices and transportation polytopes we study the degeneracies of the thermomajorization polytope and as a consequence we can characterize in which cases cyclic state transfers are possible.

15 min. break

QI 11.5 Tue 10:45 HFT-TA 441

Thermodynamic concepts in autonomous quantum systems — •Anja Seegebrecht and Tanja Schilling — University Freiburg, Freiburg, Germany

Physically sound definitions of thermodynamic quantities for open quantum systems pose a challenge. They are at best available for the weak coupling regime where the reduced dynamics can be described by Markov master equations. To extend concepts like internal energy, work and heat to processes with strong interactions and memory effects, the canonical form of the time-convolutionless master equation offers a promising possibility. This unique time-local representation has Lindblad-like structure with a Hamiltonian and a dissipator. It is obtained by minimisation of the dissipative part of the dynamics. Accordingly, it characterizes the dissipation and non-Markovianity. The identification of thermodynamic energies follows the typical method that internal energy is the expectation value of the effective Hamiltonian of the system. Changes of this local energy can be split into a part that relates to entropy variation and a part that does not, namely heat and work contributions. We contrast the minimal dissipation definition with three different approaches for autonomous systems. They are also based on this strategy but propose different decompositions of the dynamics. The comparison highlights the benefits of the canonical form.

QI 11.6 Tue 11:00 HFT-TA 441

Complexity-constrained quantum thermodynamics — Anthony Munson[1,2], Naga Teja Bhavya Kothakonda[3,4], Jonas Haferkamp[5], Nicole Yunger Halpern[1,2], Jens Eisert[4], and •Philippe Faist[4] — [1]Joint Center for Quantum Information and Computer Science, NIST and University of Maryland, College Park, MD 20742, USA — [2]Institute for Physical Science and Technology, University of Maryland, College Park, MD 20742, USA — [3]Physics Department, Universitat Autònoma de Barcelona, 08193 Bellaterra (Barcelona), Spain — [4]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany — [5]School of Engineering and Applied Sciences, Harvard University, MA 02134, USA

Complexity measures the difficulty of realizing a quantum process, such as preparing a state or implementing a unitary. We present an approach to quantifying the thermodynamic resources required to implement a process if the process's complexity is restricted. reset to the all-zero state. We show that the minimal thermodynamic work required to reset an arbitrary state to the all-zero state (Landauer erasure), if the process cannot exceed some complexity threshold, is quantified by the state's *complexity entropy.* We prove elementary properties of the complexity (relative) entropy and determine the complexity entropy's behavior under random circuits. Also, we identify information-theoretic applications of the complexity entropy. Overall, our approach extends the resource-theoretic approach to thermodynamics to integrate a notion of *time*, as quantified by *complexity.*

QI 11.7 Tue 11:15 HFT-TA 441

Storing work in thermal equilibrium: ergotropy of mean-force Gibbs states — •Karen Hovhannisyan[1] and Janet Anders[1,2] —

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Subsystems of a strongly-interacting many-body system are not in Gibbs states when the system is in thermal equilibrium as a whole. Such non-Gibbsian states can store work in the form of ergotropy. We use this observation to devise a quantum battery that is simply a detachable subsystem of a many-body lattice. The charging cycle consists of connecting the subsystem, letting it equilibrate, and then disconnecting and extracting work from it. This cycle requires very little external control and the charged state of the battery, being a part of global thermal equilibrium, can be maintained indefinitely and for free. As out system we use 1D and 2D harmonic lattices with strong long-range interactions. We show that the stored work, quantified by the Gaussian ergotropy, can increase polynomially with the size of the subsystem, showing that this setup can be potentially useful in practical implementations of noise-robust quantum batteries.

QI 11.8 Tue 11:30 HFT-TA 441

Towards a local version of the second law of thermodynamics

— •Ahana Ghoshal[1,2] and Ujjwal Sen[2] — [1]University of Siegen, Germany — [2]Harish-Chandra Research Institute, India

A local version of the second law of thermodynamics is undoubtedly a fundamentally important area of research, and is all the more important with the advent of quantum devices and networks. Here we intend to provide two investigations in this direction. In the first part, we define and study two thermodynamical quantities: the heat current deficit and the entropy production rate deficit, which are differences between the global and local versions of the corresponding quantities. The investigation leads, in certain cases, to a complementarity of the time-integrated heat current deficit and the relative entropy of entanglement between the two systems. In the second part, we obtain the Gorini-Kossakowski-Sudarshan-Lindblad master equation for two or more quantum systems connected locally to a combination of Markovian and non-Markovian heat baths. We analyze the thermodynamic quantities for such a mixed set of local environments, and derive a modified form of the Spohn's theorem for that setup. The modification of the theorem naturally leads to a witness as well as an easily computable quantifier of non-Markovianity.