Quantum Systems: Entanglement, Simulations and Information (QUANTUM)

OUTLINE

Investigation of the recent developments that have changed the status of quantum mechanics (a new "quantum revolution") and led the development of Quantum Technologies:

- quantum simulations of many-body physics and lattice gauge theories,

- entanglement in applied quantum technologies,

- open quantum systems and quantum thermodynamic machines, energetics at the nanoscale,…

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Quantum Thermodynamics

Fundamental questions at the interface between quantum theory and thermodynamics, vital for the development of quantum thermo-machines:

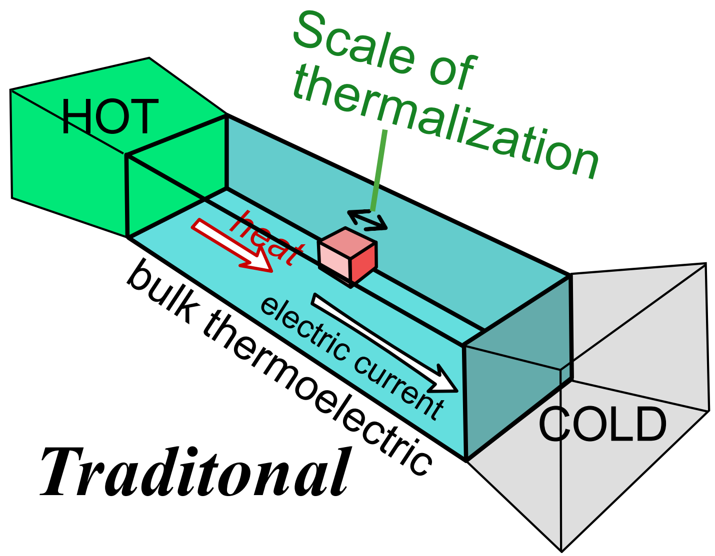
Definition of heat and work in quantum mechanics

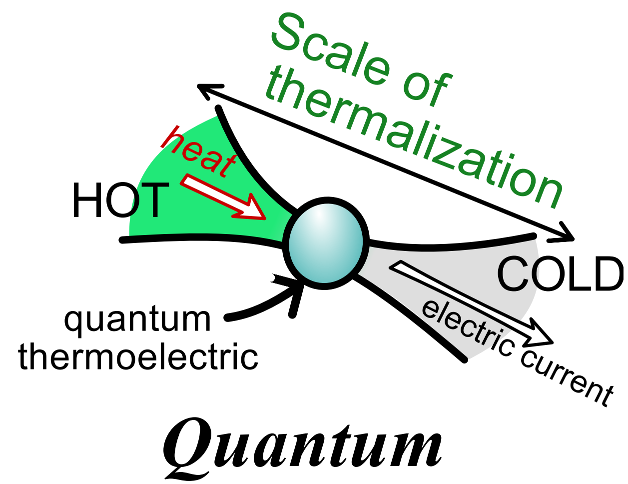
Role of coherence, entanglement, quantum measurements and fluctuations in quantum machines

Efficiency and power of small, nanoscale thermal machines

Heat management at the nanoscale (cooling hot spots, thermal diodes and transistors)

Traditional versus quantum thermoelectrics





Relaxation length (tens of nanometers at room temperature) of the order of the mean free path; inelastic scattering (phonons) thermalizes the electrons

Structures smaller than the relaxation length (many microns at low temperature); quantum interference effects; Boltzmann transport theory cannot be applied

[see G. B., G. Casati, K. Saito, R. S. Whitney, Phys. Rep. **694**, 1 (2017)]

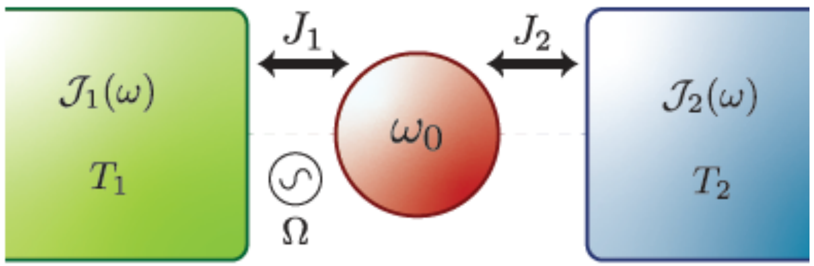
Quantum aspects relevant for nanoscale applications

Mildred Dresselhaus et al. (Adv. Materials, 2007):

"a newly emerging field of low-dimensional thermoelectricity, enabled by material nanoscience and nanotechnology... Thermoelectric phenomena are expected to play an increasingly important role in meeting the energy challenge for the future..."

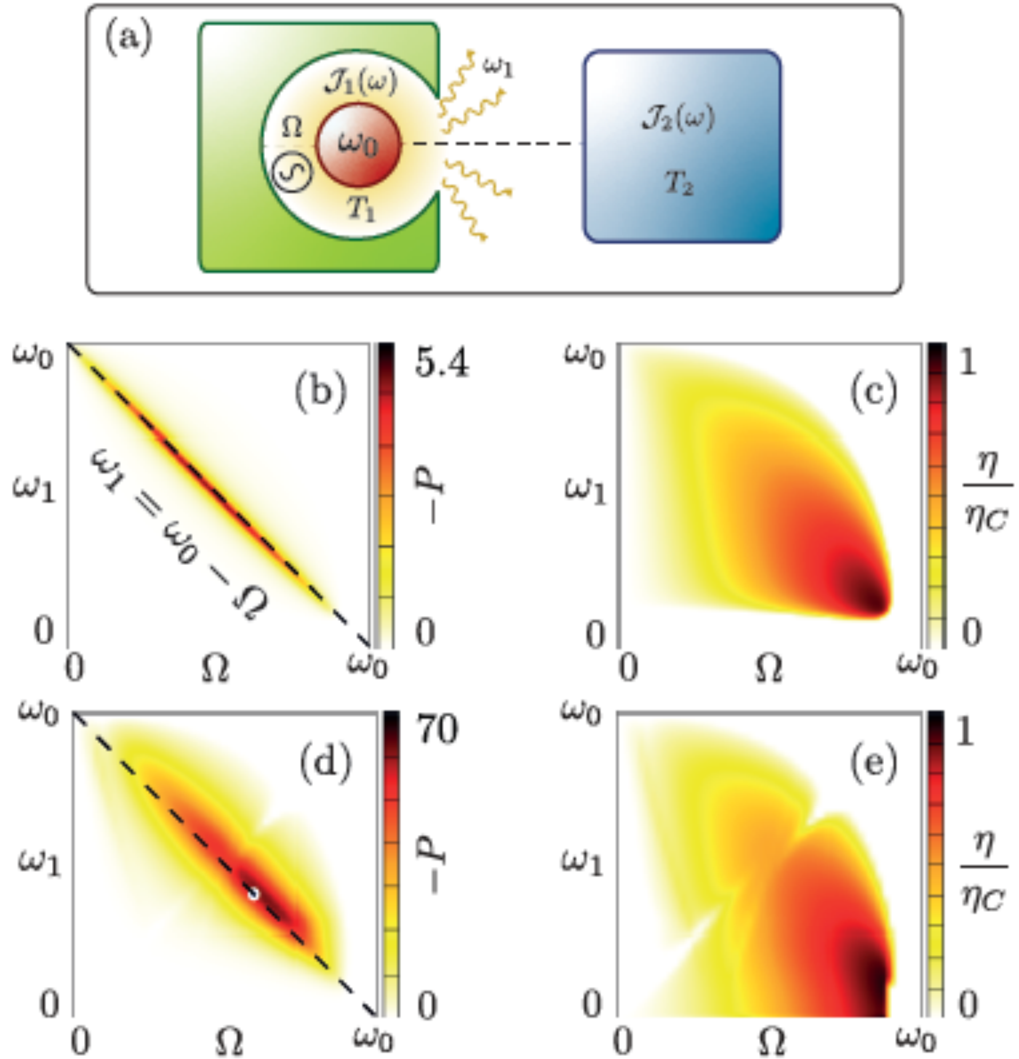
Small scale (quantum) thermoelectricity could be relevant for cooling directly on chip, by purely electronic means. Nanoscale heat management is crucial to reduce the energy cost in many applications of microelectronics and for the development of quantum machines.

Dynamical heat engines with non-Markovian reservoirs



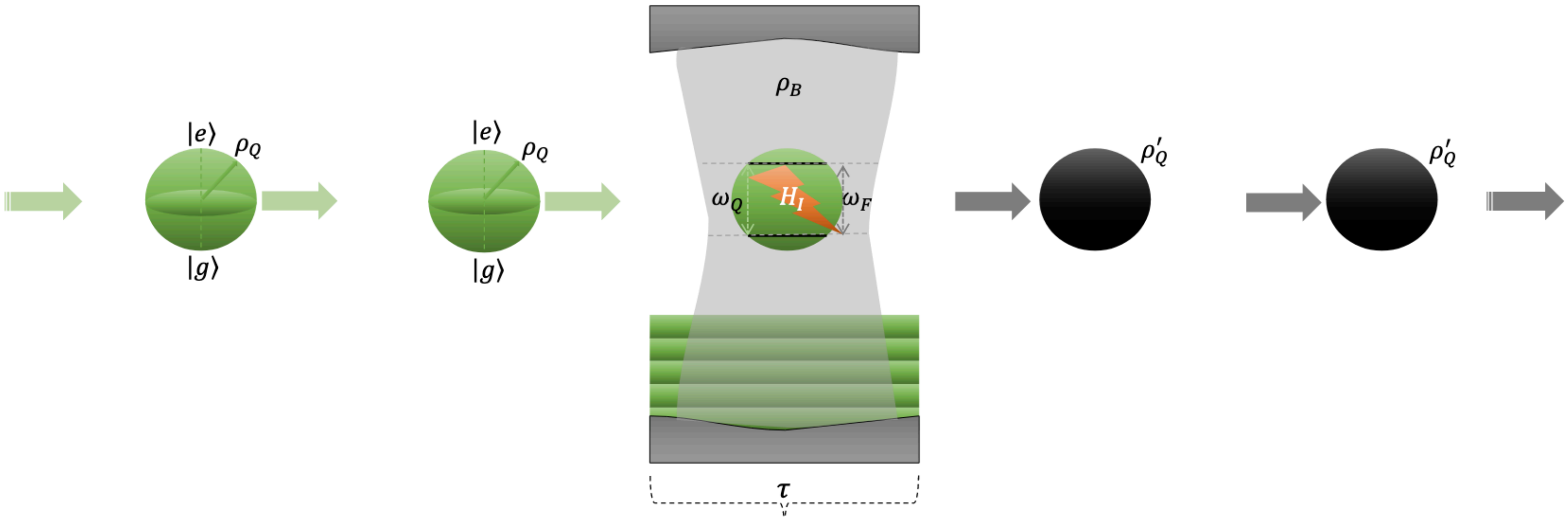
Non-Markovianity necessary condition to obtain a heat engine

Project: explore thermal diode and transistor regimes



[M. Carrega *et al.*, PRX Quantum **3**, 010323 (2022);
F. Cavaliere *et al.*, preprint arXiv:2205.01650 [quant-ph]]

Micromasers as quantum batteries



A highly excited, pure, and effectively steady state of the cavity mode, charged by coherent qubits, can be achieved

Project: explore dissipation and many-body effects

[V. shaghaghi *et al.*, preprint arXiv:2204.09995 [quant-ph]]

Summary (keywords)

Optimizing the performances of nanoscale quantum thermal engines and quantum batteries (optimal control, machine learning techniques)

Heat management in nanodevices

Quantum information protocols in the ultra-strong coupling regime

Other research lines:

Quantum chaos and characterization of quantum complexity

Quantum computing on actual quantum hardware (IBMQ, IONQ)

QUANTUM-MI publications (2021-22)

1) L. M. Cangemi, M. Carrega, A. De Candia, V. Cataudella, G. De Filippis, M. Sassetti and G. Benenti, Optimal energy conversion through anti-adiabatic driving breaking time-reversal symmetry, Phys. Rev. Res. 3, 013237 (2021).
2) J. Wang, G. Benenti, G. Casati and W. Wang, Quantum chaos and the correspondence principle, Phys. Rev. E 103, L030201 (2021).
3) A. Pizzamiglio, S. Y. Chang, M. Bondani, S. Montangero, D. Gerace and G. Benenti, Dynamical localization simulated on actual quantum hardware, Entropy 23, 654 (2021).
4) V. Balachandran, G. Benenti, G. Casati and D. Poletti, From ETH to algebraic relaxation of OTOCs in systems with conserved quantities, Phys. Rev. B 104, 104306 (2021)
5) M. Carrega, L. M. Cangemi, G. De Filippis, V. Cataudella, G. Benenti and M. Sassetti, Engineering dynamical couplings for quantum thermodynamic tasks, PRX Quantum 3, 010323 (2022).
6) V. Shaghaghi, G. M. Palma and G. Benenti, Extracting work from random collisions: A model of a quantum heat engine, Phys. Rev. E 105, 034101 (2022).
7) J. Wang, G. Casati and G. Benenti, Classical physics and blackbody radiation, Phys. Rev. Lett. 128, 134101 (2022).
8) J. Wang, G. Benenti, G. Casati and W. Wang, Statistical and dynamical properties of the quantum triangle map, J. Phys. A 55, 234002 (2022).

QUANTUM-MI preprints (2021-22)

1) I. Khomchenko, A. Ryzhov, F. Maculewicz, F. Kurth, R. Huhne, A. Golombek, M. Schleberger, C. Goupil, Ph. Lecoeur, G. Benenti, G. Schierning and H. Ouerdane, Thermoelectrics of thermoelectricity close to the superconducting phase transition, preprint arXiv:2110.11000 [cond-mat.mtrl-sci].
2) M. Valadkhani, S. Chen, F. Kowsary, G. Benenti, G. Casati and S. M. Vaez Allaei, Heat transport in carbon nanotube bundles: Frequency-dependent analysis of curvature effects, preprint.
3) V. Shaghaghi, V. Singh, G. Benenti and Dario Rosa, Micromasers as quantum batteries, preprint arXiv:2204.09995 [quant-ph].
4) F. Cavaliere, M. Carrega, G. De Filippis, V. Cataudella, G. Benenti and M. Sassetti, Non-Markovian dynamical heat engines, preprint arXiv:2205.01650 [quant-ph].
5) G. Benenti, G. Casati, F. Marchesoni and J. Wang, An autonomous circular heat engine, preprint arXiv:2205.15415 [cond-mat.stat-mech].
6) I. Khomchenko, H. Ouerdane and G. Benenti, Voltage-amplified heat rectification in SIS junctions, preprint arXiv:2206.10600 [cond-mat.mes-hall].