Scientific Report: Cost MP1209 Thermodynamics in the Quantum Regime
2nd Quantum Thermodynamics Conference
UIB, Palma de Mallorca (Spain)
20th – 24th April 2015

COST Action MP1209 held its second conference between 20th – 24th April 2015 in Palma.

During this conference the three Working Groups of the COST Action met for the fourth time and a Management Committee meeting was held.

The Local Organiser was IFISC: Roberta Zambrini, Rosa Lopez, David Sanchez, Llorenç Serra and Fernando Galve.

The conference had 88 participants of which 75% were Early Stage Researchers and 15% female. COST supported 37 of these participants.

There were 8 invited talks and 28 contributed talks. The competition to have a contributed talk was high with less than 50% of submitted works accepted. Those that weren't successful were offered the opportunity to be presented as posters, of which there were 25. Presentations can be downloaded from http://www.ifisc.uib-csic.es/qtd2/abstracts.html.

75% of invited talks were by Early Stage Researchers and 37.5% by females.

86% of contributed talks were by Early Stage Researchers and 17% by females.

17% of all presented works (talks and posters) were by females.

1 of the 3 Working Group meeting "introductory talks" was also by an Early Stage Researcher.

This is the first conference organized by the COST MP1209 Action in which the option to use the provided childcare facilities was utilized. One invited speaker attended with their 10 month old baby and another invited speaker attended with their baby and accompanying person. The actions taken by the conference's organizing committee to facilitate the use of the childcare facilities included:

- Publicizing babysitting facilities from the first conference announcement
- Information regarding the childcare facilities and possible children's activities were included on the conference web page.
- The cost of childcare was funded by the conference (from non-COST sources).
- The registration process asked participants about their possible use of the childcare facilities.
- Transport between the conference venue & hotel was carefully selected to ensure that it was suitable for parents with children.

Working Group 1 Report – Antonio Acin
Several works were presented at the conference on WG1 topics. M. Esposito presented his work with M. Galperin, where they show the difficulties encountered when attempting to formulate quantum thermodynamics for open quantum systems strongly coupled to their reservoirs and present a consistent approach resolving these problems. L. Correa and A. Pasquale described methods to measure the temperature of many-body systems via local probes. C. Gogolin showed how it is possible to define a proper notion of local temperature for systems with strong enough decay of correlations. A. Xuereb presented a thorough analysis of the thermodynamics of the trajectories followed by a quantum harmonic oscillator coupled to several dissipative baths by using a new approach to large-deviation theory

inspired by phase-space quantum optics. Finally, L. P. García-Pintos presented new time scales for equilibration of physically relevant observables.

Apart from these talks, we had the WG1 meeting. A. Acin presented the main results obtained in this WG during recent years. This was followed by a joint discussion of all attendees identifying key open questions in the working group, together with possible partial results that could be obtained in next years. The obtained list was as follows:

1. Identify properties of Hamiltonian evolutions needed for equilibration times independent of the system size. Possible progress on this question would be to understand how locality of interactions limits the speed of equilibration.
2. Prove (or disprove) the Eigenstate-Thermalization-Hypothesis (ETH). This is of course a key question in the WG. Possible partial progress would be to obtain partial results in this direction, for instance for some systems.
3. Develop a better understanding of pre-thermalization processes and whether it can be used as a resource for thermodynamic protocols or even quantum information applications.
4. Better understanding of localization phenomena. Here we can expect that techniques developed in the context of quantum information theory, for instance in the study of entanglement and quantum correlations, may play a role in the coming years.
5. Equilibration times for macroscopic-type or coarse-grained observables.
6. Identify limitations from the pure-state formalism to equilibration and thermolization processes. As for point 2 on ETH, this is a well-know and generic objective of the WP.
7. Understand the possible role of non-Markovian effects, in the form for instance of black-flow of information from the environment, in equilibration and/or themalization processes.

Working Group 2 Report – Tobias Brandes

The status of WP2 was summarized in a short talk by T. Brandes. It was pointed out that there is still some debate on the status of concepts of heat and work as a dynamical process in quantum thermodynamics, where coherences may play a role. On a more fundamental point, the role and the status of entropy and the second law remains a big challenge. A lively discuss developed around future thermo devices and quantum engines, with issues such as the use of quantum effects to achieve higher efficiency (M. Campisi), the relevance or otherwise of efficiency as a single parameter (T. Brandes, M. Huber), the need for examples where quantum is advantageous (J. Anders), classical versus quantum (R. Uzin), and others. Discussions continued with the status of single shot thermodynamics (J. Anders), and finally the call for more research in the direction of coherent/autonomous feedback schemes (T. Brandes, J. Parrondo, P. Talkner).

Working Group 3 Report – Eric Lutz

The working group meeting started with a 30-minute presentation by Nicolas Tolazzi (MPQ-Munich) that provided an overview of existing experimental platforms suitable for quantum thermodynamic experiments, as well as a detailed description of experiments that have already been recently performed. Six broad classes of experimental systems have been identified: ion traps, quantum dots, cooper-pair boxes, NMR, optomechanical systems and cold atom systems. Interestingly, each of these systems has been used to implement thermodynamic experiments in the classical regime (the fluctuation theorem has, for instance, been verified in both cooper-pair boxes and optomechanical systems). In addition, all six systems can in principle be brought to the quantum regime. Meanwhile, in the last few years a number of quantum thermodynamic experiments have been realized. Important examples include the verification of the quantum Jarzynski relation in ion traps, the test of the Tasaki-Crooks equality in NMR, the observation of the quantum Joule-Thomson effect using cold atomic gases and the implementation of a quantum thermoelectric engine with cold atoms. The second part of the discussion focused on how to increase the fraction of experimentalists in the COST action and how to increase the overlap between experimental and theoretical investigations. Concrete proposals were put forward by Robert Whitney (University of Grenoble), Anna Feshchencko (Aalto University) and Christian Gogolin (FU Berlin) aiming at bridging the language gap between the different fields and making more system-based studies.

Invited Speakers

- · Martin Bruderer (Ulm University, Germany) -keynote-
- · Peter Talkner (Augsburg University, Germany) -keynote-
- · Gerardo Adesso (University of Nottingham, UK)
- · Massimiliano Esposito (University of Luxembourg)
- · Anna Feshchenko (Aalto University, Finland)
- · Sania Jevtic (Imperial College, UK)
- · Marti Perarnau-Llobet (ICFO, Spain)
- · Janine Splettstösser (Chalmers University, Sweden)

Invited WG meeting Chairs

- · WG1: Antonio Acin (ICFO, Spain)
- · WG2: Tobias Brandes (Technische Universität Berlin, Germany)
- · WG3: Nicolas Tolazzi (Universität Mainz, Germany) &
  Eric Lutz (University of Erlangen- Nürnberg)

Scientific Committee

- · Eric Lutz (University of Erlangen-Nürnberg) -CHAIR-
- · Nicolas Brunner (Institute for Theoretical Physics University of Geneva)
- · Jochen Gemmer (University of Osnabrück, Germany)
- · Juan M.A. Parrondo (University Complutense of Madrid)
- · Killian Singer (University of Mainz, Germany)
- · Roberta Zambrini (IFISC, Spain)

Organizing committee Institute of Cross-Disciplinary Physics and Complex Systems:

- · Roberta Zambrini
- · Rosa Lopez
- · David Sanchez
- · Llorenç Serra
- · Fernando Galve

Programme

Sunday 19/4/2015
19:00 Welcome at Nautic Hotel and dinner at “el Club” restaurant
Monday 20/4/2015
Chair: J.M.Parrondo
09:30 Conference opening by Maxi San Miguel and Roberta Zambrini
09:40 Peter Talkner, Transient quantum fluctuation relations
10:30 Armen Allahverdyan, Nonequilibrium quantum fluctuations of work
11:00 Francesco Plastina, Non-adiabticity and irreversible entropy production
11:30-12:00 coffee break
Chair: T.Short
12:00 Christian Gogolin, Locality of temperature
12:30 Antonella De Pasquale, Temperature: a quantum estimation approach
13:00 Luis A. Correa, Individual quantum probes for optimal thermometry
13:30-14:30 lunch
14:30 A. Acin, **WG1 meeting**
16:00 walk to IFISC and Poster session
17:30 bus to Nautic hotel
Tuesday 21/4/2015
Chair: J.Anders
09:30 Gerardo Adesso, Optimal performance of quantum refrigerators
10:00 Michele Campisi**,** Nonequilibrium fluctuations in quantum heat engines: Theory, example, and possible solid state experiments
10:30 Raam Uzdin**,** Equivalence of different engine types in the quantum regime and quantum thermodynamic signatures
11:00 David Gelbwaser-Klimovksy, Strongly coupled quantum heat machines
11:30-12:00 coffee break

Chair: J.Gemmer
12:00 Marti Perarnau-Llobet, Work and correlations
12:30 Rodrigo Gallego, Defining work and heat from operational postulates
13:00 Gabriele De Chiara, Measuring work and heat in ultracold quantum gases
13:30-14:30 lunch
14:30 Tobias Brandes, **WG2 meeting**
Chair: L.Serra
16:00 Anna V. Feshchenko, Experimental realization of a Coulomb gap refrigerator
16:30 Bernhard Rauer, Non-equilibrium dynamics of a one-dimensional Bose gas
17:00 bus to Palma
18:00 Guided tour downtown
20:00 Social dinner
Wednesday 22/4/2015
Chair: A. Winter
9:30 Poster prizes announcement
9:40 Martin Bruderer, Controlling and Measuring Heat Transport in Ion Traps
10:30 M. Weilenmann, A Framework for Information Theoretic and Thermodynamic Entropies
11:00 Marcus Huber, The most energetic passive state
11:30-12:00 coffee break
Chair: D. Sanchez
12:00 Rafael Sánchez, Three terminal quantum Hall thermoelectrics
12:30 Robert S. Whitney, Maximum efficiency at given power output in 2 or 3 terminal thermoelectrics
13:00 Sun-Yong Hwang, Coupled Nonlinear Thermoelectric Transport in Normal-Quantum Dot-Superconductor Junctions
13:30-14:30 lunch
14:30 Serra de Tramuntana excursion (back to the hotel around 19:00)
Thursday23/4/2015
Chair: R. Lopez
9:30 Janine Splettstoesser, Heat currents and dephasing in flux qubits
10:00 Sebastien Jezouin, Quantum Limit of Heat Flow Across a Single Electronic Channel
10:30 André Xuereb, Thermodynamics of trajectories of a quantum harmonic oscillator coupled to N baths
11:00 Luis Pedro García-Pintos, Time scales of equilibration in physically relevant measurements
11:30-12:00 coffee break
Chair: P. Skrzypczyk
12:00 Gonzalo Manzano Paule, Fluctuation theorems and quantum mutual information
12:30 Matteo Lostaglio, Thermodynamics beyond free energy relations
13:00 Sania Jevtic, Exchange Fluctuation Theorem for Correlated Quantum Systems
13:30-14:30 lunch
14:30 Nicolas Tolazzi & Eric Lutz, **WG3 meeting**
Chair: J.Anders
16:00 Loïc Rondin, Kramers' Turnover measured with a vacuum levitated nanoparticle
16:30 Andreas Dechant, An all-optical nanomechanical heat engine
17:00 bus to hotel Nautic
Friday 24/4/2015
Chair: M. Bruderer
9:30 Massimiliano Esposito, Quantum thermodynamics: A nonequilibrium Green's function Approach
10:00 Hamed Mohammady, Minimising the heat dissipation of maximal information erasure
10:30 Kais Abdelkhalek, Thermodynamic costs of quantum measurements
11:00 Rebecca Schmidt, Work and heat for two-level systems in dissipative environments: Strong driving and non-Markovian dynamics
11:30-12:00 coffee break
Chair: P.Talkner
12:00 Ruari McCloskey, Heat Fluxes and Quantum Correlations in Collision Models
12:30 David Edward Bruschi, Quantum thermodynamics for a model of an expanding universe
13:00 MC meeting: Janet Anders

15:00 Transfer back to hotel or airport

INVITED TALKS

Optimal performance of quantum refrigerators

L. A. Correa, J. P. Palao, D. Alonso, and G. Adesso

We establish upper bounds on the coefficient of performance at maximum cooling power for all known models of quantum absorption refrigerators. In the special case of endoreversible refrigerators coupled to unstructured bosonic baths, the bound is refined into an exact function of the Carnot coefficient of performance. We provide general design prescriptions to saturate the bounds, and investigate how they may be pushed beyond what is classically achievable by exploiting squeezed reservoirs.

Controlling and Measuring Heat Transport in Ion Traps

A. Bermudez, M. Bruderer and M. B. Plenio

Measuring and controlling heat flow on the nanoscale poses formidable practical difficulties as elementary devices such as switches and 'ampere meters' for thermal currents are not available. We propose to overcome this problem by realizing heat transport through a chain of trapped ions, where steady-state currents of local vibrations (vibrons) are induced by a constant temperature difference between the edges of the chain. We show how to efficiently control and measure these currents by coupling vibrons to internal ion states, which can be easily manipulated in experiments. Trapped-ion crystals therefore provide a promising platform for studying heat transport, e.g., through thermal analogues of quantum wires and quantum dots. Specifically, elusive phenomena such as the onset of Fourier's law may be observable in trapped-ion systems.

Quantum thermodynamics: A nonequilibrium Green's function Approach

M. Esposito and M. Galperin

We will discuss the difficulties encountered when attempting to formulate quantum thermodynamics for open quantum systems strongly coupled to their reservoirs. A consistent approach resolving these problems will be presented within the framework of nonequilibrium Green's functions. The four fundamental laws of thermodynamics are verified and can be used to characterize transport in steady-state as well as in driven devices.

[1] M. Esposito, K. Lindenberg and C. Van den Broeck, New J. Phys. 12, 013013 (2010) [2] L. Pucci, M. Esposito and L. Peliti, J. Stat. Mech. (2013) P04005 [3] M. Esposito, M.A. Ochoa and M. Galperin, Phys. Rev. Lett. 114, 080602 (2015)

Experimental realization of a Coulomb gap refrigerator

A. V. Feshchenko, J. V. Koski and J. P. Pekola

We present the first experimental realization of a recently proposed Coulomb gap refrigerator [1, 2]. Our device is a normal single-electron transistor (SET) made of laterally proximized tunnel junctions [3]. At certain values of the bias and gate voltages, the current through the SET cools one of the junctions. The SET island is interrupted by a superconducting inclusion to permit charge transport while preventing heat flow. The temperature drop is measured with an NIS thermometer.

[1] J. P. Pekola, J. V. Koski, D. V. Averin, Phys. Rev. B 89, 081309(R) (2014) [2] A. V. Feshchenko, J. V. Koski, J. P. Pekola, Phys. Rev. B 90, 201407(R) (2014) [3] J. V. Koski, J. T. Peltonen, M. Meschke, and J. P. Pekola, Appl. Phys. Lett. 98, 203501 (2011)

Exchange Fluctuation Theorem for Correlated Quantum Systems

S. Jevtic, T. Rudolph, D. Jennings, Y. Hirono, S. Nakayama, and M. Murao

The Exchange Fluctuation Theorem (XFT) describes energy exchange between two thermal systems, and it is valid even if the systems finish arbitrarily far from equilibrium. An assumption made in the derivation of the XFT is that the two systems are initially uncorrelated. If we are to apply the XFT to quantum systems, then this assumption needs to be questioned. Our goal is to extend the XFT to describe the non- equilibrium exchange dynamics of correlated quantum states. The relation quantifies how the tendency for systems to equilibrate is modified in high-correlation environments.

Work and correlations

A. Acín, N. Brunner, D. E. Bruschi, K. V. Hovhannisyan, M. Huber, N. Friis, C. Klöckl, M. Perarnau-Llobet, and P. Skrzypczyk

We study the optimal interconversion between work and (quantum) correlations. Considering a set of uncorrelated thermal states, we derive bounds on both the mutual information and entanglement of formation that can be generated, as a function of the initial temperature and the available work. We also characterise the maximal temperature allowing for different types of entanglement generation. Finally, we consider the reverse question, i.e., the extractable work from a correlated state.

Heat currents and dephasing in flux qubits

S. Spilla, F. Hassler, A. Napoli, and J. Splettstoesser

Heat currents across Josephson junctions carried by quasiparticles are sensitive to the superconducting phase difference via Andreev reflection. As a result, heat currents due to accidental temperature gradients in flux qubits ``measure" the phase-dependent qubit state causing dephasing. We compare the emerging dephasing time for different flux qubit designs. We argue that even for vanishing temperature gradients, the study of heat conductances yields a phenomenological access to dephasing due to quasiparticle tunneling.

Transient quantum fluctuation relations

Peter Talkner

The statistics of work performed on a system that initially stays in equilibrium is constrained by so-called transient fluctuation relations known under the names of Jarzynski equality and Crooks relation. We shall introduce these relations and discuss their main prerequisites both for closed and open quantum systems. These prerequisites embrace the way how the work is determined, the time-reversal invariance of Hamiltonian systems as well as the proper identification of the system's free energy. The latter point being relevant for open systems.

M. Campisi, P. Talkner, P. Hanggi, Rev. Mod. Phys. 83, 771 (2011); ibid 1653 (2011). P. Hanggi, P. Talkner, Nat. Phys. 11, 108 (2015).

CONTRIBUTED TALKS

Thermodynamic costs of quantum measurements

Kais Abdelkhalek and David Reeb

We investigate the thermodynamic costs of performing quantum measurements. For a measurement employing a probe, we generalize and improve the results by Sagawa and Ueda (PRL 102, 250602) to the genuinely quantum case where the measurement generates classical or quantum correlations. We provide explicit gap terms and identify inefficiencies in the measurement and the outcome storage. Finally, we apply our results to analyze the full

Szilard engine cycle under possibly imperfect measurements.

Nonequilibrium quantum fluctuations of work

Armen Allahverdyan

The concept of work is basic for thermodynamics. I focus on the work done between two moments of time for a thermally isolated quantum system driven by a time-dependent Hamiltonian. I formulate two conditions needed for the fluctuating work to be physically meaningful for a system that starts its evolution from a non-equilibrium state. I propose a definition of fluctuating work that is free of previous drawbacks and that applies for a class of non-equilibrium initial states.

Quantum thermodynamics for a model of an expanding universe

Nana Liu, John Goold, Ivette Fuentes, Vlatko Vedral, Kavan Modi and David Edward Bruschi

We study thermodynamical properties of quantum fields in curved spacetime by considering the fields as quantum systems undergoing out-of-equilibrium transformations. We study non-equilibrium features by considering fluctuation relations and emergent irreversible features beyond the linear response regime. We specialise to an expanding universe setup and provide a fluctuation theorem which allows us to understand particle production due to the expansion of the universe as an entropic increase.

Nonequilibrium fluctuations in quantum heat engines: Theory, example, and possible solid state experiments

Michele Campisi, Jukka Pekola and Rosario Fazio

The stochastic thermodynamics of a quantum heat engine (including the statistics of efficiency and the compliance with the fluctuation relation) is illustrated by means of a two-qubit heat engine, where each qubit is coupled to a thermal bath and a two-qubit gate determines energy exchanges between the two qubits. We discuss possible solid state implementations with Cooper pair boxes and flux qubits, quantum gate operations, and fast calorimetric on-chip measurements of single stochastic events.

Individual quantum probes for optimal thermometry

Luis A. Correa, Mohammad Mehboudi, Gerardo Adesso and Anna Sanpera

In this talk, the task of interest is the precise estimation of the unknown temperature of a sample, by having a single quantum probe thermalize with it. I will use of the toolbox of parameter estimation, to assess the ultimate limitations on the achievable thermal sensitivity in this prototypical setup. The fundamental issue of temperature fluctuations in small systems will be thus revisited from a fresh perspective, arriving to relevant results for the practice of quantum thermometry.

An all-optical nanomechanical heat engine

Andreas Dechant, Nikolai Kiesel and Eric Lutz

We propose and theoretically investigate a nanomechanical heat engine. A levitated nanoparticle in an optical trap inside a cavity can be used to realize a Stirling cycle in the underdamped regime. The all-optical approach enables fast and flexible control of all thermodynamic parameters and the efficient optimization of the engine. We develop a systematic optimization procedure to determine optimal driving protocols and to evaluate the maximum power and the corresponding efficiency.

Measuring work and heat in ultracold quantum gases

Gabriele De Chiara, Augusto J. Roncaglia and Juan Pablo Paz

I will present a radically new method to measure heat and work in cold atomic gases. Using a light-matter interaction, known as the Faraday effect, we can measure the initial and final energy of an atomic ensemble before and after a thermodynamic transformation has taken place. For isolated systems this accounts for the work done on or extracted from the system thus verifying Jarzynski equality. For open systems there will also be a contribution of heat.

Temperature: a quantum estimation approach

Antonella De Pasquale, Davide Rossini, Rosario Fazio and Vittorio Giovannetti

We discuss the issue of temperature-locality in the quantum regime from the viewpoint of quantum estimation theory. Our strategy hinges upon the computation of the quantum Cramer-Rao Bound on the variance associated to the global temperature, via local measurements. In the low-temperature regime our approach emerges as a thermodynamics-rooted scheme able to operationally quantify the local distinguishability between the ground state and the first excited level of the system Hamiltonian.

Time scales of equilibration in physically relevant measurements

Luis Pedro García-Pintos, Anthony Short, Noah Linden, Artur Malabarba and Andreas Winter

We study the conditions under which a closed system equilibrates quickly with respect to some observable. Under certain conditions on the distribution of the matrix elements of observable and initial state, we find an upper bound on the time scales of equilibration giving much more realistic results than previously known bounds (which scale with the dimension of the system). As an application, we find a simple expression for the equilibration times of a system interacting with a thermal bath.

Strongly coupled quantum heat machines

David Gelbwaser-Klimovksy and Alan Aspuru-Guzik

A common denominator of quantum heat machines models is the weak coupling assumption, which limits the machine output. A possible way to overcome this limitation is to consider the strong coupling regime, where thermodynamic principles, may no longer hold. In this talk, I will explore this virtually unknown regime, showing the difference between weakly and strongly coupled quantum thermal machines, the advantage and limitations of each of them, and their relation with thermodynamic bounds.

Locality of temperature

Martin Kliesch, Christian Gogolin, Michael James Kastoryano, Arnau Riera and Jens Eisert

We present results leading to a local definition of temperature in spin- and fermionic-lattice systems, extending the notion of "intensivity of temperature" to interacting quantum models. We derive a perturbation formula for thermal states that captures the influence in terms of a generalized covariance. For this covariance we prove exponential clustering of correlations above a universal critical temperature implying stability of the thermal state against distant Hamiltonian perturbations.

The most energetic passive state

Antonio Acin, Karen V. Hovhannisyan, Marcus Huber, Marti Perarnau-Llobet, Paul Skrzypczyk and Jordi Tura

Passive states play a central role in thermodynamics as they are the only ones where no cyclic process can extract any amount of work. However operating on multiple copies of passive states unlocks the potential to extract some energy until the passive state with least possible energy (at a given entropy) is reached. We resolve the question how much unlockable work can be stored in passive states by deriving the general form of the most energetic passive state.

Coupled Nonlinear Thermoelectric Transport in Normal-Quantum Dot-Superconductor Junctions Sun-Yong Hwang, Rosa Lopez and David Sanchez

We explore the thermoelectric current of a quantum dot attached to normal and superconducting leads with voltage and temperature bias. Inherent particle-hole symmetry in superconductor cancels subgap thermoelectric response. However, the Andreev bound states shift as thermal bias increases. Thus, the current can be tuned by temperature in combination with voltage in nonlinear regime. We also show the importance of quasiparticle tunneling in the generation of high thermopower sensitivities.

Quantum Limit of Heat Flow Across a Single Electronic Channel

Sebastien Jezouin, François Parmentier, Anne Anthore, Ulf Gennser, Antonella Cavanna, Yong Jin and Frédéric Pierre

Quantum physics predicts that there is a fundamental maximum heat conductance across a single transport channel and that this thermal conductance quantum is universal, independent of the type of particles carrying the heat. Such universality, combined with the relationship between heat and information, signals a general limit on information transfer. Here, we report on the quantitative measurement of the quantum limited heat flow for Fermi particles and across a single electronic channel.

Heat Fluxes and Quantum Correlations in Collision Models

Salvatore Lorenzo, Ruari McCloskey, Francesco Ciccarello, Mauro Paternostro and Massimo Palma

We focus on the process of thermalisation from the point of view of a quantum system coupled with an ancilla which is coupled to a bath. The aim is to see how the system relaxes depending on the choice of the intermediary ancilla and the system-ancilla and ancilla-environment coupling. Building on previous experience, we choose to work with collision models due to their accessibility and examine Landauer’s principle as the system- ancilla ensemble evolves.

Thermodynamics beyond free energy relations

Matteo Lostaglio, David Jennings and Terry Rudolph

Recent studies developed fundamental limitations of quantum thermodynamics, in terms of a set of free energy relations. We show that these cannot properly describe quantum coherence in thermodynamics. We cast coherence as a fundamental resource of a quantum state and arrive at additional, independent thermodynamic relations, which naturally extend the existing ones. As an application, we show that the Szilard engine argument does not extend to quantum coherences without an appropriate activation.

Fluctuation theorems and quantum mutual information

Gonzalo Manzano Paule, Jordan M. Horowitz and J. M. R. Parrondo

In this talk I present a fluctuation theorem for the correlations created among the constituents of an isolated quantum system. This quantity, given by the mutual information, can be interpreted as an entropy production and its relation to time-reversal symmetry breaking is discussed. Our results are valid in a very broad range of situations and do not rely on specific details of the interaction nor on the shape of the initial (separable) states of the subsystems.

Minimising the heat dissipation of maximal information erasure

Hamed Mohammady, Masoud Mohseni and Yasser Omar

We find the global unitary evolution that minimises the heat transfer to a thermal reservoir conditional on maximising the erasure of a qubit. We consider the case when the reservoir is a d-dimensional subspace of a harmonic oscillator, and show that the optimal case exceeds Landauer's limit. We also consider the robustness, due to reservoir dimension, to energy-conserving dephasing. Finally, we consider two changes in the assumptions underlying Landauer's principle to attain better bounds.

Non-adiabticity and irreversible entropy production

Francesco Plastina, Antonio Alecce, Tony Apolalro, Giovanni Falcone, Gianluca Francica, Fernando Galve, Nicola Lo Gullo and Roberta Zambrini

I will discuss the thermodynamic properties of a closed quantum system brought out-of-equilibrium by some work performed on it, and show that the non-adiabatic part of the work (called inner friction) is intimately linked to the non-equilibrium entropy production. A specific fluctuation relation associated with the inner friction exists, which allows to show the connections among the inner friction, the speed of the thermodynamic transformation, and the occurrence of diabatic transitions.

Non-equilibrium dynamics of a one-dimensional Bose gas

Bernhard Rauer, Tim Langen, Sebastian Erne, Remi Geiger, Thomas Schweigler, Pjotrs Grisins, Igor Mazets, Thomas Gasenzer and Jörg Schmiedmayer

We investigate relaxation dynamics in a degenerate 1d Bose gas which we take out of equilibrium by coherently splitting it into two parts. In the subsequent evolution the relative phase field of the two condensates is monitored, providing a local probe for the system. This allows us to directly observe how the initial coherence between the two many-body systems is lost and how a steady state emerges. We explicitly show that this steady state is described by a generalized Gibbs ensemble.

Kramers' Turnover measured with a vacuum levitated nanoparticle

Loïc Rondin, Jan Gieseler, Romain Quidant, Christoph Dellago and Lukas Novotny.

Using a nanoparticle trapped in a bi-stable optical potential we experimentally measure the nanoparticle's transition rates for variable damping. This allows us to directly resolve the Kramers' turnover, i.e a rate maximum. Our measurements are in agreement with an analytical model that is free of adjustable parameters. This demonstrates levitated nanoparticles as an experimental platform for studying and simulating a wide range of stochastic processes and testing theoretical models predictions.

Three terminal quantum Hall thermoelectrics

Rafael Sánchez, Björn Sothmann and Andrew N. Jordan

We investigate the thermoelectric properties of a three-terminal quantum Hall conductor. We identify a contribution to the thermoelectric response that relies on the chirality of the carrier motion rather than on spatial asymmetries. The Onsager matrix becomes maximally asymmetric showing that thermoelectric measurements are sensitive to the chiral nature of the quantum Hall edge states. The possibility to generate spin-polarized currents in quantum spin Hall samples is also discussed.

Work and heat for two-level systems in dissipative environments: Strong driving and non-Markovian dynamics Rebecca Schmidt, M Florencia Carusela, Jukka P. Pekola and Joachim Ankerhold

Work, moments of work and heat flux are studied for the generic case of a strongly driven two- level system immersed in a bosonic heat bath in domains of parameter space where perturbative treatments fail. This includes the interplay between non-Markovian dynamics and moderate to strong external driving. Exact data are compared with weak coupling approaches. Further, the role of system-bath correlations in the initial thermal state are addressed.

Equivalence of different engine types in the quantum regime and quantum thermodynamic signatures Raam Uzdin and Ronnie Kosloff

We show that in the quantum regime different engine types like four-stroke, two-stroke and continuous engines are all thermodynamically equivalent and even have the same relaxation to steady state. Furthermore, it is shown that quantum engines have a quantum-thermodynamic signature. Cumulative work measurement for example can indicate the existence of quantum interference in the engine. This coherent dynamics enables work extraction far beyond the capabilities of a stochastic (dephased) engine.

A Framework for Information Theoretic and Thermodynamic Entropies

Mirjam Weilenmann, Lea Kraemer, Philippe Faist and Renato Renner

We study the application of an approach to thermodynamic entropy by Lieb and Yngvason to information-theoretic scenarios and establish a link between the phenomenological entropy known from thermodynamics and the von Neumann entropy important for information theory on a microscopic scale; two conceptually very different quantities. Simultaneously, entropic quantities relevant for thermodynamic non-equilibrium states are shown to correspond to the information-theoretic min- and max-entropies.

Maximum efficiency at given power output in 2 or 3 terminal thermoelectrics

Robert S. Whitney

Carnot efficiency is only achievable at zero power output. So what is the maximum efficiency at finite power output? The answer requires quantum theory, being ill-defined in classical thermodynamics. We use scattering theory to find the maximum efficiency for relaxation-free 2 terminal systems. We explore whether this maximum can be exceeded by adding relaxation, or with 3 terminal systems. The present answer seems to be "no".

Defining work and heat from operational postulates

Rodrigo Gallego, Henrik Wilming and Jens Eisert

Work is traditionally defined as the energy stored in a lifted weight (battery). In the quantum regime, fluctuations cease to be negligible, hence, the question arises of how to define work discounting the heat content of fluctuations. We propose an axiomatic approach to the definition of work. By imposing a set of postulates that any work measure fulfils, we show that work can be written as the free energy difference of the battery, but not as the energy difference as it is usually measured.

Thermodynamics of trajectories of a quantum harmonic oscillator coupled to N baths

Simon Pigeon, Lorenzo Fusco, André Xuereb, Gabriele De Chiara and Mauro Paternostro

We undertake a thorough analysis of the thermodynamics of the trajectories followed by a quantum harmonic oscillator coupled to N dissipative baths by using a new approach to large-deviation theory inspired by phase-space quantum optics. As an illustrative example, we study the archetypal case of a harmonic oscillator coupled to two thermal baths, allowing for a comparison with the analogous classical result, finding significant differences in the low-temperature limit.

POSTERS

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