DY 17: Statistical Physics far from Thermal Equilibrium

Time: Tuesday 10:00–13:15 Location: H48

DY 17.1 Tue 10:00 H48

First-passage fluctuation theorems — •Izaak Neri[1,2,5], Édgar Roldán[1,5], Meik Dörpinghaus[3,5], Heinrich Meyr[3,4,5], and Frank Jülicher[1,5] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Max Planck Institute for Cell and Molecular Biology, Dresden, Germany — [3]Vodafone Chair Mobile Communications Systems, Dresden — [4]Institute for Integrated Signal Processing Systems, Aachen — [5]Center for Advancing Electronics Dresden, Dresden

The Second Law of Thermodynamics states that entropy of an isolated system out of equilibrium increases until the equilibrium state is reached. Statistical physics allows to define entropy of a single trajectory in the microscopic phase space. A universal relation for the fluctuations of entropy production of stochastic systems far from thermal equilibrium follows. The entropy production fluctuation theorem states that a steady state process produces exponentially more likely a positive amount of entropy than an equal but negative amount. In this presentation we show an equivalent relation for the first-passage times of entropy production. The probability to produce for the first time a positive amount of entropy is exponentially more likely than the probability to produce for the first time an equivalent but negative amount of entropy. This novel fluctuation relation is illustrated on a couple of examples of stochastic systems.

DY 17.2 Tue 10:15 H48

Sensory capacity: an information theoretical measure of the performance of a sensor — •David Hartich[1], Andre C. Barato[2], and Udo Seifert[1] — [1]II. Institut für Theoretische Physik, Stuttgart, Germany — [2]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

For a general sensory system following an external stochastic signal, we introduce the sensory capacity [1]. This quantity characterizes the performance of a sensor: sensory capacity is maximal if the instantaneous state of the sensor has as much information about a signal as the whole time-series of the sensor. We show that adding a memory to the sensor increases the sensory capacity. This increase quantifies the improvement of the sensor with the addition of the memory. Our results are obtained with the framework of stochastic thermodynamics of bipartite systems, which allows for the definition of an efficiency that relates the rate with which the sensor learns about the signal with the energy dissipated by the sensor, which is given by the thermodynamic entropy production. We demonstrate a general tradeoff between sensory capacity and efficiency: if the sensory capacity is equal to its maximum 1, then the efficiency must be less than 1/2. As a physical realization of a sensor we consider a two component cellular network estimating a fluctuating external ligand concentration as signal. This model leads to coupled linear Langevin equations that allow us to obtain explicit analytical results.

[1] D. Hartich, A. C. Barato, and U. Seifert (2015) arXiv:1509.02111

DY 17.3 Tue 10:30 H48

Variational principles and information measures for nonequilibrium processes — •Matteo Polettini — 162 A, avenue de la Faïencerie L-1511 Luxembourg (Grand Duchy of Luxembourg)

We critically review several variational principles for nonequilibrium processes. In particular, we discuss the general form of observable constraints for the correct formulation of the minimum entropy production principle close to equilibrium (minEP), we contest the validity of the so-called maximum entropy production principle, discuss the information-theoretic structure of MAXENT far from equilibrium, and reject a conjectured convexity principle for the relative entropy of a system. Part of our analysis is based on the Fisher information metric, a statistical tool that allows to put bounds on the precision of an estimation of a random variable. We digress on possible roles of this quantity in the context of information processing in nonequilibrium systems.

DY 17.4 Tue 10:45 H48

Universal bounds on current fluctuations — •Patrick Pietzonka[1], Andre C. Barato[2], and Udo Seifert[1] — [1]II. Institut für theoretische Physik, Universität Stuttgart — [2]Max Planck Institute for the Physics of Complex Systems, Dresden

For current fluctuations in non-equilibrium steady states of Markovian processes, we derive four different universal bounds valid beyond the Gaussian regime. Different variants of these bounds apply to either the entropy change or any individual current, e.g., the rate of substrate consumption in a chemical reaction or the electron current in an electronic device. The bounds vary with respect to their degree of universality and tightness. A universal parabolic bound on the generating function of an arbitrary current depends solely on the average entropy production. A second, stronger bound requires knowledge both of the thermodynamic forces that drive the system and of the topology of the network of states. These two bounds are conjectures based on extensive numerics. An exponential bound that depends only on the average entropy production and the average number of transitions per time is rigorously proved. This bound has no obvious relation to the parabolic bound but it is typically tighter further away from equilibrium. An asymptotic bound that depends on the specific transition rates and becomes tight for large fluctuations is also derived. Our bounds generalize a recently derived relation for the relative uncertainty in current fluctuations [1] and provide a new general class of constraints for nonequilibrium systems.

[1] A. C. Barato and U. Seifert, Phys. Rev. Lett. **114**, 158101 (2015)

DY 17.5 Tue 11:00 H48

On the difference between information and heat reservoirs — •Johannes Hoppenau and Andreas Engel — Universität Oldenburg, Germany

In classical thermodynamics, there are two kinds of reservoirs: heat and work reservoirs. While the work reservoirs allow for an exchange of energy without a change of their entropy, for heat reservoirs at temperature T the exchange of the energy Q comes along with a change Q/T of the entropy. Hence, a work reservoir can be seen as a heat reservoir at infinite temperature.

With the advent of stochastic thermodynamics, during the past years the concept of Maxwell's demons has regained increased interest. An integral part of all Maxwell's demons is a memory or information reservoir. A key characteristic of an information reservoir is that its entropy can be increased without the cost of energy exchange. Hence, an obvious question to ask is, if an information reservoir can be seen as a heat bath at zero temperature. This however is not that easily possible since correlation play an essential role in memory, that are not present in heat reservoirs.

To illustrate this difference, we present a model of a tape that stores information and has an intrinsic temperature and derive general bounds of efficiency for engines in contact with this tape. Depending on the perspective, this tape is an imperfect information reservoir or an imperfect heat reservoir and engines acting on this tape are Maxwell's demons or heat engines.

DY 17.6 Tue 11:15 H48

Decision making in the arrow of time — •Édgar Roldán[1,5], Izaak Neri[1,2,5], Meik Dörpinghaus[3,5], Heinrich Meyr[3,4,5], and Frank Jülicher[1,5] — [1]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Str. 38, 01187 Dresden, Germany — [2]Max Planck Institute of Molecular Cell Biology and Genetics, Pfotenhauerstraße 108, 01307 Dresden, Germany — [3]Vodafone Chair Mobile Communications Systems, Technische Universität Dresden, 01062 Dresden, Germany — [4]Institute for Integrated Signal Processing Systems, RWTH Aachen University, 52056 Aachen, Germany. — [5]Center for Advancing Electronics Dresden, cfaed, Germany.

We show that the steady state entropy production rate of a stochastic process is inversely proportional to the minimal time needed to decide on the direction of the arrow of time. Here we apply Wald's sequential probability ratio test to optimally decide on the direction of time's arrow in stationary Markov processes. Furthermore the steady state entropy production rate can be estimated using mean first-passage times of suitable physical variables. Our results are illustrated by numerical simulations of two simple examples of nonequilibrium processes.

15 min. break

DY 17.7 Tue 11:45 H48

Work and Entropy Production in Generalized Gibbs En-

sembles — Martí Perarnau-Llobet[1], Arnau Riera[1], Rodrigo Gallego[2], •Henrik Wilming[2], and Jens Eisert[2] — [1]ICFO-Institut de Ciencies Fotoniques, 08860 Castelldefels, Barcelona, Spain — [2]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany

Thermodynamics can be put into contact with quantum mechanics by assuming that systems at thermal equilibrium can be effectively described by the Gibbs ensemble.

Here, we consider thermodynamic protocols in situations where the systems in question cannot be described accurately by a Gibbs ensemble – either because they are strongly coupled to a heat bath or because conserved quantities require the use of an effective description by a so-called Generalized Gibbs ensemble (GGE) to describe their equilibrium state after a quench, as, for example, in the case of localized systems.

In particular we study the validity of the "minimum work principle" and entropy production in optimal work-extraction protocols – both analytically and numerically. Our findings show that the minimum-work principle can break down in the presence of a large number of conserved quantities, while we can show that it remains intact if system and bath together can be well described by a Gibbs ensemble, even in the strongly interacting regime. Since we consider large but finite baths, our results can also be understood as corrections to the usual assumption of ideal infinite heat baths, which do not degrade when used in thermodynamic protocols.

DY 17.8 Tue 12:00 H48

Defining work from operational principles — •Rodrigo Gallego, Jens Eisert, and Henrik Wilming — Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany

In recent years we have witnessed a concentrated effort to make sense of thermodynamics for small-scale systems. One of the main difficulties is that, at the nano-scale, thermal fluctuations of energy in general render it conceptually difficult to distinguish work from heat. Despite of several attempts to resolve this issue, many of which inspired by quantum information theory, there is still remarkable little consensus on it. In this work, we attempt to define work in a strictly operational way. In our resource-theoretic approach, agents wish to agree upon how much work needs to be invested to effect a transition from one state of an arbitrary quantum work-storage device to another. We introduce basic operational principles, and deduce from them a strict set of mathematical properties that any reasonable function quantifying such work has to fulfill. We show that one work quantifier satisfying all the required properties is the difference of the non-equilibrium free energy of the initial and final state of the work-storage system. More generally, for any work quantifier fulfilling the stated properties, we can derive a quantitative second law in the sense of bounding the work that can be performed using some non-equilibrium resource by the work that is needed to create it. We furthermore discuss the role of path dependence for work quantifiers and the connection to the concept of probability-distributions of work.

DY 17.9 Tue 12:15 H48

Performance of a nanoscale refrigerator — •Obinna Abah and Eric Lutz — Department of Physics, University of Erlangen-Nuremberg, Germany

We consider a quantum Otto refrigerator cycle of a time-dependent frequency harmonic oscillator. We investigate the coefficient of performance at maximum figure of merit for adiabatic and nonadiabatic frequency modulations. We further derive the characteristic time bounding the refrigerator functionality for nonadiabatic transformations. The validity of both cases in both high- and low-temperature limits are discussed.

DY 17.10 Tue 12:30 H48

Nonequilibrium thermodynamics of open degenerate quantum systems — Gregory Bulnes Cuetara[1], Massimiliano Esposito[2], and •Gernot Schaller[3] — [1]Dept. of Chemistry & Biochemistry, UCSD, Urey Hall, 9500 Gilman Dr., La Jolla, CA 92093-0340, USA — [2]University of Luxembourg, Physics and Materials Science Research Unit, Campus Limpertsberg BRB 0.03, 162a avenue de la Faïencerie, L-1511 Luxembourg, G. D. Luxembourg — [3]Institut für Theoretische Physik, Technische Universität Berlin, Eugene-P.-Wigner-Gebäude PN 147, Hardenbergstr. 36, 10623 Berlin

We establish quantum stochastic thermodynamics for open systems with degenerate energy eigenstates. The Born-Markov-secular quantum master equation (QME) leads in this case to couplings between degenerate populations and their coherences. We show that our genuine quantum formulation nevertheless reduces to conventional stochastic thermodynamics with time-dependent rates satisfying local detailed balance, when the QME is represented in the time dependent basis diagonalizing the system density matrix. We illustrate our findings by considering transport through a parallel double quantum dot junction with degenerate levels, where the coupling to two different environments may drag the system towards a pure state.

DY 17.11 Tue 12:45 H48

Causal Entropic Forces: Dynamics and Pattern Formation — •Hannes Hornischer, Stephan Herminghaus, and Marco G. Mazza — MPI for Dynamics and Self-Organization, Göttingen

One basic principle of evolution is survival, that is, organisms distance themselves from situations threatening their physical health and thereby enlarge their accessible space of possible futures. We use a path-based entropy, causal entropy, which can be viewed as a measure for the diversity of future options, and examined the dynamics of a particle solely driven by a causal entropic force towards states of highest entropy production. Without any extra information about the system and solely due to entropic force those particles are able to adapt to changes in their environment, overcome potential barriers, find the fastest escape paths in evacuation scenarios. Many particles in a confined space would develop stable spatial patterns. This basic and general approach has the potential to give deeper understanding in social interactions in the context of behavioral ecology, for example applied to insects, fish or humans.

DY 17.12 Tue 13:00 H48

Switching kinetics of a roadblock particle in an exclusion process — •Mamata Sahoo[1] and Stefan Klumpp[2,3] — [1]Computational Modelling & Simulation Section, National Institute for Interdisciplinary Science and Technology, Thiruvananthapuram - 695019, India — [2]Department of Theory and Bio-Systems, Max Planck Institute of Colloids and Interfaces, Science Park Golm, 14424 Potsdam, Germany — [3]Institute for Nonlinear Dynamics, Georg August University Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany

Motivated by complex transport processes occurring in nature, we study the switching dynamics of a "roadblock" particle in a totally asymmetric simple exclusion process (TASEP). The roadblock particle blocks the traffic of moving particles while bound to the lattice, but can stochastically unbind or switch off, thus enabling the traffic to pass. We use simulations to study the dependence of the particle flux on the on/off switching dynamics of the roadblock, which exhibits a surprisingly rich dynamic behaviour. In particular, unlike in other studied TASEP variants with defects, here we observe that the particle flux is affected by the roadblock even in the initiation-limited or low density phase if the roadblock dynamics is slow. Rapid switching off the roadblock results in the typical behaviour of a TASEP with a defect/pause with reduced maximal current, but no effect of the roadblock on the flux in the initiation-limited phase. Moreover, in an intermediate range of roadblock rates, the particle current is found to be system-size dependent.