DY 23: Stochastic Thermodynamics

Time: Tuesday 14:00–15:30 Location: H20

DY 23.1 Tue 14:00 H20

Cycling tames power fluctuations near optimum efficiency — •Viktor Holubec[1,2] and Artem Ryabov[2] — [1]Institut für Theoretische Physik, Universität Leipzig, Leipzig, Germany — [2]Department of Macromolecular Physics, Faculty of Mathematics and Physics, Charles University, Praha, Czech Republic

According to the laws of thermodynamics, no heat engine can beat the efficiency of a Carnot cycle. This efficiency traditionally comes with vanishing power output and practical designs, optimized for power, generally achieve far less. Recently, various strategies to obtain Carnot's efficiency at large power were proposed. However, a thermodynamic uncertainty relation implies that steady-state heat engines can operate in this regime only at the cost of large fluctuations that render them immensely unreliable. Here, we demonstrate that this unfortunate trade-off can be overcome by designs operating cyclically under quasi-static conditions. The experimentally relevant yet exactly solvable model of an overdamped Brownian heat engine is used to illustrate the formal result. Our study highlights that work in cyclic heat engines and that in quasi-static ones are different stochastic processes.

[1] Viktor Holubec and Artem Ryabov, Phys. Rev. Lett. 121, 120601 (2018)

DY 23.2 Tue 14:15 H20

Phase transition in thermodynamically consistent biochemical oscillators — •Basile Nguyen[1], Udo Seifert[1], and Andre C. Barato[2] — [1]II. Institut für Theoretische Physik, Universität Stuttgart, Stuttgart, Germany — [2]Department of Physics, University of Houston

Biochemical oscillations are ubiquitous in living organisms. In an autonomous system, not influenced by an external signal, they can only occur out of equilibrium. We show that they emerge through a generic nonequilibrium phase transition, with a characteristic qualitative behavior at criticality. The control parameter is the thermodynamic force which must be above a certain threshold for the onset of biochemical oscillations. This critical behavior is characterized by the thermodynamic flux associated with the thermodynamic force, its diffusion coefficient, and the stationary distribution of the oscillating chemical species. We discuss metrics for the precision of biochemical oscillations by comparing two observables, the Fano factor associated with the thermodynamic flux and the number of coherent oscillations. Since the Fano factor can be small even when there are no biochemical oscillations, we argue that the number of coherent oscillations is more appropriate to quantify the precision of biochemical oscillations. Our results are obtained with three thermodynamically consistent versions of known models: the Brusselator, the activator-inhibitor model, and a model for KaiC oscillations.

[1] B. Nguyen, U. Seifert and A. C. Barato, *J. Chem. Phys.* **149**, 045101 (2018)

DY 23.3 Tue 14:30 H20

Stochastic thermodynamics of self-oscillations: the electron shuttle — •Christopher W. Wächtler[1], Philipp Strasberg[2], Sabine H. L. Klapp[1], Gernot Schaller[1], and Christopher Jarzynski[3] — [1]Institute of Theoretical Physics, Berlin, Germany — [2]Complex Systems and Statistical Mechanics, Luxembourg, Luxembourg — [3]Institute for Physical Science and Technology, College Park, USA

Self-oscillation is a phenomenon studied across many scientific disciplines, including the engineering of efficient heat engines. We investigate an example of a nano-scale system exhibiting a transition towards self-oscillation, namely the single electron shuttle, from a thermodynamic perspective. To this end we employ different levels of description: The fully stochastic level, the mean-field level, and a perturbative solution. Investigating the dynamical behaviour we find that the perturbation theory works particularly well for small amplitudes of the self-oscillation. Consistent derivations of the laws of thermodynamics for this model system can be formulated at these levels. Although the stochastic nature of the system smears out the abrupt transition observed at the mean-field level, the probability density still shows signs of the Hopf bifurcation. Beyond the mean-field description, thermodynamic quantities lack such a corresponding abrupt transition. Nevertheless, the transition towards self-oscillation is also observed in the stochastic and perturbative description.

DY 23.4 Tue 14:45 H20

Hidden degrees of freedom and fluctuation theorems: An analytically solvable model — •Jannik Ehrich and Marcel Kahlen — Institut für Physik, Carl von Ossietzky Universität Oldenburg, 26111 Oldenburg, Germany

In some situations in stochastic thermodynamics not all relevant slow degrees of freedom are accessible. Consequently, one adopts an effective description involving only the visible parts of the system. This gives rise to an apparent entropy production that violates standard fluctuation theorems. We present an analytically solvable model illustrating how the fluctuation theorems are modified. Furthermore, we define an alternative to the apparent entropy production: the marginal entropy production which fulfills the fluctuation theorems in the usual form. We show that the non-Markovianity of the visible process is responsible for the deviations in the fluctuation theorems.

[1] M. Kahlen and J. Ehrich, J. Stat. Mech. (2018) 063204

DY 23.5 Tue 15:00 H20

Discrete delay as the limit of distributed memory – An explicit study of the limit from a thermodynamic perspective — •Sarah A. M. Loos, Simon M. Hermann, and Sabine H. L. Klapp — Institut für theoretische Physik, TU Berlin, Germany

Stochastic thermodynamics provides a consistent description of a wide class of Langevin systems [1,2], but the Markov assumption is often crucial [1,2]. While some non-Markovian systems have indeed been studied in great detail, the case of a *discrete* delay in a continuous control is still insufficiently understood [2,3]. This is especially true in the presence of nonlinear forces.

In this talk, I will discuss the possibility of describing delayed dynamics as the limiting case of a process with gamma-distributed memory kernel of decreasing width [4]. While the kernel indeed decays smoothly to a delta peak, generating a discrete delay, we find that the (thermo-)dynamical properties are in fact only recovered in the delta limit. We investigate a way out by introducing colored noise, which at the same time allows us to explicitly study the impact of measurement errors. In fact, we find a divergent total entropy production for the error-free case. Considering linear and nonlinear example systems, we also study work and heat [3] and their fluctuations.

[1] U. Seifert, Rep. Prog. Phys. **75**, 126001 (2012).
[2] M. L. Rosinberg, T. Munakata, G. Tarjus, PRE **91**, 042114 (2015).
[3] S. A. M. Loos and S. H. L. Klapp, ArXiv:1806.04995 (2018).
[4] A. Longtin, Complex time-delay systems (Springer, 2010).

DY 23.6 Tue 15:15 H20

Entropy production in systems with distributed delay via Markovian embedding — •Simon M. Hermann, Sarah A. M. Loos, and Sabine H. L. Klapp — TU Berlin

We study overdamped systems with extended memory kernels at temperature $\mathcal{T}$ in the framework of stochastic thermodynamics [1-3]. The (distributed) delay renders the dynamics non-Markovian. As a consequence the time-reversed process appearing in the path integral representation of the entropy production is acausal [2] making a calculation of this key quantity highly nontrivial. This can be circumvented by a Markovian embedding technique [4]. In particular, we replace the memory term by a set of n auxiliary variables with heat baths at temperature $\mathcal{T}'$ coupled to the original one on a unidirectional ring. In this way, we construct a Markovian system that generates the same dynamics as the delayed system. If $\mathcal{T}' \neq 0$, the additional heat baths introduce correlations in the noise. Here we consider explicitly systems with different numbers of auxiliary variables, corresponding to different memory kernels and associated noise correlations. We calculate the heat and entropy production focusing on a non-linear (bistable) system. For an infinite number of auxiliary variables the kernel collapses onto a δ-distribution producing a system with discrete delay [3].

[1] U. Seifert, Rep. Prog. Phys. **75**, 126001 (2012).
[2] M. L. Rosinberg et al., PRE **91**, 042114 (2015).
[3] S. A. M. Loos, S. H. L. Klapp, ArXiv: 1806.04995 (2018).
[4] F. M. Atay, ed. Complex time-delay systems. Springer, 2010.