DY 27: Statistical Physics far from Thermal Equilibrium II

Time: Tuesday 14:00–15:30 Location: ZEU/0114

DY 27.1 Tue 14:00 ZEU/0114

Efficiency of Carnot-like engine for intracellular diffusivity fluctuations and diffusing diffusivity — •Yuichi Itto — Aichi Institute of Technology, Japan — ICP, Universität Stuttgart, Germany

In contemporary physics of intracellular diffusion, much attention is paid to understanding how environmental conditions affect the diffusivity [1], the change of which is crucial, e.g., for tuning the rates of biochemical reactions. Recently, the heat-like engine for local diffusivity fluctuations, which slowly vary and obey a universal exponential law, has been constructed to extract the diffusivity change in a cycle realized by compression/expansion of cells and temperature change [2]: it has the Carnot-like efficiency determined by the average diffusivity.

Here, the effect of slowly varying fluctuation on the efficiency [3] is discussed based on "diffusing diffusivity" [4] that describes the dynamics of the fluctuation distribution by an advection-diffusion equation, the stationary solution of which is of the exponential type. The entropy of the fluctuations, which gives the exponential law at its maximum, takes positive production rate under the dynamics. The tendency to approach the (stationary) average diffusivity is dominantly governed by the factor characterizing the diffusion term in its square root, showing its peculiar role in view of the fact that the exponential law is due to the advection term.

References [1] N. Bellotto, J. Agudo-Canalejo, R. Colin, R. Golestanian, G. Malengo, V. Sourjik, eLife 11, e82654 (2022). [2] Y. Itto, Eur. Phys. J. B 98, 183 (2025). [3] Y. Itto, arXiv:2511.06851 (2025). [4] M. V. Chubynsky, G. W. Slater, Phys. Rev. Lett. 113, 098302 (2014).

DY 27.2 Tue 14:15 ZEU/0114

Relaxation speed in quenched-random force fields — •Jan Meibohm and Sabine H.L. Klapp — Technische Universität Berlin, Institut für Physik und Astronomie, Fachgruppe Theoretische Physik, Hardenbergstraße 36, 10623 Berlin, Germany

We determine the asymptotic relaxation speed of a Brownian particle in quenched-random force fields with a harmonic background in dimensions $d \geq 2$. For random forces derived from a potential, we show that relaxation is generally slower than in the unperturbed case when the background is isotropic. By contrast, for strongly anisotropic backgrounds, where the background is stiffer in all directions except one, we find a crossover between slow and fast relaxation, similar to the one-dimensional case discussed in [1]. Allowing for non-potential forces changes this picture and leads to generally faster relaxation. In the limits of small and large correlation length of the random force, we identify universal regimes in which the relaxation speed becomes independent of of the details of the random forces. Finally, we analyse a scaling limit for quasi-isotropic backgrounds at weak disorder, where the change in relaxation speed becomes anomalously large.

[1] Meibohm & Klapp, Phys. Rev. Lett., 134.8, 087101 (2025)

DY 27.3 Tue 14:30 ZEU/0114

Mpemba effect for a particle in a bistable potential: classical versus quantum — •Jannis Michael Melles[1], Hartmut Löwen[1], Benno Liebchen[2], and Alexander Antonov[1] — [1]Institut für Theoretische Physik II: Weiche Materie, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany — [2]Institut für Physik der kondensierten Materie, Technische Universität Darmstadt, Darmstadt, Germany

An anomalous cooling behavior where initially hot systems cool faster than initially warm ones is referred to as the Mpemba effect and clearly goes beyond quasi-static thermodynamics. For classical particles, such a cooling behavior has been thoroughly studied for a simple paradigmatic set up involving a single classical colloidal particle in a bistable optical potential [1]. We quantize this model and consider a quantum particle coupled to an external bath with the Lindblad damping [2]. The Mpemba effect does occur during the cooling of this quantum system; however, the origin of the anomalous cooling is qualitatively massively different from that of its classical counterpart for temperatures close to or at zero. Additionally, we identify a doubled inverse quantum Mpemba effect when the system is heated instead. Our results are amenable for an experimental verification with an ultracold atom in a suitable laser-optical trap potential.

[1] A. Kumar and J. Bechhoefer, Nature **584**, 64 (2020)

[2] J. Melles, H. Löwen, B. Liebchen and A. Antonov, to be published

DY 27.4 Tue 14:45 ZEU/0114

Brownian gyrators: from mono- to quadrupolar gyration — •Iman Abdoli and Hartmut Löwen — Institut für Theoretische Physik II - Soft Matter, Heinrich-Heine-Universität Düsseldorf, Universitätsstraße 1, D-40225 Düsseldorf, Germany

Thermally anisotropic Brownian systems-where different spatial directions are coupled to different effective temperatures-break detailed balance and generate circulating probability currents, exemplified by the Brownian gyrator. Such systems provide a minimal framework for studying nonequilibrium energy conversion and the emergence of directed motion and torques driven purely by fluctuations. We demonstrate how these anisotropic fluctuations can be harnessed as a microscopic heat engine, whose efficiency can approach Carnot performance at maximum power when appropriately loaded with external mechanical forces [1]. Furthermore, we show that confining a thermally anisotropic particle to a narrow ring produces quadrupolar steady-state gyration, a symmetry-protected circulation pattern arising solely from anisotropic noise [2]. These results highlight the rich flux structures and energetic functionalities enabled by thermal anisotropy.

[1] I Abdoli, A Sharma, H Löwen, Phys. Fluids. 37 (4)

[2] I Abdoli, H Löwen, arXiv preprint arXiv:2508.08792

DY 27.5 Tue 15:00 ZEU/0114

Role of kinetics in mesoscopic dynamics of a driven Potts model — •Maciej Chudak[1], Massimiliano Esposito[2], and Krzysztof Ptaszyński[1] — [1]Institute of Molecular Physics, Polish Academy of Sciences, Mariana Smoluchowskiego 17, 60-179 Poznań, Poland — [2]Department of Physics and Materials Science, University of Luxembourg, 30 Avenue des Hauts-Fourneaux, L-4362 Esch-sur-Alzette, Luxembourg

The Potts model is a generalization of the Ising model, where spins can take more than two states. We study a driven three-state nonequilibrium Potts model with homogeneous all-to-all coupling. At a macroscopic level, this model exhibits complex behavior such as synchronization and persistent oscillations (limit cycles). In the mean-field limit the model dynamics is described via deterministic equations of motion. Choice of the transition rate function can reshape the phase diagram of the model. We identified seven distinct dynamical phases separated by seven bifurcation types. Beyond the mean-field analysis, we characterize the effect of rare fluctuations on the model behavior. We determine the coherence lifetime of the oscillations and compare it to a thermodynamic bound given by the entropy production per cycle. The trade-off between coherence lifetime and entropy production can be fine-tuned. We characterize the rare stochastic transitions among the coexisting mean-field attractors using the instanton approach. Such transitions tend to relax the system to a single attractor that determines the macroscopic behavior of the model. In case of multistability, the ordered state is usually the most likely.

DY 27.6 Tue 15:15 ZEU/0114

Continuous-time multifarious systems — •Jakob Metson[1], Saeed Osat[1,2], and Ramin Golestanian[1,3] — [1]Max Planck Institute for Dynamics and Self-Organization (MPI-DS), 37077 Göttingen, Germany — [2]Institute for Theoretical Physics IV, University of Stuttgart, 70569 Stuttgart, Germany — [3]Rudolf Peierls Centre for Theoretical Physics, University of Oxford, Oxford OX1 3PU, United Kingdom

Multifarious assembly models consider multiple structures assembled from a shared set of components. We explore Gillespie simulations of lattice-based assembly models, comparing these to Monte Carlo simulations. We start with an equilibrium model, in which detailed balance is obeyed. However, due to the rough energy landscape, the systems often end up in long-lived metastable states. Despite this, the Gillespie and Monte Carlo simulations are largely consistent. We present physical arguments to predict the state boundaries, which also reconciles a small discrepancy between the two simulation methods. We furthermore study an explicitly non-equilibrium model, the non-reciprocal multifarious self-organisation model. Here, non-reciprocal interactions between the building blocks break detailed balance. Also in this case, the Gillespie and Monte Carlo simulations demonstrate the same range of behaviours. Additionally, we explore the timescales of shape-shifting present in this model, developing analytical calculations to compare with simulations. Overall, these results demonstrate that both Gillespie and Monte Carlo simulations can be relied on to explore such systems, even when the dynamics are far from equilibrium.