DY 12: Focus Session: Relaxation Timescales in Open Quantum Systems (joint session TT/DY)

In the quantum year 2025 many applications of quantum systems are revisited for their actual physical implementability. Realizing that no quantum system is truly isolated from its environment highlights the need for a thorough understanding of the coupling between an open system and its environment. While many standard treatments lead to Lindblad equations, the underlying approximations are not always applicable and require detailed case-by-case studies. This theoretical focus session provides a platform discussing modern developments in the field in the regime of strongly interacting or driven open systems and their impact on relaxation timescales. We aim to enhance attention and trigger also experimental activity in the field of system-environment interactions and the induced relaxation timescales.

Coordinators: Gernot Schaller (Helmholtz-Zentrum Dresden-Rossendorf), Nikodem Szpak (Universität Duisburg-Essen)

Time: Monday 15:00–18:00 Location: CHE/0089

Topical Talk DY 12.1 Mon 15:00 CHE/0089
Markovian and non-Markovian approaches to quantum relaxation — •Heinz-Peter Breuer — Institute of Physics, University of Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany

Relaxation and decoherence processes in open quantum systems are often approximated by means of a Markovian evolution in which the open system irretrievably loses information to its surroundings, expressing the memoryless nature of the dynamics. However, strongly coupled open systems often exhibit a pronounced non-Markovian behavior distinguished by a flow of information from the environment back to the open system. This information backflow implies the presence of memory effects and represents the key feature of non-Markovian quantum dynamics. In the talk we will discuss fundamental physical concepts used to characterize and quantify non-Markovian relaxation dynamics in open systems, and present some applications to irreversibility and entropy production in nonequilibrium quantum thermodynamics.

Topical Talk DY 12.2 Mon 15:30 CHE/0089
Asymptotic relaxation in quantum Markovian dynamics — •Susana Huelga — Institute of Theoretical Physics, Ulm University, Germany

We investigate the long-time dynamics of generic time-dependent GKLS master equations and provide sufficient conditions such that the dynamics is asymptotically independent of the initial state. These conditions represent a natural extension of the Spohn-Frigerio theorem to the case of a time-dependent generator. To illustrate our results, we analyze a specific master equation for driven systems and connect our conditions to the microscopic Hamiltonian of system and environment. The case of a 3-level system is also treated in detail. A brief mention of the non-Markovian case is included, with specific focus on time-local master equations which are asymptotically in Lindblad form. These findings pave the way for the development of a more general theory of relaxation beyond the Markovian case.

Topical Talk DY 12.3 Mon 16:00 CHE/0089
Floquet engineering of open quantum Systems — •André Eckardt — Institut für Physik und Astronomie, TU Berlin, Berlin

In recent years, we have seen tremendous progress in the control of quantum systems by means of time-periodic driving. This includes the realization of effective time-independent Hamiltonians with interesting properties, such as artificial magnetic fields coupling to the motion of charge neutral particles in quantum simulators (e.g. of ultracold atoms in optical lattice or photons in superconducting circuits). Also phenomena without equilibrium counterpart, like chiral edge modes connecting Bloch bands with zero Chern number, have been investigated. Another paradigm for the control of quantum systems is reservoir engineering. Here a system is coupled to a controlled environment that is designed to either cool the system or to stabilize a non-equilibrium steady state of interest. I will report on recent theoretical work, where we combine both approaches in open Floquet systems. One motivation is to use dissipation in order to counteract unwanted heating, as it necessarily occurs in Floquet engineered systems, e,.g. for the preparation of Floquet engineered topological states of matter. The other motivation is the stabilization of interesting non-equilibrium steady states beyond the strict constraints of thermal equilibrium. Here I will discuss driving-induced non-equilibrium Bose condensation in high-temperature environments. Finally, I will also briefly address challenges arising when simulating open many-body quantum systems out of equilibrium and ideas how to tackle them.

15 min. break

Topical Talk DY 12.4 Mon 16:45 CHE/0089
Nonequilibrium thermodynamics of time-dependent quantum transport — •Janine Splettstoesser — Chalmers University of Technology, Gothenburg, Sweden

Quantum transport induced by time-dependent driving fields is not only of interest when considering the conductor's charge response. On the contrary, in recent years there has been strong interest in the thermodynamics and energetic properties of quantum conductors. By applying time-dependent driving fields to a conductor cyclic quantum heat engines can be implemented and quantum properties can be used to rapidly load and discharge so-called quantum batteries.

In this presentation, I will first show how different time-scales in the response of a quantum dot impact the (energy) decay of a quantum dot brought out of equilibrium. This is visible both in the relative entropy, where Coulomb interaction results in an anomalous decay referred to as Mpemba effect [1], as well as in the geometric properties of a slowly driven cyclic engine [2]. I will then show how the precision of time-dependently driven engines is bounded by the produced or dissipated power [3].

[1] J. Graf, J. Splettstoesser, J. Monsel, J. Phys.: Condens. Matter 37, 195302 (2025)
[2] J. Monsel, J. Schulenborg, Th. Baquet, J. Splettstoesser, Phys. Rev. B 106, 035405 (2022)
[3] L. Tesser, J. Balduque, J. Splettstoesser, arXiv:2509.07583 (2025)

Topical Talk DY 12.5 Mon 17:15 CHE/0089
Connecting time-nonlocal and time-local quantum master equations — •Maarten Wegewijs — Peter Grünberg Institut, Forschungszentrum Jülich, 52425 Jülich, Germany — Institute for Theory of Statistical Physics, RWTH Aachen, 52056 Aachen, Germany

A perhaps puzzling feature of open-system dynamics is that it admits both a retarded description via a *time-nonlocal* memory-kernel $\mathcal{K}$ and an *equivalent* time-convolutionless description by a *time-local* generator $\mathcal{G}$. This leads to a split in approaches to the problem of time scales in open quantum systems.

In this talk I discuss an elegant fixed-point relation $\mathcal{G} = \hat{\mathcal{K}}(\mathcal{G})$ that connects these two approaches directly, without first solving the respective quantum master equations for the dynamics ultimately of interest. As applications, I connect the distinct results (!) obtained when expanding in the same perturbation parameter and relate distinct timescales (!) obtained by approximations approaching the same, exact stationary state. The fixed-point relation is also explicitly related to quantum Markovianity as defined by completely-positive divisibility of the dynamics (Huelga, Rivas, Plenio): What generates the retardation of the memory kernel turns out to be precisely what defines the Markovian divisibility of the dynamics. Exact solutions of simple models of electron transport (resonant level) and atomic-decay (dissipative Jaynes-Cummings) illustate these findings.

[1] SciPost Phys. 7, 012 (2019)
[2] Phys. Rev. X 11, 021041 (2021)
[3] Phys. Rev. B 104, 155407 (2021)
[4] SciPost Phys. 12, 121 (2022)

[5] J. Chem. Phys. 161 (2024)

DY 12.6 Mon 17:45 CHE/0089

Coupling–energy driven pumping through quantum dots: The role of coherences — •Lukas Litzba[1], Gernot Schaller[2], Jürgen König[1], and Nikodem Szpak[1] — [1]Universität Duisburg-Essen, Duisburg, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany

We study the impact of off–resonant tunneling and coherences on the electron transport through quantum dots. We focus on two electron pump setups where first–order tunneling processes are suppressed and the pumping mechanism is exclusively driven by modulations of the coupling energy. For calculations we use an exact solution for a non–Coulomb interacting situation. The first setup is driven by a coupling and decoupling procedure of the quantum dot and the environment and the second setup by measurement–induced effects resembling the anti–Zeno effect. We show that both electron pumps are based on decoherence operations and modulations of the coupling energy and there is quantitative and qualitative agreement between them. Furthermore, we show that non–Markovian effects can increase the performance of the devices and are signatures for the importance of coherences in electron transport.