Lecture announcement for the winter semester 2025-2026

MaS Advanced Statistical Physics

Area of Specialization "Foundations of Quantum Technologies: Matter, Light and Information"

(Keywords: Irreversibility, non-Equilibrium, quantum Master, non-Markovian, kinetic equations, linear response)

Tuesdays 10-11:30 in K1TP

Modeling irreversible quantum systems

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Breaking a glass is an example of macroscopic irreversibility. We never observe the reversed motion. However, the fundamental equations of motion would allow for the reversed motion to occur. This seeming contradiction is resolved by the observation that the reversed motion is indeed possible, but it would be necessary to implement a very specific, coordinated initial condition for a huge number of degrees of freedom which is practically impossible to achieve.

In terms of friction in Newton's equation of motion, irreversibility is modeled macroscopically. Heat conduction and diffusion equations also describe irreversible processes. The same applies to transport equations such as the Boltzmann equation or calculation rules for dissipative transport quantities in linear response theory, where a fluctuation-dissipation theorem can be formulated. Irreversible quantum systems showing decoherence, dissipation and relaxation to stationarity are described very successfully by quantum master equations, which model the time evolution as a semigroup with a preferred time direction. In order to achieve thermodynamic equilibrium in a closed system with Hamiltonian dynamics, ideas of so called ergodicity in classical physics or eigenstate thermalization in quantum systems have been proposed despite the reversibility of the underlying equations of motion.

In this lecture course the above mentioned modelings are reported and put into context of a recently developed modeling of irreversible quantum systems incorporating also memory effects and initial correlations going beyond the semigroup approach. This relaxator Liouville modeling emerges from a systematic investigation of the conditions for macroscopic irreversibility with microscopic reversibility. It is based on the spectral content of the time evolution operator, the Liouville, for quantum states. The emergence of negative imaginary parts in the spectrum indicates relaxing processes with a preferred time direction. The usual differential equations of motion are reformulated via the Laplace transform as algebraic equations. The Laplace transform is known from electrical engineering as the appropriate way to discuss superpositions of relaxing oscillations with memory effects.

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