Instytut Fizyki Molekularnej Polskiej Akademii Nauk

Rozprawa doktorska

Nierównowagowa fizyka statystyczna układów kropek kwantowych: fluktuacje prądowe i termodynamika przepływu informacji

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Poznań 2019

Abstract

Nonequilibrium statistical physics of quantum dot systems: current fluctuations and thermodynamics of information flow

This dissertation is concerned with application of the new and rapidly developing framework of nonequilibrium statistical mechanics for the investigation of dynamics and thermodynamics of small systems far from thermodynamic equilibrium, and, in particular, the systems of quantum dots coupled to the leads. On the one hand, the goal of the thesis is to characterize the influence of the internal dynamics of the studied systems on fluctuations of currents flowing through them. On the other hand, the analysis of quantum dot systems is intended to provide insight into fundamental laws governing the dynamics and thermodynamics of physical phenomena occurring at the nanoscale.

The first part of the dissertation investigates the influence of microscopic dynamics of quantum dot systems on current fluctuations. In particular, it is focused on application of the framework characterizing the statistical distributions of the waiting times between the subsequent electron jumps. It is demonstrated that such distributions provide additional information about short-time dynamics of the analyzed systems (e.g., the coherent spin oscillations) in comparison with the quantities traditionally used to describe the current fluctuations, such as the Fano factor. Moreover, the new mathematical relations are derived, which relate different quantities characterizing the long-time and short-time fluctuations.

The next part of the thesis describes the influence of quantum coherence on performance of nanoscopic heat engines. It is demonstrated that the quantum coherence can reduce fluctuations of the power output of heat engines, thus enhancing the sta-

bility of their operation. This is because the power fluctuations in classical stochastic systems cannot be reduced below the certain bound, given by the recently discovered thermodynamic uncertainty relation. The thesis demonstrates, using the example of the quantum-dot-based thermoelectric generator, that this bound is not applicable to quantum systems.

The last part of the dissertation is concerned with the analysis of the connection between thermodynamics and the information theory. A shining example of such a connection is the operation of so called autonomous Maxwell demons, i.e., the systems in which one of the subsystems cools its environment and converts heat into work (seemingly breaking the second law of thermodynamics) due to feedback control of its dynamics by another subsystem. The previous research on such setups were limited to the classical regime. In this thesis, instead, the autonomous Maxwell demons is proposed, which mechanism of operation is based on the coherent spin dynamics. To describe its operation quantitatively, the generalized version of the second law of thermodynamics is derived which relates the local heat balance to the quantum information flow.

The results contribute to the better understanding of dynamics and thermodynamics of nanoscopic systems – not only quantum dots, but also, e.g., biomolecular systems or superconducting devices. This demonstrates that the analysis of nanoelectronic systems is a suitable starting point to gain insight into the physical phenomena occurring at the nanoscale and the fundamental laws governing them.