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Report on the PhD Thesis "Heat processes in non-equilibrium stochastic systems"
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Supervisor: Mgr. Karel Netočný, PhD, Charles University, Prague

Background
The presented PhD thesis deals with the topic of stochastic thermodynamics. This is a very active field of current research, investigating the theoretical description of small driven systems in which energy fluctuations are prevalent and cannot be neglected. In particular, also thermodynamic quantities like work and heat fluctuate. This is quite in contrast to classical thermodynamics, which, as a theory for macroscopic systems, is concerned with mean quantities. While classical thermodynamics has been developed in the 18th century to understand, control, and improve heat engines, a similar role might be played by stochastic thermodynamics for machines on the micro and nano-scale.

Summary of the thesis
The thesis is divided into seven chapters covering 178 pages. Following the short introduction, in chapters 2 and 3 the mathematical tools for the treatment of stochastic processes are introduced, which are needed later to study non-equilibrium systems governed by Markovian dynamics. These chapters demonstrate the candidate's excellent understanding of the mathematics and its application to physical problems. In chapter 3, the stochastic thermodynamics of small systems in equilibrium is reviewed. Chapters 4 to 6 present the actual research and some new results. In chapter 4, systems driven by non-potential forces are studied. The time evolution of the state probability distribution is investigated for a slow variation of external parameters and the effect on the work and heat fluctuations is determined. Based on the excess (reversible) heat in the quasi-static limit, a generalized heat capacity is defined. Several specific systems are studied in detail: a discrete two-level system, a discrete three-level system, and a single particle diffusing in a two-dimensional well and driven by a torque. These models are well chosen and clearly demonstrate the physical consequences of the theoretical results. Chapter 5 treats a special class of non-equilibrium processes, namely a periodic variation of the control parameter(s). These protocols are non-autonomous but the system relaxes into a quasi-stationary, periodically modulated, state. General results are obtained using Floquet's theorem and subsequently applied to a driven two-level system with two different choices for the transition rates. Finally, chapter 6 is devoted to systems with a time-scale separation between slow and fast degrees of freedom. This is an important issue since often we are interested only in the large-scale, slow behavior of the system. The thesis is concluded in chapter 7.

I found that the bibliography deserves some criticism since it is quite short (40 references) for a PhD thesis and does not reflect the variety of problems and number of people working in this field. There are works by others that connect with the topics treated in the thesis that are not cited.

Main results
As the main contribution I see the detailed discussion of mean work and heat for quasi-stationary processes, i.e., for processes due to a variation of external parameters that is slow compared to the intrinsic relaxation time. In particular,

both work and heat can be split into a “housekeeping” part and an excess part, where the latter captures the departure from thermal equilibrium. The thesis thus provides a nice and comprehensive framework to treat quasi-stationary processes in stochastic thermodynamics. A novel result is the demonstration of the usefulness of the generalized heat capacity. New results are also obtained for periodically driven systems, a class of protocols that has received comparably less attention so far.

Conclusion
The thesis is well structured and written in a clear and concise way. The length is appropriate. The candidate has proven the ability to conduct research in theoretical physics and to present his novel and relevant results to the scientific community. The latter is demonstrated by two publications in peer-reviewed journals and a third publication that is listed as “in preparation” in the bibliography. The bibliography could be more complete but still shows sufficient knowledge of the relevant literature in the field. The thesis thus meets all requirements and I, therefore, recommend it for defense and, after the successful defense, to award Mr. Jiří Pešek the academic degree of Doctor of Philosophy (PhD).

Sincerely,

Thomas Speck