PERIODIC THERMODYNAMICS OF MICRO- AND NANO-SYSTEMS

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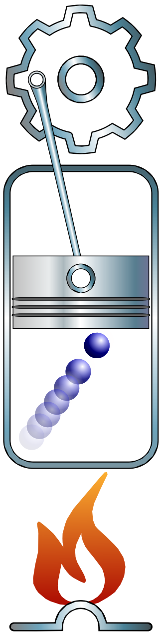

Figure 1: Otto engine with a single particle.

Thermodynamic cycles have always been a key-concept in the description of macroscopic machines such as Otto or Diesel engines. Modern experimental techniques now make it possible to implement such processes with micro- and nano-systems subject to periodic driving fields and temperature variations, see for example [1, 2].

Here, we develop a universal framework for the thermodynamic description of such systems [3, 4, 5]. Covering both, the classical and the quantum realm, our approach relies on the consistent formulation of the first and the second law in terms of time-independent affinities and fluxes. This scheme in particular leads to a systematic definition of generalized linear-response coefficients akin to conventional Onsager coefficients. Focusing on Markovian dynamics, we show that, first, these coefficients can be divided into an adiabatic part and a Green-Kubo type contribution containing deviations from adiabaticity. Second, the total coefficients obey a reciprocity relation, which traces back to microreversibility and can be regarded as an extension of the celebrated Onsager-Casimir symmetry. Third, we derive an additional constraint, which is significantly sharper than the second law and can not be obtained from time-reversal symmetry.

As a key-application, our theory allow exploration of the performance limits mesoscopic heat engines operating under linear-response condtions, see Fig. 1. Specifically, our previously derived constraints imply that such devices are subject to a general trade-off relation between power and efficiency. This result rules out the option of Carnot efficiency at finite power, a peculiar phenomenon, which is currently the subject of an active debate.

[1] V. Blickle, C. Bechinger *Realization of a micrometer-sized stochastic heat engine*. Nat. Phys. **8**, 143 (2011).

[2] J. Roßnagel, S. T. Dawkins, K. N. Tolazzi, O. Abah, E. Lutz, F. Schmidt-Kaler, K. Singer *A single-atom heat engine*. Science **352**, 325 (2015).

[3] K. Brandner, K. Saito, U. Seifert *Thermodynamics of Micro- and Nano-Systems Driven by Periodic Temperature Variations*. Phys. Rev. X **5**, 031019 (2015).

[4] M. Bauer, K. Brandner, U. Seifert *Optimal performance of periodically driven, stochastic heat engines under limited control*. Phys. Rev. E **93**, 042112 (2016).

[5] K. Brandner, U. Seifert *Periodic thermodynamics of open quantum systems*. Phys. Rev. E **93**, 062134 (2016).