Bounds on Efficiency and Power of thermoelectric Heat Engines with Broken Time-Reversal Symmetry

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A cornerstone result of classical thermodynamics states that the Carnot value is an upper bound on the efficiency of any heat engine as a direct consequence of the second law. Moreover, it is generally believed that this bound can be reached only in the quasi-static limit, which is inevitably accompanied by vanishing power output. This expectation, however, has recently been called into question by G. Benenti *et al.* [1]. Considering thermoelectric energy conversion in the presence of a magnetic field, they show that broken time-reversal symmetry might indeed lead to Carnot efficiency at finite power.

We scrutinize this exciting option, by investigating the simple but paradigmatic class of multi-terminal models, for which we derive a universal constraint on the Onsager coefficients depending only on the number of terminals and implying a stronger bound on efficiency than the bare second law [2,3]. Our new bound becomes, however, successively weaker as the number of terminals is increased and finally disappears when this number goes to infinity [3]. In a second step, we therefore investigate, whether not only efficiency but also power can be bounded. We present strong numerical evidence for the existence of an additional constraint bounding power to vanish at least linearly when the maximum efficiency is approached [5]. This result holds for an arbitrarily large number of terminals and thus finally rules out the option of Carnot efficiency at finite power for the multi-terminal set-up.

We illustrate our findings by a simple classical model utilizing the Nernst effect, within which the previously predicted bounds on efficiency can indeed be saturated for large magnetic fields and small fugacity in the thermochemical reservoirs [4].

[1] G. Benenti, K. Saito, and G. Casati, Phys. Rev. Lett. **106**, 230602 (2011)
[2] K. Brandner, K. Saito and U. Seifert, Phys. Rev. Lett. **110**, 070603 (2013)
[3] K. Brandner and U. Seifert, New J. Phys. **15**, 105003 (2013)
[4] J. Stark, K. Brandner, K. Saito and U. Seifert, Phys. Rev. Lett. **112**, 140601 (2014)
[5] K. Brandner and U. Seifert, to appear in Phys. Rev. E (2015)