MICROSCOPIC BROWNIAN HEAT ENGINES: A QUANTUM DYNAMICAL FRAMEWORK

S. Chaturvedi

School of Physics, University of Hyderabad, Hyderabad 500046, India, E-mail: scsp@uohyd.ernet.in

EXTENDED ABSTRACT

Inspired by a recent experimental work of Blickle and Bechinger [Nature, **8**, 143 (2011)] on a microscopic realization of the Stirling cycle through a colloidal particle in an optical trap, we develop a self contained formalism for describing the performance of microscopic Brownian heat engines like Carnot, Stirling and Otto engines modelled after a quantum harmonic oscillator in contact with a heat bath [quant-ph arXiv:1303.1233]. The appropriate combinations of isobaric, isochoric and isentropic steps involved in the three cycles considered here are achieved by contolling the 'spring constant' of the harmonic potential and the temperature of the heat bath. Our starting point is the master equation for describing the Brownian motion of a quantum harmonic oscillator obtained by Agarwal [Phys. Rev. A **4**, 739 (1971)]. This master equation can be cast into Langevin equations through the use of Wigner phase space description which in turn permit a convenient thermodynamic interpretation in a manner similar to that developed by Sekimoto [J. Phys. Soc. Jpn, **66**, 123 (1997)] in the classical context. The formalism developed here, besides reproducing the standard thermodynamics results in the steady state enables us to study the role dissipation plays in determining the efficiency of Brownian heat engines under actual laboratory conditions. In particular, we analyse in detail the dynamics associated with decoupling a system in equilibrium with one bath and recoupling it to another bath and obtain exact analytical results which are shown to have significant ramifications on the efficiencies of engines involving such a step. We also develop a simple yet powerful technique for computing corrections to the steady state results arising from finite operation time and use it to arrive at the thermodynamic complementarity relations for various operating conditions and also to compute the efficiencies at maximum power for the three engines cited above. Our principal results include (i) development of a self contained formalism for computing efficiencies of Brownian engines both in the classical as well as quantum contexts (ii) an exact analysis of the role of damping in the process of coupling the system to a bath at a higher temperature and its influence on the performance of the Stirling engine (iii) computation of the irreversible heat in isothermal processes and the derivation of complementarity relations (iv) a detailed analysis of the role of damping as well as finite time corrections on the efficiency of the Stirling engine at maximum power.