Jan Klaers

ETH Zürich

A minimalist nano-mechanical engine beyond the Carnot limit

Heat engines, as employed in cars, ships and airplanes, are everyday examples showing that heat can produce directed motion. The efficient conversion of thermal energy to mechanical work by an engine is, however, an ongoing technological challenge. Since the pioneering work of Carnot, it is known that the efficiency of engines is bounded by a fundamental upper limit - the Carnot limit. Nowadays, micro- and nanotechnological methods allow to test thermodynamics far away from the thermodynamic limit. Highly miniaturized forms of heat engines have been experimentally realized, where the working medium is represented by a single particle instead of 10^23 particles as in the macroscopic world. Theoretical studies suggest that the efficiency of such engines may overcome the standard Carnot limit by employing stationary, non-equilibrium reservoirs that are characterized by a temperature as well as further parameters, for example, quantum coherent, quantum correlated and squeezed thermal reservoirs. In a proof-of-principle experiment, we demonstrate that the efficiency of a minimalist nano-mechanical heat engine coupled to squeezed thermal noise is not bounded by the standard Carnot limit. Furthermore, a cycle process can be realized that allows to extract mechanical work from a single squeezed thermal reservoir. These results quantitatively test our understanding of non-equilibrium thermodynamics at small scales and provide a new perspective on the design of efficient, highly miniaturized engines.