On the efficiency of a Brownian heat engine

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A heat engine extracts a work operating between two heat baths at different temperatures T_H and $T_C(< T_H)$. The efficiency η of a heat engine is measured by the ratio of the extracted work to the absorbed heat from a hotter heat bath. According to the thermodynamic second law, it is bounded from above by the Carnot efficiency $\eta_C = 1 - T_C/T_H$ that can be achieved only by the reversible heat engines. There are two general statements concerning the efficiency of nonequilibrium heat engines: (i) The efficiency of a heat engine operating at the maximum power could be universal and given by $\eta_{EMP} = 1 - \sqrt{1 - \eta_C}$. This result is derived in so-called endoreversible heat engines. (ii) The prabability density for the efficiency of a heat engine with a time-symmetric protocol is minimum at $\eta = \eta_C$, that is to say, the Carnot efficiency is least probable. This result is derived for systems with bounded energy. In this talk, we introduce an exactly solvable model for a Brownian heat engine. When one varies model parameters, the model acts as a heat engine or a heat pump. We find that the efficiency at maximum power is given by the universal form $\eta_{EMP} = 1 - \sqrt{1 - \eta_C}$ even though the engine is not endoreversible. This result indicates that the proposed form of η_{EMP} is more universal than expected. Relying on the solvability, we can calculate the large deviation function for the efficiency. The analytic solution shows that the Carnot efficiency is not least probable. This exemplifies the importance of the energy fluctuations in nonequilbrium systems.