

Fluctuating thermodynamics in the Caldeira Leggett model - from the quantum mechanical to an effective Langevin description

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We compute the statistics of heat for classical and quantum particles in contact with collections of harmonic oscillators acting as thermal sources. The generating functions (GF) can be expressed exactly using the path integral approach, taking also into account the contribution to dynamics and heat statistics due to a time-dependent system-bath coupling. We explicitly verify that in the semiclassical limit there is a perfect matching between the quantum and classical statistics, and in the Ohmic case both models correspond to the counting statistics of a Langevin particle when the coupling contributions to the work are neglected. In the strong coupling regime we prove that the role of the system-bath interactions can be completely assessed by adopting new thermodynamically consistent equations for heat, work and internal energy at the trajectory level, the latter reducing to the usual Sekimoto characterization in the weak-coupling limit. The role of the quantum corrections to the classical limit are discussed and the quantum signatures in the heat distribution are identified using an analytical procedure. As a final result, all the path integrals are computed explicitly and a compact form of the steady-state heat GF for a system coupled to an arbitrary number of baths is given. Thanks to the quantum-classical correspondence proved in the first part, the analytic formula for the GF can be used to compute the exact statistics of the heat in all the cases mentioned above, from the Caldeira-Leggett model to the Zwanzig model (classical harmonic oscillators) and for a Langevin particle.