Non-Markovian quantum thermodynamics: second law and fluctuation theorems

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Abstract

We bring together Keldysh theory and quantum thermodynamics, by showing that a real-time diagramatic technique can provide a quantum equivalent of stochastic thermodynamics for non-Markovian quantum machines (heat engines, refrigerators, etc). Taking any interacting quantum system with arbitrary coupling to ideal reservoirs of electrons and bosons (phonons or photons), we identify symmetries between quantum trajectories and their time-reverses on the Keldysh contour. These lead to quantum fluctuation theorems the same as the well-known classical ones (Jarzynski and Crooks equalities, non-equilibrium partition identity, etc), but which hold whether the system's dynamics are Markovian or not. Hence, such systems obey the second law of thermodynamics on average, even if fluctuations may violate it. Our proof applies to systems with Kondo effects or other strong correlations, and to systems in superposition states or with time-dependent driving.
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