Functional approach to energy-exchange, application to the spin boson model for weak and strong coupling.

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Abstract
The emerging field of quantum thermodynamics aims to extend basic concepts of thermodynamics at the nanoscale. Indeed lowering the dimension of a system, fluctuations and quantum effects become crucial and classical thermodynamics cannot be simply applied. The question of how a small system exchanges heat and energy with a bigger one is very important both from technological and fundamental point of view. A deep understanding of heat exchange at the nanoscale is necessary in view of the realization of quantum devices such as quantum heat engines which could have great technological impact. Despite much recent efforts, the thermodynamics of quantum systems is still poorly understood, at least when compared to its classical counterpart. Here we aim to go a step forward towards a microscopic and rigorous description of heat exchange in quantum system. We consider a quantum system coupled to a thermal reservoir and the energy flows between them. We approach the problem with the path integral technique. In this framework we can write a general heat influence functional which embodies all the dissipative mechanisms and allows us to study heat processes. As an application, we concentrate on a two level system, described by the Hamiltonian $H_{\rm S} = -\frac{\Delta}{2}\sigma_x - \frac{\epsilon(t)}{2}\sigma_z$, where Δ is the tunneling amplitude and $\epsilon(t)$ describe a generic time-dependent external bias. The two level system is coupled to a thermal bath and we calculate, by means of the heat influence functional, the average heat and the heat power exchanged between them. We derive general expressions for the time evolution of these quantities. We investigate the system dynamics in a wide range of temperature, exploiting also memory effects in the so-called quantum noise regime. Here we found that quantum noise induces non-trivial contributions to the system dynamics and these can be observed in the time evolution of the average heat and heat power. We also extend our formalism to the strong coupling regime, where system and reservoir are strongly interacting, even in presence of an external time-dependent driving force. In such a case we can identify the different contributions to the energy exchange, as a function of the driving frequency

References

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