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Local ergotropy: connection with quantum phase transitions and its “extended”version

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A fundamental problem in quantum thermodynamics is to properly quantify the work extractable from out-of-equilibrium systems. While for closed systems maximum quantum work extraction is defined in terms of the ergotropy functional, this question is unclear in systems interacting with an environment. First approaches towards schematizations of open quantum batteries involved the use of the Lindblad master equation, under Markovian and weak-coupling assumptions [1]. Later, in order to consider arbitrary Hamiltonian coupling, the concept of local ergotropy was proposed in [2] as the maximum extractable work from the system-environment compound by applying a local unitary on the system.
Being interested in potential connections with many-body phenomena beyond the Markov approximation [3], we investigate a two-qubit open Rabi model, focusing on local ergotropy, within a parameter regime where a Berezinskii-Kosterlitz-Thouless dissipative phase transition occurs [4]. We define a protocol for charging, storing in quasi-decoherence free subspaces, and discharging the two-qubit system, interpreted as the working principle of an open quantum battery. We further examine the impact of the phase transition on local ergotropy and identify potential markers based on it.
From a more fundamental point of view, we unfold formal weaknesses in the definition of local ergotropy, such as the fact that it is not guaranteed to be non-increasing in time [5]. We then introduce the concept of extended local ergotropy by exploiting the free-evolution of the system-environment compound. At variance with the local ergotropy, the extended local ergotropy is greater by construction, is non-increasing in time, and activates the potential of work extraction in many cases. We provide examples based on the Jaynes-Cummings model, presenting practical protocols and analytic results that serve as proof of principle for the aforementioned advantages.
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Title

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