FINITE-TIME QUANTUM SZILARD ENGINE UNDER QUANTUM SHAPE EFFECTS

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ABSTRACT

The quantum Szilard engine provides a profound example establishing a rigorous link between quantum thermodynamics and quantum information. A single particle Szilard engine in a quantum domain with quantum measurements has been initially carried out by Zurek, demonstrating the consistency of measurement cost with the second law of thermodynamics [1]. The validity of Landauer's principle in a quantum Szilard engine in the absence of an explicit Maxwell's demon has also later been demonstrated [2]. While quasistatic variations give us maximum limits for work and heat exchanges, the finite-time analysis is important to capture the effect of quantum coherences. Recently, a finite-time quantum Szilard engine has been proposed to investigate the trade-off between power and efficiency, using a spin-1/2 particle as a working medium, with Maxwell's demon performing non-ideal quantum measurement to extract work [3]. The redistribution of energy levels during a time-dependent potential barrier insertion governed by a Markovian LGKS master equation is also analyzed through a finite-time Stirling engine [4]. Building upon these recent works, here we study the work extraction process of a quantum Szilard engine in finite time under size-invariant shape transformations [5]. Size-invariant shape transformation is a geometric technique of continuously changing the shape of an object without altering its sizes. It allows one to separate the influences of quantum size and shape effects and to examine the pure quantum shape effects in confined systems with quantized energy levels.

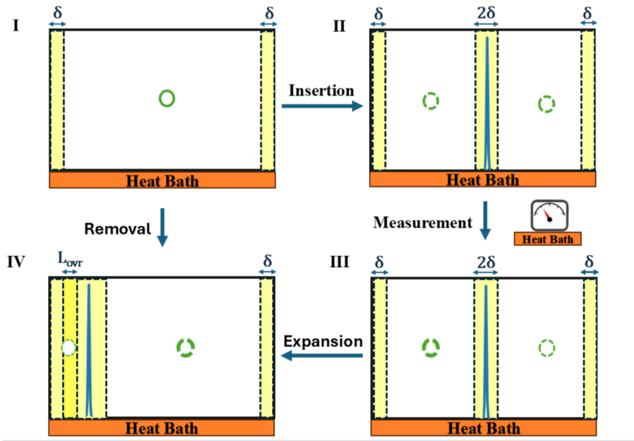

Figure 1: Representation of a quantum Szilard engine setup with boundary layers. I → II the insertion of a finite δ-function potential partition, II → III weak measurement is applied, and the particle is localized partially to each compartment with different probability density. III → IV the partition expands. IV → I the system returns to its initial state.

By altering the shape of the working medium without changing its sizes, we inspect the influences in the spectrum and the work output of the engine. We also explore the effect of localization due to weak measurement and its thermodynamic manifestation in comparison with the projective measurement. The system is assumed to be in contact with a thermal bath, which is modeled by a collection of harmonic oscillators. Dynamics of the Szilard engine, for the conditions that we outlined, is governed by a Markovian LGKS master equation. To perform a finite-time thermodynamic analysis of the engine, we solve the master equation numerically. The relevant thermodynamic quantities such as changes in internal energy due to heat and work contributions and changes in entropy are also calculated. Our work links the role of finite-time Markovian evolution on measurement-based heat engines with the unique contribution of operating it under the quantum shape effect.

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