Phaseonium-driven quantum thermodynamics: controllable reservoirs and efficiency enhancement

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Abstract: We investigate phaseonium-driven collision models as controllable quantum reservoirs, enabling tunable heating, cooling, and enhanced thermodynamic efficiency in cavity systems. This framework highlights coherence as a resource and provides a recipe for scalable quantum engine.

Quantum thermodynamics explores how genuinely quantum resources—such as coherence— can be exploited to control energy flows and enhance the performance of thermal machines. In this work, we consider a system of one or more optical cavities interacting sequentially with a beam of three-level atoms prepared in a coherent superposition (phaseonium) [1]. Within the collision model formalism, each interaction step is described by a unitary map followed by a partial trace over the ancilla, leading to a discrete-time evolution of the system.

A key result is that phaseonium atoms act as non-thermal reservoirs with tunable effective temperature, determined by their coherence phase and population imbalance [2]. In particular, the steady state of a cavity corresponds to a Gibbs state with an effective temperature which can be continuously controlled via the coherence phase of the ancillas.

Building on this framework, we further show how phaseonium can be employed as a quantum fuel for an optomechanical engine [3], in a setup shown in Figure 1. Remarkably, quantum coherence enables efficiency enhancements beyond classical thermal limits.

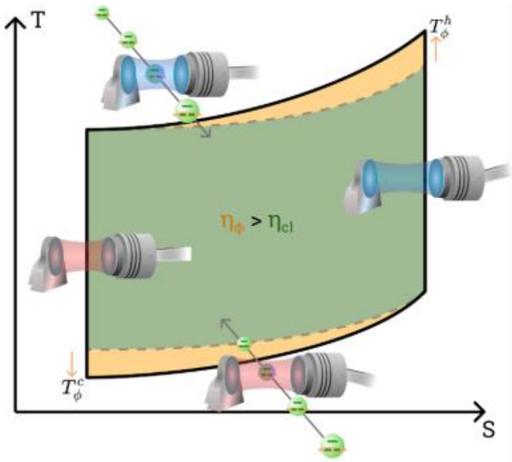

Fig. 1 Thermal engine setup and T-S diagram. The engine is a cavity field with one movable mirror acting as a piston. Two different streams of phaseonium atoms act as quantum baths to push the temperature over the classical limits, achieving better efficiency.

A central conceptual message emerging from these works is that quantum coherence plays the role of a thermodynamic control parameter, allowing one to engineer environments.

References

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