UNCONVENTIONAL THERMODYNAMIC SPONTANEITY DUE TO NONUNIFORM LEVEL SCALING

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ABSTRACT

Thermodynamics of quantum confined systems is different than their classical counterparts due to quantum size and shape effects. While quantum size effects cause effects like loss of extensivity of thermodynamic properties, the quantum shape effects cause even more unconventional effects including classically inconceivable thermodynamic behaviours, such as spontaneous transitions into lower entropy states, temperature-dependent work exchanges, cooling by adiabatic compression or heating by adiabatic expansion, and net work extraction occurring at the cold side (as opposed to the hot side) in thermodynamic cycles [1,2].

Here we consider a quantum particle confined in a nested domain (red and blue regions) like the one shown in Figure 1a. Both outer and inner square boundaries are impenetrable for the particle. The inner square is free to rotate, which allows one to control the shape of the domain with the shape parameter θ rotation angle, without changing the sizes (volume, area, etc.) of the domain. This technique of generating a specific type of geometric coupling between the energy levels of a quantum system called the size-invariant shape transformation [3]. Unlike global transformations of the system parameters, which affect all energy levels uniformly, local transformations, such as shape, can modulate specific regions of the spectrum in a nonuniform manner.

We investigate the variations of thermodynamic quantities, such as free energy, entropy and internal energy, under quantum shape effects. We observe that entropy of the system decreases spontaneously due to the nonuniform level scaling. We explain the fundamental reason behind this phenomenon by introducing a novel effect called the quantum thermal avalanche [3]. Furthermore, we explore the possibility of leveraging the effect in a two-level quantum systems and show that it is possible to exploit the nonuniform level scaling even in the simplest nontrivial quantum systems [4].

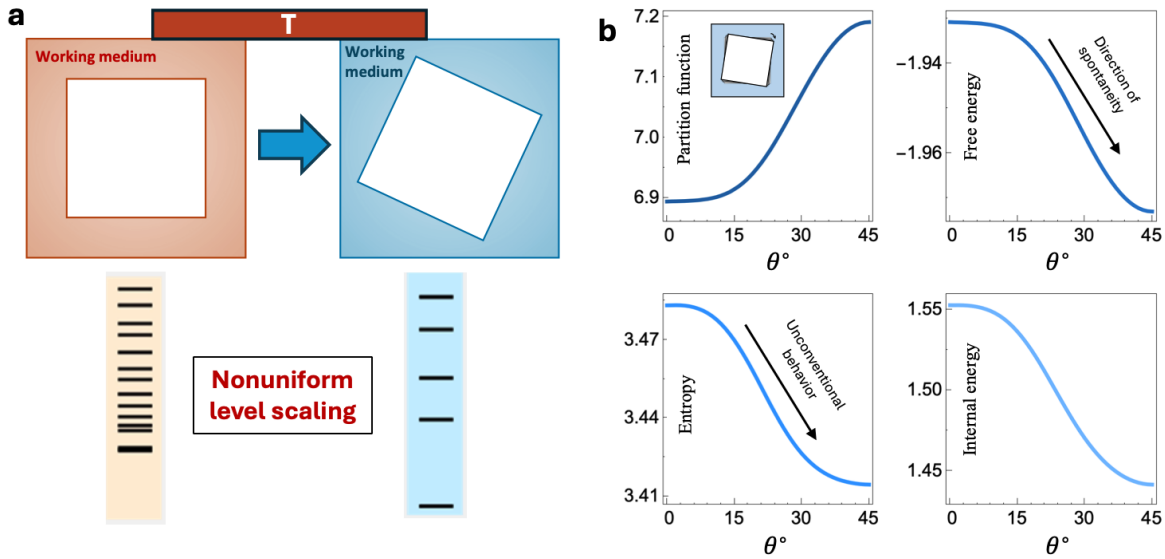

Figure 1: (a) Size-invariant shape transformation causes a nonuniform level scaling in the energy spectrum of the quantum particle confined in the working medium. Rotation angle of the inner object determines the shape of the confinement domain by keeping the sizes fixed. (b) Variation of the thermodynamic quantities under a quasistatic and isothermal size-invariant shape transformation. Entropy of the system reduces in the direction of thermodynamic spontaneity, which is a hallmark of the quantum shape effect.

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