Abstract

The ansatz of steepest entropy ascent (SEA) has been recently identified as the fourth law of thermodynamics. The law describes a system's evolution from an out-of-equilibrium state toward the globally unique stable equilibrium state of maximum entropy. The SEA ansatz sets the second law of thermodynamics as a foundation to merge mechanics and thermodynamics. We present a brief introduction to the fundamental tenets of the theory and provide the underlying principles contributing to formalism. SEA equation of motion is highly nonlinear; its exact analytical solutions are limited and available only for some very special cases. We have successfully developed an approximate analytical tool called the fixed Lagrange's multiplier (FLM) method to help us analytically solve the two-level and higher dimensional systems.

Quantum walks are used as a universal model of computation. Using this model, we analyze a single component $N-$level system and apply our FLM scheme to solve the SEA equation of motion analytically. A comparison of the solution obtained using FLM, and the complete numerical solution is presented, and we notice strong agreement. Regions of maximum entropy production rate in agreement with the SEA have been identified.

To extend the SEA analysis to simple composites involving two qubits, we need analytical roots and relevant results for the case of four-level Bloch vector formalism. We present a general framework for the characterization of $N-$level Bloch parametrization. We provide analytical roots for the $N = 3$ level and completely parametrized roots for the $N = 4$ level. We also provide a framework for finding an analytical trace of general operators in this representation.

Lastly, we address the problem of no-signaling in a nonlinear quantum theory. It has been well established in the literature that a nonlinear theory of quantum mechanics allows for faster-than-light communication (signaling) between two noninteracting parts of a composite system. However, we show that SEA is built to respect no-signaling. We present the equation of motion for composite systems. We consider the cases of separable composites and nonseparable entangled/mixed composites in the form of Bell diagonal states. Our results confirm that the SEA is a valid theory involving nonlinear dynamics that respects no-signaling criteria and presents a fundamental approach to the problem of decoherence modeling for open and closed quantum systems.

Keywords: Fourth law of thermodynamics, Steepest entropy ascent, Spontaneous decoherence, Entropy generation, Nonequilibrium dynamics, Bloch representation, No-signaling, Nonlinear quantum theory