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A Cavity Optomechanics Approach to Non-Equilibrium Thermodynamics

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Abstract

The study of heat, work, and temperature, as well as their relationships, in large systems typically restricted to equilibrium or near equilibrium states is an essential subfield of physics known as classical thermodynamics. On the other hand, the majority of natural systems are not in thermodynamic equilibrium, or states that are not in equilibrium. Although nonequilibrium thermodynamics was developed more than a century ago to comprehend nonequilibrium phenomena like the measure of irreversibility, it is still a work in progress rather than a well-established field.

Keywords: Thermodynamics • Electromagnetic • Optomechanics

Introduction

This article focuses on recent advances in small-system nonequilibrium thermodynamics. The fields of stochastic thermodynamics and quantum thermodynamics, depending on whether the fluctuations are thermal or quantum, arise when the size of a system decreases, the impact of its surroundings increases, and the fundamental fluctuations become fundamentally more significant, frequently quite far from equilibrium. Among the fascinating aspects of stochastic and quantum thermodynamics are fluctuations theorems, their relationship to quantum information, and stochastic/quantum thermodynamic machines. As a result of advancements in material science and laser technology, a variety of platforms, such as superconducting circuits, cavity optomechanical systems, and cold atoms, trapped ions, biological molecules, have been developed for studying stochastic and quantum thermodynamics [1,2].

Literature Review

Cavity optomechanics, which uses radiation pressure to link mechanical motions and electromagnetic degrees of freedom, holds promise for both fundamental and applied research. One fixed and one vibrating end mirror in a prototype cavity optomechanical system. The optical cavity increases the radiation pressure force and provides a feedback mechanism for controlling the mechanical resonator's motion at the macroscopic and mesoscopic scales. In the field of cavity optomechanics, remarkable advances include ultrasensitive motion detections, ground-state cooling of mechanical resonators, and quantum-level manipulation of photons and phonons [3].

It has recently been established that cavity optomechanics is an excellent platform for studying nonequilibrium thermodynamics. Underdamped operation and real-time single trajectory measurements are made possible by cavity optomechanical systems, which combine highly sensitive optical detection with high-quality mechanical resonators in an optical cavity. Cavity optomechanical systems, on the other hand, are able to achieve motional quantum ground state and are highly controllable and scalable thanks to the optomechanical interaction. This makes it possible for researchers to investigate the underlying physical mechanisms under a variety of parameter conditions. We focus on the experimental results of the most recent developments in cavity optomechanical systems' nonequilibrium thermodynamics in this article. There are four topics covered in nonequilibrium thermodynamics: fundamental thermodynamic principles, physical phenomena, and practical applications [4].

Discussion

Entropy production is a crucial physical quantity in thermodynamics that is closely related to the fundamental thermodynamic laws. A measure of irreversibility, entropy production can be produced by any finite-time thermodynamic process. The operation of heat engines, information thermodynamics, heat transport, and fluctuation theorems are all closely related to it. One of the most crucial tasks in nonequilibrium thermodynamics is therefore evaluating the production of irreversible entropy. A mesoscopic mechanical resonator's nonequilibrium thermodynamics were recently examined in light of the effect of weak continuous measurements. This system takes into account the effects of both optical and phononic environments thanks to the coupling of a nanomechanical resonator to an optical cavity. The position of the mechanical resonator is continuously monitored using homodyne measurements on the output optical field. Entropy production at the level of individual quantum trajectories can be characterized using the phase-space formalism and state retrodiction techniques [5].

The thermodynamics generalization of fluctuation theorems can be applied to small nonequilibrium systems. They can be applied to a wide range of nonequilibrium situations because they are equalities to the probability distribution functions of thermodynamic quantities that are primarily related to the production of entropy. The Jarzynski equality and Crooks relation, which reformulated the inequality of the second law into equalities and revealed the universal laws that the fluctuating thermodynamic variables must obey in processes that are arbitrarily far from equilibrium, are two examples of various forms of fluctuation theorems that have been developed over the past two decades. Biomolecules, colloidal particles, and electric circuits are just a few examples of systems where fluctuation theorems have been demonstrated. An overdamped Langevin equation is used to describe the majority of these experiments. Extending fluctuation theorems to the underdamped regime and quantum systems is feasible thanks to the advantages of optomechanical systems [6].

The transient fluctuation theorem, differential fluctuation theorem, and the fluctuation theorem with fast control are just a few examples of the various situations in which the fluctuation theorems in levitated optomechanical systems have been investigated by various groups. The optomechanics physics does not necessarily prohibit these experiments from using a cavity. The radiation pressure interaction is typically much stronger in cavity optomechanical systems than it is in free-space devices. The levitated nanoparticle has recently been laser-cooled into its quantum ground state of motion within an optical cavity. This makes it possible to study quantum motional states and nonequilibrium thermodynamics in cavity optomechanical systems with levitated particles in the future.The transfer of thermal energy from a warmer to a cooler object is a fundamental thermodynamic phenomenon known as heat transfer. Radiation, convection, and conduction are all well-known fundamental means of transferring heat.

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The investigation of heat transfer in small nonequilibrium systems has recently emerged as a burgeoning field of inquiry. At the nanoscale and atomic scale, novel forms of heat transfer may exist. Fong et al. observed phonon heat transfer through quantum fluctuations across a vacuum. However, a number of issues, including communication with phonons, energy harvesting, and heat dissipation in electronic devices, all involve small-scale manipulation of heat transfer. Numerous phononic devices are made possible by the ability to control heat flow. In quantum correlated spins, the reversal of heat flow has been demonstrated. Optomechanical arrays have been used to investigate heat diffusion. Optomechanical cooling has been thought of as using a heat valve to control the flow of heat between the hot bath and the cold bath. Breaking the time-reversal symmetry in an array of optomechanical cavities and modulating the dynamical back action in a membrane-in-the-middle system has led to the proposal of nonreciprocal heat flow manipulation [7-10].

Conclusion

It makes sense to investigate heat transfer in a non-equilibrium system by contacting multiple thermal baths with multiple mechanical resonators because heat flux is typically driven by a thermal gradient. In a two-membrane cavity optomechanical system, a novel mechanism for the transport of phonon heat has recently been developed. These are just a few of the system's unique benefits: It is made up of two nanomechanical resonators whose properties, like mechanical frequency and bath temperature, can be changed in a variety of ways; because the mechanical resonators are coupled by the cavity field, the interacting range could theoretically be infinitely long and the coupling strength could be adjusted optomechanically; Using an optical method, the trajectories of two resonators can be independently monitored in real time with very high sensitivity.

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Conflict of Interest

None.

References

1. Seifert, Udo. "Stochastic thermodynamics, fluctuation theorems and molecular machines." *Rep Prog Phys* 75 (2012): 126001.
2. Ciliberto, Sergio. "Experiments in stochastic thermodynamics: Short history and perspectives." *Phys Rev* 7 (2017): 021051.
3. Goold, John, Marcus Huber, Arnau Riera and Lídia Del Rio, et al. "The role of quantum information in thermodynamics-a topical review." *J Phys A Math Theor* 49 (2016): 143001.
4. Martínez, Ignacio A, Édgar Roldán, Luis Dinis and Raúl A. Rica. "Colloidal heat engines: A review." *Soft Matter* 13 (2017): 22-36.
5. Pekola, Jukka P. "Towards quantum thermodynamics in electronic circuits." *Nat Phys* 11 (2015): 118-123.
6. Peterson, R. W, T. Purdy, N. S. Kampel and R. Andrews, et al. "Laser cooling of a micromechanical membrane to the quantum backaction limit." *Phys Rev Lett* 116 (2016): 063601.
7. Teufel, John D, Tobias Donner, M. A. Castellanos-Beltran and Jennifer W. Harlow, et al. "Nanomechanical motion measured with an imprecision below that at the standard quantum limit." *Nat Nanotechnol* 4 (2009): 820-823.
8. De Cooman, Gert. "Belief models: An order-theoretic investigation." *Ann Math Artif Intell* 45 (2005): 5-34.
9. Lu, Shuaihua, Qionghua Zhou, Yilv Guo and Yehui Zhang, et al. "Coupling a crystal graph multilayer descriptor to active learning for rapid discovery of 2D ferromagnetic semiconductors/half-metals/metals." Adv Mater 32 (2020): 2002658.
10. Miyazato, Itsuki, Yuzuru Tanaka and Keisuke Takahashi. "Accelerating the discovery of hidden two-dimensional magnets using machine learning and first principle calculations." *J Phys Condens Matter* 30 (2018): 06LT01.

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