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Bosonic thermodynamics: Linear versus nonlinear interactions

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We carried out a quantum thermodynamic analysis of linear versus non-linear interactions in bosonic systems (phonon, photons, etc). We show that linear dynamics (e.g. linear optics) imposes a relation that is more general than the second law of thermodynamics: for modes undergoing a linear evolution, the full mean occupation number, i.e., the photon number for optical modes, does not decrease, provided the evolution starts from a (generalized) diagonal state. This relation connects to noise increasing (or heating), is akin to the second law, and holds for a wide set of initial states. We show that heating can be reversed via nonlinear interactions between the modes. They can cool, i.e., decrease the full mean occupation number and the related noise, an equilibrium system of modes provided their frequencies are different. Such an effect cannot exist in energy cooling, where only a part of an equilibrium system is cooled. We describe the cooling setup via both efficiency and coefficient of performance and relate the cooling effect to the Manley-Rowe theorem in nonlinear physics and electrodynamics. Together with noise also the Bose entropy of modes increases during a linear evolution, though this relation imposes additional limitations on the initial states and on linear evolution. We deduce from this result that the formation of Bose-Einstein condensate is impossible in a closed system undergoing linear evolution if this condensate was not present in the system initially. We conclude that non-linear interactions in bosonic systems is an important thermodynamic resource.

Theme

Theme 2. Quantum effects in energy processes and materials

Primary author: ALLAHVERDYAN, Armen (Alikhanyan National Laboratory)

Presenter: ALLAHVERDYAN, Armen (Alikhanyan National Laboratory)

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