Irreversible Entropy Production in Quantum Systems Out of Equilibrium

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Abstract

Every finite-time transformation results in some production of entropy, which signals the occurrence of irreversibility. Quantifying the amount of irreversible entropy produced is a goal of paramount importance. It is a key quantity for the characterisation of non-equilibrium processes, and its minimisation improves the efficiency of thermal machines. So far, nanoscale systems have been used for the experimental study of classical out-of-equilibrium thermodynamics. At the same time, significant success has been achieved recently in operating nanoscale systems fully in the quantum regime, thus offering a unique possibility to test the non-equilibrium thermodynamic framework in unexplored working conditions. However, to date irreversible entropy production arising from quantum dynamics has not been experimentally investigated. We measure the rate of entropy production in a non-equilibrium steady-state (NESS) for two different experimental open quantum systems, a micro-mechanical resonator and a Bose-Einstein condensate (BEC) coupled to a high-finesse cavity.

We compare the experimental data to the predictions of a framework that we develop for the open dynamics of coupled quantum harmonic oscillators, demonstrating how they captures key features of our setups, such as the cooling of the mechanical resonator and signatures of a structural quantum phase transition in the condensate. Our work demonstrates the possibility to explore non-equilibrium thermodynamics in driven mesoscopic quantum systems, and paves the way to a systematic experimental assessment of the implications of out-of-equilibrium processes on such systems.

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