Thermodynamics of quantum time crystals

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Time-translation symmetry breaking is a mechanism for the emergence of non-stationary many-body phases, so-called time-crystals, in Markovian open quantum systems. Dynamical aspects of time-crystals have been extensively explored over the recent years. However, much less is known about their thermodynamic properties, also due to the intrinsic nonequilibrium nature of these phases. Here, we consider the paradigmatic boundary time-crystal system, in a finite-temperature environment, and demonstrate the persistence of the time-crystalline phase at any temperature. Furthermore, we analyze thermodynamic aspects of the model investigating, in particular, heat currents, power exchange and irreversible entropy production. Our work sheds light on the thermodynamic cost of sustaining nonequilibrium time-crystalline phases and provides a framework for characterizing time-crystals as possible resources for, e.g., quantum sensing. Our results may be verified in experiments, for example with trapped ions or superconducting circuits, since we connect thermodynamic quantities with mean value and covariance of collective (magnetization) operators.

[1] Federico Carollo, Igor Lesanovsky, Mauro Antezza, Gabriele De Chiara, arXiv:2306.07330