Heat-Bath Algorithmic Cooling with Thermal Operations

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Heat-Bath Algorithmic Cooling is a technique for producing pure quantum systems by utilizing a surrounding heat-bath. Here we connect the study of these cooling techniques to the resource theory of thermal operations, enabling us to derive provably optimal cooling protocols under a variety of experimental restrictions on the available control. For qubit systems, we find that a surprisingly simple, optimal protocol consisting of repeated application of a Pauli X unitary and a thermal operation can achieve purity converging exponentially quickly to one. What is more, this thermal operation can be well approximated using a Jaynes Cummings interaction between the system and a single thermal bosonic mode and we consider experimental implementations of this. In addition, we investigate the role of quantum coherence and non-Markovianity in cooling protocols and extend our results to higher dimensional systems. Finally, by considering the role of correlations with auxiliary systems in cooling, we show that purity arbitrary close to one can be achieved in a fixed number of operations. Our results serve to find practical applications for the resource theoretic approach to quantum thermodynamics and suggest relevant experimental implementations.