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Fundamental Precision Limits in Finite-Dimensional Quantum Thermal Machines

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Enhancing the precision of a thermodynamic process inevitably comes with a thermodynamic cost. This idea was recently formalized as the thermodynamic uncertainty relation, which states that the lower bound on the relative variance of thermodynamic currents decreases as entropy production increases. From another perspective, this relation suggests that if entropy production could become infinitely large, the lower bound on the relative variance could approach zero. However, achieving infinite entropy production is clearly impossible in practice. This implies that physical constraints impose fundamental limits on precision, independent of the system's dynamics. In this work, we derive such fundamental precision limits for open quantum thermal machines with finite-dimensional systems and environments. Crucially, these bounds depend only on the initial configuration and not on the dynamics. Using a quantum battery as a case study, we show that these fundamental limits reveal a trade-off between the amount of stored energy and the charging precision.

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