Thermodynamics of a minimal algorithmic cooling refrigerator

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Setup: Heat-Bath Algorithmic Cooling in an NV Center

— Heat-Bath Algorithmic Cooling (HBAC)

What is it?
1. Protocol for initializing pure qubits for computation.
2. A thermodynamic device: a refrigerator

— Our Work

Goals:
1. **Improve & Explain** the model behind an experiment that achieves the HBAC cooling limits. ¹
2. **Thermodynamic analysis** of HBAC.

— Processes

Central electron spin e⁺:
1. Interaction mediator in Compression step,
   \[ U: \begin{pmatrix} 1 \text{0} \text{0} \end{pmatrix} \rightarrow \begin{pmatrix} 0 \text{1} \text{1} \end{pmatrix}. \]
2. Thermal bath in the Refresh step,
   \[ \rho_{tr} \rightarrow \text{tr}_{tr}(\rho_{tr}) \otimes \rho_{r}(T_h). \]

Theory vs Experiment

1. Thermodynamic performance matches the experiment (see Power and COP).
2. Maximal coefficient of performance maintained near cooling limits (compare with Fig. 1b).
3. Spin-off: maximal power achieved under protocol \( \theta = \theta_n \).

Key results

1. Generalized cooling limits
   \[ \zeta_1(\infty) = \frac{\epsilon_2 + \epsilon_3}{1 + \epsilon_2 \epsilon_3}. \]
2. Model better fits experimental data.
3. Demonstration that HBAC can achieve the Carnot fundamental COP bounds of cooling.