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Toward Quantum Computing Phase Diagrams of Gauge Theories with Thermal Pure Quantum States

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Sign problems in Monte Carlo simulations have long hindered studies of phase diagrams of lattice gauge theories (LGTs) at finite densities. Quantum computation of LGTs does not encounter sign problems, but preparing thermal states needed for a complete phase-diagram analysis on quantum devices is a difficult and resource-intensive process. Thermal Pure Quantum (TPQ) states have been proposed in recent years as an efficient method to reliably estimate thermal expectation values on a quantum computer. We propose a new form of TPQ states, called Physical Thermal Pure Quantum (PTPQ) states, to quantum compute thermal expectation values and non-equal time correlation functions of LGTs at finite temperature and density. We illustrate the approach by computing the chiral phase diagram of a toy theory accessible to near-term quantum hardware, 1+1 dimensional $\mathbb{Z}_2$ LGT coupled to staggered fermions, and analyze the resource requirement of the associated quantum algorithms. Our approach may open new paths forward in simulating the phase diagram of strong interactions in nature using the ever-improving quantum computers.

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