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Bosonic vs. Fermionic Matter in Quantum Simulations of Gauge Theories

Quantum link models extend lattice gauge theories beyond the traditional Wilson formulation and present promising candidates for both digital and analog quantum simulations. Fermionic matter coupled to quantum link gauge fields has been extensively studied, revealing a phase diagram that includes transitions from the columnar phase in the quantum dimer model to the resonating valence bond phase in the quantum link model, potentially passing through a disordered liquid-like phase. In this study, we investigate the model coupled to hardcore bosons and identify a similar phase structure, though with a more intricate mixture of phases around the transition. Our analysis reveals that near the transition region, a narrow and distinct ordered phase emerges, characterized by gauge fields forming plaquette configurations with alternating orientations, which is then followed by a thinner, liquid-like regime. This complexity primarily stems from the differences in particle statistics, which manifest prominently when the matter degrees of freedom become dynamic. Notably, our findings suggest that bosons can effectively replace fermions in lattice gauge theory simulations, offering solutions to the challenges posed by fermions in both digital and analog quantum simulations.

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