Variational Quantum Algorithms for Ground-State Properties and Analysis of the spin-$\frac{1}{2}$ Kagome Heisenberg Model

Abstract

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Determining the ground state of the Heisenberg Antiferromagnet (HAFM) on the Kagome lattice remains a significant challenge due to its geometric frustration and highly entangled nature. Classical computational methods, such as exact diagonalization and tensor networks, struggle to scale efficiently, restricting access to larger system sizes. The exponential growth of the Hilbert space, coupled with a nearly degenerate low-energy spectrum, limits the accuracy of classical approximations, leaving fundamental properties such as the energy gap and correlation functions difficult to resolve.

This work presents a Variational Quantum Eigensolver (VQE) framework that employs a symmetry-preserving ansatz designed to encode XXYYZZ interactions and frustration effects. By explicitly incorporating the symmetries of the Kagome lattice, the ansatz enhances optimization efficiency. To mitigate challenges such as barren plateaus, the approach leverages stabilizer-based initialization and iterative energy minimization, refining cost functions for improved extraction of spin gaps and correlation functions. Additionally, Variational Quantum Deflation (VQD) is utilized to investigate excited states, providing deeper insight into the system's low-energy structure.

By integrating quantum variational methods with a symmetry-aware design, this study explores the feasibility of near-term quantum hardware in addressing strongly correlated lattice models, marking a step toward quantum advantage in frustrated quantum magnetism.