Abstract

While magnets typically exhibit long-range magnetic order at low temperatures, systems with frustration can host a state known as a quantum spin liquid (QSL), which lacks magnetic order even in its ground state. QSLs exhibit remarkable properties, such as topological order and fractionalized excitations, and have consequently garnered significant attention in the field of condensed matter physics. The history of QSL research dates back to the resonating valence bond (RVB) state proposed by Anderson. The RVB state has been investigated as a potential parent phase for superconductivity in cuprates. Mean-field theories have suggested that carrier doping into such states could induce exotic superconductivity. A major breakthrough in the study of QSLs was the introduction of the Kitaev model, an exactly solvable model that realizes a QSL ground state. Analogous to the RVB case, carrier doping into the Kitaev spin liquid has been explored, with mean-field analyses predicting the emergence of exotic superconducting phases, including topological superconductivity. However, recent numerical studies have presented negative results regarding the emergence of superconductivity via carrier doping. These findings imply that alternative approaches must be explored to achieve a superconducting state in the carrier-doped Kitaev spin liquid.

In this study, as an alternative approach, we numerically investigate the magnetic properties and the potential emergence of superconductivity induced by carrier doping in the Kitaev-Heisenberg ladder model with anisotropic interactions and hoppings. Using the exact diagonalization, density matrix renormalization group, and variational uniform matrix product state method, we construct global phase diagrams for the undoped system of two distinct ladder geometries consisting of 4-site and 6-site plaquettes. We identify a variety of magnetic phases, including the Kitaev spin liquid phases, and discovered a rung triplet phase, which is firstly found state in the context of Kitaev physics. Subsequently, we evaluate a two-hole binding energy and superconducting correlation functions in the carrier-doped system. Our analysis reveals the signature of superconductivity in the spiral and rung singlet phases of the 4-site plaquette model, as well as the spiral, stripy, Néel, and zigzag phases of the 6-site plaquette model. These results provide implications for an emergence of superconductivity in the doped Kitaev-Heisenberg model on a honeycom lattice, and theoretical guidance for the exploration of exotic

superconductivity in Kitaev candidate materials.