

Emergent Phenomena in Quantum Materials: The Interplay of Dilution, Disorder, and Correlations

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We explore emergent quantum phenomena in correlated and topological materials under the influence of dilution and disorder. We first investigate a diluted one-band Hubbard model using semiclassical Monte Carlo calculations on a simple cubic lattice. This work demonstrates that site dilution can induce an antiferromagnetic metallic state via percolative conduction, thus providing a route to engineer new antiferromagnetic metals for spintronics. Next, we examine the stability of quantum skyrmions under random bond disorder in a Heisenberg model on the square lattice with Dzyaloshinskii–Moriya interactions, employing the neural network quantum states technique. We find that while disorder destabilizes the skyrmions, it paradoxically enhances local quantum entanglement. Finally, we analyze the nature of one-dimensional topological insulators and their long-range ordering in the presence of correlations by utilizing exact diagonalization method, detailing the evolution of edge states and spin correlations. Collectively, these results show the complex, often constructive, interplay between dilution, disorder, and correlations in tuning ground states, inducing novel transport properties, and stabilizing quantum phases in these materials.