Skyrmionic qubits stabilized by Dzyaloshinskii-Moriya interaction as platforms for qubits and quantum gates

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Quantum computation departs from the classical paradigm of deterministic, bit-based processing by exploiting inherently quantum phenomena such as superposition and entanglement. We propose a framework for qubit realization based on skyrmionic states stabilized by the Dzyaloshinskii–Moriya interaction (DMI) in two-dimensional spin lattices [1]. The model incorporates competing exchange interactions, perpendicular magnetic anisotropy, and Zeeman coupling, and is solved via exact diagonalization under periodic (PBC) and open boundary conditions (OBC). A quantum skyrmionic phase emerges under PBC within a parameter space defined by DMI strength, exchange, external field, and anisotropy, whereas OBC favor classical-like, topologically protected skyrmions. Quantum logic gates (Pauli X, Y, Z, and Hadamard) are implemented for both skyrmion types. Energy density and entanglement entropy analyses reveal that quantum skyrmions are susceptible to DMI-driven decoherence and reduced gate fidelity, while classical-like skyrmions retain enhanced stability. Exact simulations of qubit dynamics, including drive effects and Lindblad decoherence, demonstrate tunable anharmonic energy levels and coherent Bloch-sphere manipulation, positioning these skyrmionic states as promising candidates for qubit implementation. Overall, the Dzyaloshinskii–Moriya interaction plays a dual role, stabilizing skyrmionic qubits while simultaneously inducing decoherence during gate operations. Finally, we outline a forward-looking paradigm in which skyrmionic qubit architectures may be integrated with skyrmion-based neuromorphic architectures, enabling neuromorphic logic to augment and actively reinforce the stability of topological skyrmionic qubits.

Reference
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