Confinement-Tunable Synthetic Gauge Fields and Floquet Topological Phenomena in a Driven Quantum Wire Qubit

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Theoretical analysis demonstrates that a spin qubit in a parabolic quantum wire, when driven by a bichromatic field, exhibits a confinement-tunable synthetic gauge field leading to novel Floquet topological phenomena. The underlying mechanism for topological protection of qubit states against time-periodic perturbations is presented. The analysis reveals a confinement-induced topological Landau-Zener transition, characterized by a shift from preserved symmetries to chiral interference patterns in Landau-Zener-Stückelberg-Majorana interferometry. The emergence of non-Abelian geometric phases under cyclic evolution in curved confinement and phase-parameter space is identified, enabling holonomic quantum computation. Furthermore, the prediction of unconventional Floquet-Bloch oscillations in the quasi-energy and resonance transition probability spectra as a function of the biharmonic phase indicates exotic properties, such as fractal spectra and fractional Floquet tunnelling. These phenomena provide direct evidence of coherent transport in the synthetic dimension. Concrete experimental pathways for realizing these effects in semiconductor heterostructures are proposed, and the framework is extended to multi-qubit entanglement generation with a quantitative analysis of its inherent resilience to decoherence. Collectively, these findings position quantum wire materials as a versatile and scalable platform for Floquet engineering, topological quantum control, and fault-tolerant quantum information processing.