Experimental progress in nonadiabatic geometric gates with a superconducting qubit

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Quantum computation can be performed via a universal set of quantum gates, such as two non-commuting one-qubit gates and a nontrivial two-qubit gate, which are actually unitary evolutions governed by the Hamiltonian of a quantum system. Different from dynamic phases, geometric phases depend only on some global geometric features of the evolution path and are largely insensitive to local inaccuracies and fluctuations, making geometric quantum computation robust against some control errors.

The early schemes of geometric quantum computation were based on adiabatic Abelian and non-Abelian geometric phases, requiring a long-run time for a quantum system to evolve adiabatically. To overcome such a shortcoming, the nonadiabatic geometric quantum computation schemes were pushed forward based on the nonadiabatic Abelian or non-Abelian geometric phases. So far, the nonadiabatic geometric and holonomic gates have been experimentally demonstrated in various physical systems, such as trapped ions [1], nuclear magnetic resonance [2,3], and superconducting transmon qubit systems [4]. In ref. [4], the nonadiabatic holonomic one-qubit gates are realized in the lowest three-level ladder-type system with the second excited state as an auxiliary level, but the fidelity of the resultant gates was lessened by

the relatively short coherence time of the second excited state of the transmon qubit system.

Recently, two research groups respectively from Zhejiang University and Shandong University reported an experiment for the implementation of nonadiabatic geometric gates in a cyclic evolution of a superconducting qubit system [5]. They demonstrated several specific one-qubit quantum gates: identity operator I , Hadamard gate H , and rotation gates $R_x(\pi)$, $R_x(\pi/2)$, $R_y(\pi)$, $R_y(\pi/2)$, $R_z(\pi)$, $R_z(\pi/2)$. In their scheme, they only used the two lowest levels of a superconducting transmon qubit, thus avoiding the influence from the short coherence time of the second excited state reported in ref. [4]. Evidenced by the average fidelity of these gates up to 99.6%, this experiment showed that geometric gates have higher fidelity than dynamic gates.

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