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ABSTRACT:

The evolution of a quantum state along a closed path in Hilbert space can result in a geometric phase, which depends – in contrast to the dynamic phase – only on the trajectory of the state vector. In our experiments, we study different realizations of geometric phases in the circuit quantum electrodynamics (QED) architecture. We first measure the geometric phase of a harmonic oscillator realized as the electromagnetic field in the cavity. Here, the qubit serves as an interferometer to measure the geometric phase, which is otherwise unobservable due to the linearity of the harmonic oscillator. Second, we simulate the influence of noise on the qubit geometric phase by adding artificial noise to the control parameters. A pronounced dependence of the geometric contribution to dephasing on the path and on the direction of noise is observed. The measured noise resilience of the geometric phase can potentially be used for quantum computation fully based on geometric operations. Thus, we finally realize non-commuting, matrix-valued geometric phases by employing a transmon qubit as a three-level system and demonstrate the non-commutativity of the corresponding single-qubit gates. Assisted by two-qubit gates, these may form the basis for a universal set of geometric quantum gates.