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Qutrits and geometric phase via quantum control in ultracold spin-1 systems

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Using the exceptional controllability of an ultracold atoms platform, we explore novel approaches to quantum state preparation and transformation using radio- and microwave-frequency fields. As an introductory example of such state control, we explored a three-level subset of rubidium-87's ground states and created atomic "qutrits," demonstrating the capacity to create arbitrary states, and to perform single-qutrit operations on them [1]. In another set of experiments, we make use of geometric rather than dynamical phase [2]. By dressing the atoms with frequency-modulated electromagnetic fields, we prepare an effectively degenerate manifold of basis states that allows us to apply non-Abelian geometric phases. We vary the parameters of the dressing field to traverse complete loops, known as holonomies, in an abstract parameter space, and can transform the quantum states, performing the equivalent of single-qubit operations. We evaluate the experimental performance of this protocol in an ensemble of ultracold rubidium-87 atoms and develop insight into the true robustness of the scheme under practical conditions. From here, we see new opportunities for exploring beyond the single-particle regime to explore geometric phases in many-body systems.

[1] Joseph Lindon, Arina Tashchilina, Logan W. Cooke, Lindsay J. LeBlanc
Phys. Rev. Appl. 19, 034089 (2023)
[2] Logan W. Cooke, Arina Tashchilina, Mason Protter, Joseph Lindon, Tian Ooi, Frank Marsiglio, Joseph Maciejko, Lindsay J. LeBlanc. Phys. Rev. Research 6, 013057 (2024).

Keyword-1

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Keyword-2

Quantum control

Keyword-3

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