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(G*) POS-E30 – Quantum Gates in a Cold Atom System

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Quantum computing requires the ability to prepare and manipulate arbitrary quantum states and read out results. Cold atom systems are a proven and highly versatile platform for the study of quantum computing and other aspects of quantum physics. They have been used to develop quantum memories, to study adiabatic quantum computing, and for quantum simulation.

In this work, we explore a variety of quantum computing operations that are possible in this cold-atom system, including those with non-trivial topological character. To work with qubits, we label particular m_F states as $|1\rangle$ and $|0\rangle$. Our cold atoms also provide direct and convenient multi-qudit manifolds for study including qutrits (3 levels: e.g., the m_F states in an $F = 1$ hyperfine state) and ququints (5 levels: e.g., in an $F = 2$ hyperfine state). In our system, this dimensionality can be dynamically adjusted as interactions with some levels can be suppressed by higher detuning (via the quadratic Zeeman shift) or by destructive interference between optical transition pathways.

Our apparatus uses ultracold atoms of ^{87}Rb to simulate a wide array of Hamiltonians by coupling atomic states via optical, microwave, and modulated magnetic fields. Two-photon coupling between states is achieved by sending in two laser beams with a frequency difference $\Delta\omega_L$ matching the states'energy difference, ω. Microwave sources are used to directly couple between hyperfine levels. Meanwhile, the separation between Zeeman sublevels is controlled by changing the strength of an external magnetic field.

After state preparation and quantum operations are performed, we measure the output via the populations in each m_F state by Stern-Gerlach imaging. To fully characterize a state, the phases of m_F states need to be determined. In some cases, this information can be found by re-generating the state, then applying operators which have a known effect. For example, by applying a tuned $\frac{\pi}{2}$ rotation to a qubit before imaging, information about the x- and y-populations can be discerned in addition to the z-populations. Because of the wide array of tools available for the manipulation of ultracold atomic systems, they are a powerful platform for the study of quantum computing.

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