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Quantum Information Processing with Alkaline-Earth-Like Atoms

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Ultracold alkaline-earth-like atoms offer an attractive platform for quantum information processing. Nuclear spins are decoupled from electronic angular momentum in the closed shell 1S0 ground state, thereby providing a robust and isolated degree of freedom for a storing qubit. The 1S->3P intercombinations lines provide the means to optically manipulate qubits in unique ways with very long coherence times. We present a variety of protocols that make use of these features. Due to the identical particle statistics, nuclear-spin exchange can be used to implement a sqrt-swap entangling quantum logic gate via cold s-wave collisions, even when there is no hyperfine or spin-spin dipolar interactions. The ability to independently manipulate nuclear and electronic degrees of freedom can allow us to cool atomic motion without decohering nuclear spin qubits via laser cooling or sympathetic cooling in a BEC reservoir. Finally, optical Feshbach resonances on the intercombination line allow for control of atom coupling strengths at the heart of many protocols in QIP.