

QUANTUM INFORMATION PROCESSING WITH ^{171}Yb

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Implementations of quantum processors face an intrinsic conflict. Qubits that encode quantum information must be strongly coupled to control pulses and to one another in order to perform quantum logic, while simultaneously they must be weakly coupled to the noisy environment that induces errors. In this talk, we propose a new scheme for quantum logic based on an “exchange blockade” arising from Fermi symmetry in order to resolve this conflict. We consider a hybrid approach based on NMR and ultracold cold collisions of trapped neutral atoms. Group-II elements, with two valence electrons in a closed shell possess no electron spin and thus no hyperfine interaction with nuclear spin when in the electronic ground state. Nuclear spin, nonetheless strongly affects the interaction between these atoms solely due to the symmetry of identical particles. In a fermionic species, the dominant ultracold s-wave collisions are forbidden by the Pauli exclusion principle when the nuclei are in a symmetric spin state, and are allowed only for the nuclear-spin antisymmetric states. The single-channel cold collisions, governed by *electronic interactions* between atoms, thus induce an exchange interaction between *nuclei*, even though there is no direct interaction between nuclei or between electrons and nuclei. In addition, nuclear spins inside the closed electronic shell are protected from inelastic spin flips during the collision. The ability of nuclear spins to act a switch that turns on and off electron interactions provides a mechanism by which quantum information can be protected from the environment while simultaneously qubits are strongly coupled to one another.

As a concrete realization, we consider ^{171}Yb , currently being considered as a possible candidate for an optical atomic clock. Coherent collisions require well-localized atomic wave packets whose motion is highly controlled. We evaluate the performance of two-qubit entangling gates using dipole traps formed by tightly focused optical tweezers, recently used to trap individual atoms. Adiabatic evolution is employed to bring two atoms into the same trap where the exchange blockade generates the entangling SQRT(SWAP) logic gate. We evaluate the fidelity and entanglement generated as a function of gate time and interaction strength.

An additional benefit of the Group-II elements is the potential to cool atoms without decohering the qubit. Implementation of high-fidelity entangling interactions via cold collisions requires precise control of atomic center of mass motion and thus cooling near to the ground state of the microtraps. In the process of performing such a gate, atoms will invariably heat, degrading performance of further operations. Laser cooling, however, is typically accompanied by optical pumping, which decoheres the quantum superposition stored in the internal state of the atom. In Group-II elements, the absence of hyperfine interactions in relevant states and the application of large magnetic fields allow us to employ atom-photon couplings that decouple from the nuclear spin. We consider a protocol for performing resolved-sideband laser cooling which preserves nuclear spin coherence.