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Robust and Addressable Control of Atomic Qubits and Qudits

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The standard paradigm for quantum computation and simulation with neutral atoms assumes that constituent atoms can be used as individually addressable qubits. To accomplish this in optical lattices with sub-micron atom separation, we have developed a resonance addressing scheme that combines a position dependent light shift of the qubit transition with resonant microwave (μw) pulses. In a proof-of-principle experiment, we show that numerically optimized composite pulses can implement quantum gates on Cs qubits at targeted lattice sites, with minimal cross-talk to neighboring sites and significant robustness against uncertainty in the atom position. Coherence is verified through two-pulse experiments, and the average gate fidelity is measured to be 95+/-3% [1]. Because most atoms have more than two accessible levels, one might also consider if the existing toolbox for qubit control can be extended to d-level systems (qudits). Over the past several years we have used the 16-dimensional ground hyperfine manifold of cold, untrapped Cs atoms as an experimental testbed for such work. Driving the atoms with a combination of phase modulated radio frequency (rf) and μw magnetic fields, we use numerical optimization techniques to design control waveforms (rf and μw phases as function of time) that accomplish a wide range of control tasks, from quantum state-to-state maps [2] to full unitary transformations, with average fidelities that vary from >99% for the former to $\sim$ 98% for the latter. We further show that tools for inhomogeneous control and dynamical decoupling can be generalized to qudits, allowing transformations that are robust to static as well as dynamic perturbations, and thus in principle compatible with optical traps and the resonance addressing scheme demonstrated for qubits.

[1] J. H. Lee et al., Nature Comm. **4**, Article no. 2027 (2013), doi:10.1038/ncomms3027.
[2] A. Smith et al, Phys. Rev. Lett. **111**, 170502 (2013).