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Quantum control of ultracold atomic collisions for quantum logic gates

IVAN DEUTSCH, University of New Mexico

Ultracold trapped neutral atoms are a natural system for quantum information processors given the atoms' weak coupling to the environment and the ability to coherently control their dynamics including, electronic, spin, and motional degrees of freedom [1]. By encoding quantum information in the hyperfine magnetic sublevels of an alkali atom, two-qubit quantum logic can be implement through spin-dependent ultracold elastic collisions in optical lattices [2]. I will present a new method for robustly controlling collisions based on the "trap-induced shape resonance" (TISR) [3]. Like the magnetic Feschbach resonance, in the TISR a weakly-bound molecular state is made resonant with a trap vibrational state through the trapping potential energy. The TISR allows for strong interaction between trapped but separated atoms, providing new avenues for robust encodings of quantum information, protected from fluctuations in control parameters. A particularly promising candidate species is Cs-133, whose dimer potential posses an extremely weakly bound state near dissociation. Scattering lengths on the order of 100nm are possible for appropriate choices of encodings, larger that the typical trapped wavepacket, and thus leading to very strong interaction. To deal with the complexity of the multichannel scattering problem at short range, and the trapping potential at long range, we have developed a generalized multichannel energy-dependent Fermi pseudo-potential, including higher partial waves, and second order spin-orbit coupling. This provides a powerful method for importing precision molecular data, obtained through free-atom scattering studies, into the trapped-atom protocol. [1] I. H. Deutsch et al., Fort. der Phys. 48, 925 (2000). [2] D. Jaksch et al., Phys. Rev. Lett. 82,1975 (1999); O. Mandel et al., Nature 425, 937 (2003). [3] R. Stock et al., Phys. Rev. Lett. 91, 183201 (2003).