Interacting atoms under strong quantum confinement

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We will discuss the effects of interactions on confined ultra-cold atoms. The marked effects will be clarified for three situations that are of interest for experiments with Bose-Einstein condensates near a collisional Feshbach resonance[1] and possible uses in Quantum computing[2].

First we present energy level shifts of a tightly-confined trapped alkali atom in the presence of a second trapped atom[3]. Using a microscopic description of the interaction energy between the two atoms, we present results for two sodium and two cesium atoms confined in a spherically symmetric harmonic optical trap. We show that for Na where the scattering length is small compared to the size of realistic optical traps the effect of the interaction can be quantitatively described by a (regularized) delta function potential with a strength proportional to the scattering length. For cesium, however, the scattering length is large and the delta function potential is inadequate in describing the energy level shifts.

Secondly, we have calculated the time-dependent dynamics of two ultra-cold Na atoms in an atom trap where a time-dependent magnetic field $B(t)$ moves a Feshbach resonance state across the energy threshold for a binary collision[4]. Our coupled channels scattering calculations, which reproduce the observed properties of such resonances in sodium atom collisions, can be reduced to an effective two-channel configuration interaction model for one bound state and one continuum. The model is adapted to describe the time-dependent dynamics induced by $B(t)$ for two atoms trapped either in a strongly-confining single well of an optical lattice or in an optical potential in the presence of a Bose-Einstein condensate. We show that a simple Landau-Zener curve crossing model gives quantitative agreement with exact calculations of field-induced transition rates. If $B(t)$ sweeps the resonance across threshold from above, two atoms in the ground state of the trap potential can be efficiently converted to translationally cold dimer molecules. If the resonance is swept from below, the atoms can be removed from the ground state and placed in hot vibrational levels of the trap. Our calculations reproduce the rapid atom loss rates observed in a Na Bose-Einstein condensate due to sweeping a Feshbach resonance state through the binary collision threshold.

Finally, the confining potentials of individual atoms need not be overlapping or even harmonic. Unlike for a spherically symmetric harmonic trap, the center of mass motion now couples to the relative motion and the system quickly becomes numerically intractable. We present preliminary calculations for *one-dimensional* rubidium that attempts to include inharmonicity and effects of non overlapping wells.

[1] S.M. Inouye, R. Andrews, J. Stenger, H.-J. Miesner, D. M. Stamper-Kurn, and W. Ketterle, Nature **392**, 151 (1998); J. Stenger, S. Inouye, M. R. Andrews, H.-J. Miesner, D.M. Stamper-

Kurn and W. Ketterle, Phys. Rev. Lett. **82**, 2422 (1999).

[2] G.K. Brennen, C.M. Caves, P.S. Jessen, and I.H. Deutsch, Phys. Rev. Lett. **82**, 1060 (1999); D. Jaksch, H.-J. Briegel, J.I. Cirac, C.W. Gardiner, and P. Zoller, Phys. Rev. Lett. **82**, 1975 (1999); H.J. Briegel, T. Calarco, D. Jaksch, J.I. Cirac, and P. Zoller, J. Mod. Optic **47**, 415 (2000).

[3] E. Tiesinga, C.J. Williams, F.H. Mies, and P.S. Julienne Phys. Rev. A, March (2000).

[4] F.H. Mies, E. Tiesinga, and P.S. Julienne, Phys. Rev. A **61**, 022721 (2000).