Stony Brook University
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Doctoral Defense Announcement

Abstract

Two-Component Bosons in State-Dependent Optical Lattices

By

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Ultracold atoms in optical lattices provide a highly controllable environment for the clean experimental realization of various model Hamiltonians from condensed matter and statistical physics. For example, the two-component Bose-Hubbard model, which reduces to an anisotropic spin-½ Heisenberg model in a certain limit and thus allows for the study of quantum magnetism, can be implemented by using bosons with two different internal states that couple differently to an optical lattice potential. In this thesis, I present our first experiments with two-component hyperfine-state mixtures of ultracold ^{87}Rb atoms in a state-dependent optical lattice, both in the strongly correlated regime and in the context of nonlinear atom optics.

For the production of ^{87}Rb Bose-Einstein condensates we have developed a moving-coil transporter apparatus featuring a magnetic TOP trap which serves as a "phase-space funnel" to load a crossed optical dipole trap. The apparatus further incorporates a three-dimensional optical lattice setup with simultaneously usable hyperfine state-dependent and state-independent lattice beams of different spacing along the vertical axis. Internal state control is performed via rf and microwave Rabi pulses and Landau-Zener sweeps.

As a first step towards studying strongly correlated two-component mixtures, we have realized a state-selective superfluid-to-Mott insulator transition, where one component enters the Mott insulator regime, while the other one stays superfluid. Using the state-dependent lattice we can tune the second component's properties from highly superfluid to strongly localized. At both extremes we find a reduction of the coherence of the primary component, i.e. a shift of the Mott transition to smaller values of the ratio U/t of interaction to tunneling. We ascribe this to a polaron-like dressing on the one hand, and a "quantum emulsion" causing a disordered atomic background potential on the other hand.

Further, we have observed and studied four-wave mixing of two-component matter waves. Using state-selective Kapitza-Dirac diffraction of a two-component BEC, we prepare seed and pump modes differing both in momentum and internal state. A novel collinear four-wave mixing process then populates the initially empty output modes. While this process can complicate studies of bosonic mixtures loaded into state-dependent optical lattices, it might prove useful for possible applications in quantum atom optics.

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