Quantum Simulation using Ultracold atoms in Optical Lattices

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Quantum degenerate gases in optical lattices have offered new possibilities in the study of quantum many-body systems. Important parameters such as the interaction strength, the tunneling rate, the temperature, and the lattice site occupancy, are easily tuned, enabling us to investigate the system in a systematic manner. The atoms in optical lattices can be regarded as a quantum simulator of the Hubbard model, an important model to describe condensed matter systems. Many of the experiments on quantum degenerate atoms in optical lattices have been performed with alkali-atoms so far. By working with ultracold ytterbium (Yb), an alkaline-earth-metal-like atom, there are several unique features and advantages. First, Yb has a variety of stable isotopes: five bosonic and two fermionic isotopes. This allows us to study not only a Bose-Einstein condensate (BEC) and a degenerate Fermi gas (DFG) but also quantum degenerate mixtures such as Bose-Bose, Bose-Fermi and Fermi-Fermi mixtures. Recently, all the possible isotopes has been cooled down to quantum degenerate regime[1]. Six spin components of ^{173}Yb with the nuclear spin I=5/2 enables us to study an enlarged spin symmetry of fermionic atoms in optical lattices[2]. Second, there are two useful ultranarrow transitions. One is the $^1S_0 -^3 P_0$ transition, which is used in an optical lattice clock. The other is the $^1S_0 -^3 P_2$ transition, which also has a ultranarrow linewidth of about 10 mHz. Both ultranarrow transitions enable us to perform high-resolution laser spectroscopy of atoms in an optical lattice to probe quantum phases. In addition, these transitions are expected to be useful for an optical Feshbach resonance to tune the scattering length with negligible heating[3].

We have realized a superfluid-Mott insulator transition of bosonic isotopes[4] and a metal-Mott insulator transition of fermionic isotope with both SU(2) and SU(6) spin symmetry. Moreover, making use of a rich variety of isotopes of Yb, we have also realized a novel type of Mott insulator system: a dual Mott insulator system of bosonic and fermionic atoms, where two Mott insulators compete with each other[5]. In a dual Mott insulator system, depending on the relative filling and the sign of the interspecies interaction, a mixed Mott insulator, a phase separated insulator and various types of composite particles are show to be realized with experimental and theoretical study. We will report on our recent experimental results on quantum simulations using quantum degenerate Yb atoms in 3D optical lattices. Finally, the study on the dual Mott insulator is a collaborative work with Dr. Kensuke Inaba and Dr. Makoto Yamashita at NTT Basic Research Laboratories.

References

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