Quantum Simulation Using Quantum Degenerate Ytterbium Atoms in Optical Lattices

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The idea that a quantum system which is difficult to control and is never clean can be efficiently simulated by another quantum system which is easy to control and is super-clean, is sometimes referred to as Quantum simulation based on the Feynman's pioneering statement. From this point of view, we are aiming at realizing the quantum simulator of strongly-correlated systems which remain unsolved and are of particular importance in physics, with ultra-cold fermionic atoms in a three-dimensional optical lattice [1]. With this cold atom system, we can finely control many important parameters such as temperature, on-site atom-atom interaction, tunneling rates between adjacent sites and layers, filling factor, and so on. In particular, we plan to work with ytterbium (Yb) atoms since the Yb atoms have ultra-narrow optical transitions which are useful to probe weak interactions. Another important advantage is the existence of a rich variety of isotopes, that is, two fermions and five bosons, which will extend the variety of the simulation.

So far, we have succeeded in creating BEC and Fermi-degeneracy of Yb atoms[2], and also their mixture. Collective excitations have been studied for BEC as well as the boson-fermion mixture. We have also succeeded in loading such quantum degenerate Yb atoms in a one-dimensional optical lattice at a period of 266 nm. A clear interference fringe for the superfluid state of BEC at a weak lattice potential has been observed, while the fringe has disappeared at a deeper lattice potential. In addition, we have successfully performed high-resolution laser spectroscopy of such quantum degenerate gases in a simple harmonic trap as well as in a one-dimensional optical lattice with ultra-narrow intercombination lines.

We will discuss these experimental results and the future plan.

[1] W. Hofstetter, et al., Phys. Rev. Lett. **89**, 220407(2002).
[2] T. Fukuhara, et al., Phys. Rev. Lett. **98**, 030401(2007).