Field:
Chemistry/Biochemistry

Session Topic:
Ultracold Molecules

Speaker:
Takashi MUKAIYAMA, The University of Electro-Communications

1. Introduction

When two atoms move toward each other, they would collide. This is due to the interaction between atoms: one of the atoms feels the existence of the other when they are close. The way two atoms interact is determined by the detailed structure of the atoms, therefore you may think that the atomic interaction is not something we can control at will. However, it turned out that this is not true. We can actually control the interaction between atoms through the magic of molecular states.

When the total energy of two colliding atoms happens to be close to the energy of a state in which two atoms are bound (namely a molecular state), the effect of interaction between two atoms would be strongly affected by the existence of the molecular state. In the past decade, we found out the way to tune the molecular state energy so that we can artificially change an inter-atomic interaction stronger or weaker. We can even change the interaction from repulsive to attractive. This tunability of interaction makes an ultracold gas unique and useful model system for fundamental physics researches.

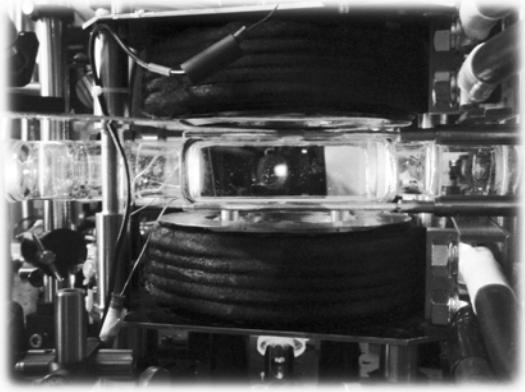
2. Bose-Einstein condensation of fermions

In nature, all the particles are classified into two kinds of particles. One is Bose particles (we call them bosons). Bosons like to get together and would not mind occupying the same state with other bosons. They form Bose-Einstein condensate (BEC) phase at lower temperature than the critical temperature. The other type of particles is Fermi particles (fermions). Fermions are loners and they never share the state with other fermions. At absolute zero temperature, fermions fill up the states from the lowest energy state one by one. This is called degenerate Fermi gas (DFG) phase.

Although fermions do not show a BEC phase transition when they are moving independently, it is known that fermions can cause a BEC phase transition when two fermions form a pair, which can be considered as a composite particle of a boson. One good example of this BEC transition is superconductivity, which is considered to be a BEC of electrons which are originally fermions. It is widely known from accumulated researches that a fermion pair BEC becomes more robust as the interaction between fermions gets stronger. This means that the BEC phase transition occurs at higher temperature for stronger interaction between fermions. Thanks to the tunability of inter-atomic interaction in an ultracold atom system, we can create very strongly-interacting fermions and therefore we can create robust BEC of fermion pairs.

3. Experiment with ultracold fermionic atoms

Our system of interest is an ultracold gas of ^{6}Li atoms. By shining the laser whose optical frequency tuned precisely to atomic transition, we can obtain ultracold atomic gases (it may sound surprising that a laser cool atoms rather than heat them up). The right picture shows a trapped gas of ^{6}Li atoms in a first stage trap (bright spot at the center of the picture is an atomic cloud). Atoms are then transferred to the next stage trap with a smaller trap volume. After removing hot atoms, atoms left in the trap have lower kinetic energy than before. This is so called evaporative cooling. By repeating this process, we eventually obtain roughly 10^6 atoms with the temperature of lower than 10^{-6} K. When atoms are cooled down to this temperature range and the inter-atomic interaction is cranked up, we see that fermion pairs start to move in lock-step which is the evidence of BEC phase transition. The observed critical temperature can be called very "high temperature" in the sense that, if the density of atoms is scaled to that of electrons in metals, BEC would occur far above room temperature. Full understanding of the fermion pair BEC of atoms will hopefully give us some hint to explore new materials which show an actual superconductivity in room temperature.



4. Conclusion

Thanks to the existence of molecular state near two free-atom threshold, the strength of interaction between atoms can be controlled at will by experimentalists. With the tunability of interaction, an ultracold atomic gas system can mimic other physical systems composed of interacting particles such as electrons in superconductors. Studying fermion pair BEC in an ultracold atom system is expected to be a complementary research to exploration high-T_c materials.

References

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