Experiments with Interacting Bose and Fermi Gases

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Citable URI: http://hdl.handle.net/1721.1/33797
Date Issued: 2006-08-24

Abstract:
In the past few years, the study of trapped fermionic atoms evolved from the first cooling experiments which produced quantum degenerate samples to becoming one of the most exciting branches of current atomic physics research. This thesis covers experiments done throughout this period, which can be grouped in three sets of studies. First, degenerate 6Li Fermi gases have been produced by sympathetic cooling with bosonic 23Na. For this, an existing 23Na Bose-Einstein condensation apparatus was upgraded to an experiment capable of producing degenerate 6Li Fermi gases and 6Li-23Na degenerate Fermi-Bose mixtures. The cooling methods have been developed in two different stages, resulting in the production of degenerate 6Li Fermi gases with temperatures below 0.05 TF and up to $7 \times 10^7$ atoms, and of degenerate 6Li-23Na mixtures with a few million atoms in each of the components. Second, the properties of 6Li-23Na mixtures at different magnetic fields have been investigated, resulting in the discovery of three interspecies 6Li-23Na Feshbach resonances, which opens up the possibility to study strongly interacting Bose-Fermi mixtures in this system. This investigations also led to the observation of other Feshbach resonances in 6Li and 23Na. Third, the properties of strongly interacting 6Li spin mixtures in the strong interacting regime near a Feshbach resonance have been investigated. Weakly bound 6Li2 molecules have been produced and Bose condensed on the repulsive side of the Feshbach resonance. Pure molecular condensates with up to $3 \times 10^6$ molecules have been produced. The properties of the interacting Fermi gas were investigated on the attractive side of the resonance using rapid field ramps to the other side of the resonance. Fermion pairing, and condensation of these pairs was observed near the resonance, offering evidence for superfluid behavior in a strongly interacting Fermi gas.

Description:
Thesis Supervisor: Wolfgang Ketterle Title: John D. MacArthur Professor of Physics URI: http://hdl.handle.net/1721.1/33797 Series/Report no.: Technical Report (Massachusetts Institute of Technology, Research Laboratory of Electronics); 716

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Ultracold dipolar gases - a challenge for experiments and theory. The study of ultracold Bose gases beyond the Gross-Pitaevskii description. The study of the lower bound state and BCS transition in dense ultracold Fermi gases with Feshbach resonance. More Physics 1999. We present the rigorous microscopic quantum theory of the interaction of ultracold Bose and Fermi gases with the electromagnetic field of vacuum and laser photons. The main attention has been paid to the consistent consideration of dynamical dipole-dipole interactions. The theory developed is shown to be consistent with the general principles of the canonical quantization of electromagnetic field in a medium. Fermi-Dirac and Bose-Einstein distribution. When we discussed the ideal gas we assumed that quantum effects were not important. This was implied when we introduced the term $1/N$ for the partition function for the ideal gas, because this term only was valid in the limit when the number of states are many compared to the number of particles. This is not in correspondence with experiments, which show that the heat capacity goes to zero at $T=0$ in the low temperature limit. What went wrong? We have ignored interactions among the atoms – which probably may be important for lattice vibrations. Mainly because there are different vibration modes in systems with many atoms – the atoms may vibrate together to form low frequency modes. First, degenerate $^{6}$Li Fermi gases have been produced by sympathetic cooling with bosonic $^{23}$Na. For this, an existing $^{23}$Na Bose-Einstein condensation apparatus was upgraded to an experiment capable of producing degenerate $^{6}$Li Fermi gases and $^{6}$Li-$^{23}$Na degenerate Fermi-Bose mixtures. The cooling methods have been developed in two different stages, resulting in the production of degenerate $^{6}$Li Fermi gases with temperatures below 0.05 TF and up to $7 \times 10^7$ atoms, and of degenerate $^{6}$Li-$^{23}$Na mixtures with a few million atoms in each of the components.