Ultra-cold Bose and Fermi gases: playing with Feshbach resonances

Laboratoire Kastler Brossel, ENS, 24 rue Lhomond, 75231 Paris CEDEX 05, France

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We report on recent experiments on ultra-cold mixtures of Bose and Fermi gases confined in magnetic or optical traps. First, we have produced a quasi-pure $^7$Li Bose-Einstein condensate immersed in a $^6$Li Fermi sea at a common temperature of $0.28 \mu \text{K} \simeq 0.2(1) \, T_C = 0.2(1) \, T_F$ where $T_C$ is the BEC critical temperature and $T_F$ the Fermi temperature [1]. Behaving as an ideal gas in the radial trap dimension, the condensate has a one-dimensional character. This mixture of fermionic and bosonic quantum systems opens interesting possibilities for the study of phase separation, the influence of the superfluidity of the Bose system on the Fermi degeneracy and of the cooling limits of the Bose-Fermi mixed gas.

Second, the large effective attractive interaction between $^6$Li $|F = 1/2, m_F = +1/2\rangle$ and $|F = 1/2, m_F = -1/2\rangle$ makes this atom a good candidate for searching for BCS pairing if the temperature can be made sufficiently low [2]. In particular it has been recently predicted that near a Feshbach resonance the BCS transition temperature could become as high as $0.5 \, T_F$ [3]. In the $^6$Li $|F = 1/2, m_F = \pm 1/2\rangle$ spin states, such a Feshbach resonance occurs for a magnetic field near 810 Gauss [2, 4]. As these states cannot be trapped magnetically, we have constructed a far detuned crossed dipole trap in which all hyperfine states of both lithium isotopes can be confined in an adjustable external magnetic field.

As a first step, we have observed a Feshbach resonance in $^7$Li predicted at 725 Gauss [4]. Using this resonance we magnetically tuned the effective interactions in a $^7$Li Bose-Einstein condensate from repulsive to attractive and produced bright matter-wave solitons [5, 6]. Soliton propagation in a one-dimensional optical waveguide without dispersion over a distance of 1.1 mm is observed. A simple theoretical model explains the stability region of the soliton. Progress on optical trapping of $^6$Li fermions will be reported.