Quasi Two-Dimensional ^{6}Li Fermi gas

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Two-dimensional Fermi gases can behave in surprisingly different ways from their three-dimensional counterparts. This becomes particularly important for a two-component Fermi gas in the Bose-Einstein condensate (BEC) to Bardeen-Cooper-Schrieffer (BCS) crossover region, where the 3D scattering length is widely tunable. In 2D, bound states can exist even on the BCS side of the Feshbach resonance. In quasi-2D mesoscopic behaviours can also emerge. One example is shell structure which arises due to the filling of discrete shells in the tightly confined transverse direction. This shell structure leads to steps and discontinuities in the evolution of various physical parameters such as the density profile, chemical potential and specific heat [1]. We have studied the crossover from 2D to 3D in a weakly interacting Fermi gas and have seen the emergence of shell structure in the density profiles.

A 2D Fermi gas must satisfy $k_BT, E_F < \hbar\omega_\perp$. We achieve this using a 2D optical trap produced by tightly focusing a circular Gaussian beam in one direction with a cylindrical lens. The trapping frequencies are $\omega_z/2\pi \approx$ 2.8 kHz and $\omega_r/2\pi \approx$ 47 Hz ($\omega_x \approx \omega_y \equiv \omega_r$) in the tight and weakly confined directions, respectively, giving an aspect ratio of $\sim$ 60. For an ideal Fermi gas, $E_F < \hbar\omega_\perp$ for $N \lesssim$ 1800, to achieve the 2D regime.

We have observed reduced dimensionality by studying the evolution of the cloud size versus atom number [2]. Figure 1(a) below shows the root mean square (rms) cloud width in the weakly confined radial (y) direction (main panel) and the tightly confined (z) directions (inset) as a function of atom number N at 992 G ($a = -4300\,a_0$) after 500 μs time of flight. The scaling of the cloud width with atom number is seen to change in both figures showing the signature of the dimensional crossover. The solid and dashed lines are scaled theoretical calculations of the cloud width for a weakly interacting and ideal Fermi gas, respectively. The data points agree very well with the weakly interacting theory. Figure 1(b) shows the aspect ratio $\kappa = \sigma_z/\sigma_y$ of the cloud versus atom number. For a 3D cloud the aspect ratio would be constant for all N; however, the variations we see indicate a clear departure from 3D behaviour. The steps in the gradient of the aspect ratio (inset) correspond to the occupation of new transverse shells, for atom numbers predicted at the location of the arrows. This is the first study of this dimensional crossover and the associated shell structure in a Fermi gas and opens the way to studies of the phase diagram and superfluidity in 2D Fermi gases.

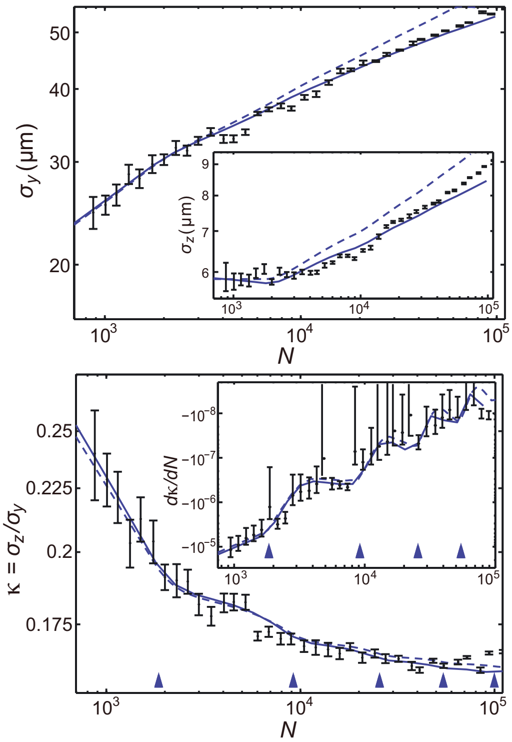

Figure 1: Cloud size (a) and aspect ratio (b) for a weakly interacting Fermi gas in the dimensional crossover from 2D to 3D. Points represent the experimental data and the solid (dashed) line is the theoretical prediction for a weakly interacting (ideal) Fermi gas.

References

[1] J. Schneider and H. Wallis, Phys. Rev. A **57**, 1253 (1998).
[2] P. Dyke *et al.*, arXiv:1011.1327 [cond-mat.quant-gas] (2010).