The thermodynamics of the strongly interacting Fermi gas in the crossover from BEC to BCS

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Cold atomic Fermi gases provide a clean and well-defined paradigm of strongly interacting Fermi systems and have attracted much interest across diverse subfields of physics. They have also been the subject of intensive experimental studies in recent years.

We investigate the thermodynamics of the crossover between the Bose-Einstein condensate (BEC) and the Bardeen-Cooper-Schrieffer (BCS) limits in the two-species Fermi gas with attractive contact interaction in three (3D) and two (2D) spatial dimensions. In 3D we focus on the unitary limit of strongest interaction [1,2], while in 2D we consider the strongly interacting regime in the crossover [3]. The system undergoes a phase transition to a superfluid below a critical temperature but in 2D the transition is of the Berezinskii-Kosterlitz-Thouless type. We use auxiliary-field quantum Monte Carlo (AFMC) methods in the canonical ensemble on a discrete lattice and extrapolate to the continuum limit [2].

We study the superfluid phase transition and, in particular, the extent of a pseudogap regime, in which pairing correlations exist above the critical temperature for superfluidity. To this end, we calculate several observables including the condensate fraction and a model-independent pairing gap. We also calculate the contact which measures the pair correlation at short distances and is a fundamental property of quantum many-body systems with short-range correlations. We observe a rapid increase in the contact as the temperature decreases below the critical temperature for superfluidity in both 3D [2] and 2D [3]. The calculation of the contact has been a major challenge with many theories using uncontrolled approximations that lead to widely different results. Our results for the 3D unitary gas are in excellent agreement with recent precision experiments by two leading experimental groups [5].

Finally, we calculate the spin susceptibility and determine a spin gap temperature below which the spin susceptibility is suppressed due to pairing correlations.

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