Ultra-cold Fermi gases

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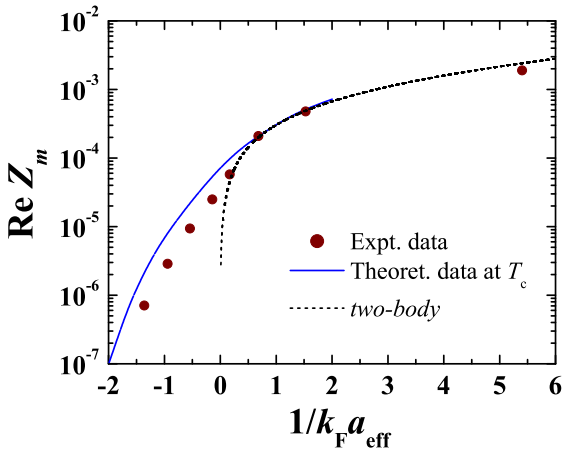
Molecule formation in ultracold degenerate quantum gases is one of the central topics in the overall ACQAO program, due to the strong quantum correlations in these systems. An experimental program in ultra-cold molecule formation using fermionic ^{6}Li near a Feshbach resonance is underway at the SUT node of ACQAO. The work described here provides theoretical support for possible experimental investigations of superfluidity near the Feshbach resonance. There are additional links being established internationally with experimental groups at Ecole Normale Superieure (France), and Innsbruck University (Austria), which have already verified some earlier predictions.

In these systems, the inter-atomic interaction strength can be varied by tuning the energy of a near-resonant molecular state with a magnetic field. These rapid experimental developments constitute an ideal testing ground for theoretical studies of the BCS-BEC crossover. However, theoretical results available in the literature are limited in the strongly correlated unitary regime. In 2005, we developed the theory of the BCS-BEC crossover both above and below the transition temperature. In this work we have used diagrammatic perturbation theory methods to treat an interacting ultra-cold Fermi gas with a Feshbach resonance [1]. The strong fluctuations of the preformed Cooper-pairs and of the Feshbach molecules have been incorporated within a self-consistent T-matrix approximation above threshold, while inter-molecular interactions were successfully included below threshold.



We have applied this theory to explore the normal phase of the gas at BCS-BEC crossover, including resonance width effects. It was found that the superfluid transition temperature increases monotonically at all widths as the effective interaction between atoms becomes more attractive. Furthermore, we have characterized the fraction Z_m (see figure) and lifetime of Feshbach molecules at T_c. As shown in the figure, our many-body calculations agree much better than simple two-body theory with the recent measurements on a gas of ^{6}Li atoms near the broad Feshbach resonance at 834 Gauss [2].

Next, we have calculated a theory for a superfluid Fermi gas near the BCS-BEC crossover [4], with the inclusion of pairing fluctuation contributions to the free energy. We obtained an equation of state of the gas, and compared it with recent four-body scattering calculations and Quantum Monte Carlo simulations at zero temperature. Excellent agreement is found for all interaction strengths. The temperature dependence of the equation of state was also studied in the unitary limit, and agrees with available path integral Monte Carlo results. Furthermore, by using the local density approximation we have studied the superfluid Fermi gas in a harmonic trap, showing that in experiments the temperature can be usefully calibrated by making use of the entropy, which is invariant during an adiabatic conversion into the weakly-interacting limit of molecular BEC [5].

References

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[3] P. D. Drummond, J. F. Corney, X.-J. Liu and H. Hu, in *Laser Spectroscopy: Projeceedings of the XVII International Conference*, edited by E. A. Hinds, A. Ferguson and E. Riis, (World Scientific, 2005) 167-177 (2005).
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[5] Hui Hu, Xia-Ji Liu, and P. D. Drummond, Phys. Rev. A, in press.