Universality in Strongly Interacting Fermi Gases

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The theory of strongly interacting fermions is of great interest. Interacting fermions are involved in some of the most important unanswered questions in condensed matter physics, nuclear physics, astrophysics and cosmology. Though weakly-interacting fermions are well understood, new approaches are required to treat strong interactions. In these cases, one encounters a "strongly correlated" picture which occurs in many fundamental systems ranging from strongly interacting electrons to quarks.

The main theoretical difficulty lies in the absence of any small coupling parameter in the strongly interacting regime, which is crucial for estimating the errors of approximate approaches. Although there are numerous efforts to develop strong-coupling perturbation theories of interacting fermions, notably the many-body T-matrix fluctuation theories their accuracy is not well-understood. Quantum Monte Carlo (QMC) simulations are also less helpful than one would like, due to the sign problem for fermions or, in the case of lattice calculations, the need for extrapolation to the zero filling factor limit.

Recent developments in ultracold atomic Fermi gases near a Feshbach resonance with widely tunable interaction strength, densities, and temperatures have provided a unique opportunity to quantitatively test different strong-coupling theories. In these systems, when tuned to have an infinite s-wave scattering length - the unitarity limit - a simple universal thermodynamic behavior emerges [1]. Due to the pioneering efforts of many experimentalists, the accuracy of thermodynamic measurements at unitarity has improved significantly. A breakthrough occurred in early 2007, when both energy and entropy in trapped Fermi gases were measured without invoking any specific theoretical model [2]. This milestone experiment, arguably the most accurate measurement in cold atoms, has an accuracy at the level of a few percent.

We give an overview of the current experimental and theoretical situation, including detailed quantitative comparisons of theory and several different experiments that establish the first evidence for universality. We also explore the extension of these theories to new regimes, including the exactly soluble one-dimensional regime, where the FFLO or modulated superfluid phase can form in the case of a polarized Fermi gas, and possible regimes with more than two types of interacting fermion. Finally, we explore the open question of how to distinguish between existing theories of strongly interacting Fermi gases.

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[1] H. Hu, P. D. Drummond, and X.-J. Liu, Nat. Phys. **3**, 469 (2007).
[2] L. Luo *et al.*, Phys. Rev. Lett. **98**, 080402 (2007).