Universal thermodynamics of strongly interacting Fermi gases

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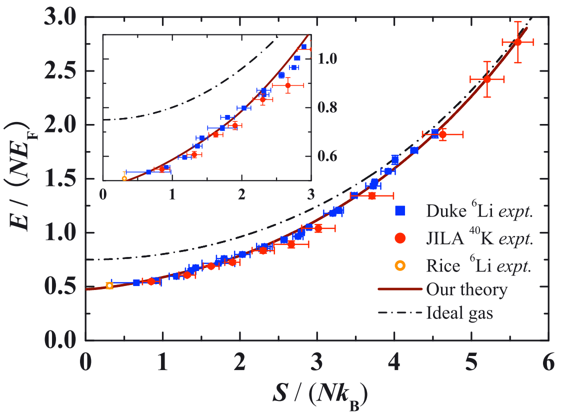
Strongly interacting Fermi gases are of great interest. Not only are fermions the most common particles in the universe, but they are also thought to have a universal behavior for strong interactions. Ultra-cold Fermi gases provide an exciting opportunity to test this prediction in the laboratory, thus allowing the interior properties of neutron stars to be investigated via experiments on earth. We demonstrate universality by comparing our strong interaction theory [1,2] with experiments on two different ultra-cold Fermi gases [3,4,5]. These measurements could be carried out with the SUT ^6Li apparatus.

In these experiments, the tunable magnetic field causes a Feshbach resonance or BCS-BEC crossover. This is a strongly interacting regime called the unitarity limit, which leaves the inter-atomic distance as the only relevant length scale. At this point, the gas should exhibit a universal thermodynamics, independent of any microscopic details of the underlying interactions [1,2]. *We find that, indeed, the thermodynamics is universal, and independent of which atomic species we compare with.*

Operationally, the energy is measurable simply from the radius of the strongly interacting fermion cloud, which shrinks due to the attractive interactions. The entropy of the gas is measured at various temperatures below 1 μ K by an adiabatic magnetic field sweep of the strongly interacting gas to a weakly interacting regime, where the entropy is known from the cloud size after the sweep. These ground-breaking experiments provide a precise measurement, accurate to the level of a few percent, with exceptional accuracy in the recent Duke experiments [3]. They offer an ideal opportunity to quantitatively test the universal predictions of microscopic many-body theories against experimental measurements.



Here we compare these experiments with our theoretical predictions on the entropy-energy relation of a strongly interacting trapped Fermi gas [6]. The agreement between theory and experiment is excellent for almost all the measured data, as shown in Fig. 1. This figure gives our predictions for the entropy (i.e., temperature) dependence of the energy of a harmonically trapped, strongly interacting Fermi gas. Exactly the same theory is used in all cases, with results from three different laboratories [3,4,5].

A key finding from the comparison is that the lowest experimentally accessible temperature of strongly interacting atomic gases at unitarity is in the range 0.10-0.15 T_F. This value, about half of the estimated critical temperature, has a significant impact on the determination of the universal many-body parameter β that describes the ground state energy of a Fermi gas in the unitarity limit. By removing the finite-temperature enhancement, we extract from the experimental data, $\beta \sim 0.59 \pm 0.07$, which agrees fairly well with the most accurate quantum Monte Carlo simulations, $\beta \sim 0.58 \pm 0.01$, and our theoretical predictions [1], $\beta = 0.599$. It is important to improve the accuracy of this measurement.

References

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