Precision thermodynamics of the cold atomic unitary Fermi gas

Yoram Alhassid[1], Scott Jensen[1], and Christopher N. Gilbreth[2]

[1]*Center for Theoretical Physics, Sloane Physics Laboratory, Yale University, New Haven, Connecticut 06520, USA*

[2]*Department of Physics, Central Washington University, Ellensburg,Washington 98926, USA*

Cold atomic quantum gases are of great interest in diverse areas of physics since they provide a clean and well-defined paradigm of strongly interacting systems, and they have been the subject of intensive experimental studies. Of particular interest is the unitary Fermi gas (UFG) of two-component fermions with a contact interaction characterized by the strongest interaction of infinite scattering length. The UFG undergoes a phase transition to a superfluid below a certain critical temperature. The accurate calculation of thermodynamic properties of the UFG across the superfluid phase transition has been a major challenge, with many theories using uncontrolled approximations that lead to widely different results even qualitatively.

A fundamental thermodynamic property of the UFG is the contact, measuring the pair correlation at short distances. It also characterizes the tail of the momentum distribution and the high-frequency tail of the shear viscosity spectral function. Various theories yielded qualitatively different results for the temperature dependence of the contact.

We use canonical-ensemble auxiliary-field quantum Monte Carlo (AFMC) methods [1,2] on a spatial lattice to calculate the temperature dependence of the contact in the spin-balanced UFG [3]. We extrapolate to the continuum limit by taking increasingly larger lattices at a fixed but large number of particles. The calculations are accurate up to controlled statistical errors. We find a dramatic increase of the contact as the temperature decreases below the critical temperature for superfluidity. Our results are in excellent agreement with very recent precision experiments by the Swinburne [4] and MIT [5] groups, both below and above the critical temperature.

We also present novel continuum limit results for the thermal energy of the UFG, and extract the Bertsch parameter (defined as the ground-state energy of the UFG in units of the Fermi gas ground-state energy) using our lowest temperature results.

[1] S. Jensen, C.N. Gilbreth, and Y. Alhassid, arXiv:1801.06163.

[2] For a recent review of AFMC, see Y. Alhassid, in *Emergent Phenomena in Atomic Nuclei from Large-Scale Modeling: a Symmetry-Guided Perspective*, edited by K.D. Launey, (World Scientific, Singapore, 2017), Ch. 9, arXiv:1607.01870.

[3] S. Jensen, C.N. Gilbreth, and Y. Alhassid, arXiv:1906.10117.

[4] C. Carcy et al, Phys. Rev. Lett. 122 (2019) 203401.

[5] B. Mukherjee et al, Phys. Rev. Lett. 122 (2019) 203402.