Precision thermodynamics of the Fermi polaron in its strongly coupling regime

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The Fermi polaron, describing the short-range interaction of an impurity with a polarized Fermi sea, is a fundamental problem in quantum many-body physics first discussed by Landau. Ultracold Fermi gases have recently been used to realize a Fermi polaron in the context of spin-imbalanced Fermi liquids. Most calculations for the Fermi polaron in its strongly coupling regime are based on uncontrolled approximations. We have used controlled canonical-ensemble lattice auxiliary-field quantum Monte Carlo (AFMC) methods [2] to study the Fermi polaron in this regime.

Recent theoretical work has explored the impurity free energy of the polaron, linking the thermodynamics of the polaron with its spectral response. The impurity free energy, defined as the difference between the free energy of the interacting and non-interacting systems, is of interest because it relates two experimentally accessible spectral functions, the injection and ejection functions. The AFMC calculation of spectral functions requires a numerical analytic continuation, which is not always reliable. We developed a novel method to calculate the polaron's impurity free energy of polaron directly and accurately in AFMC.

We calculated the polaron's impurity free energy as a function of temperature in the limit of strongest interaction (unitary limit), and as a function of the coupling strength, and compare these results with other theoretical results and recent experiments [3].

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[1] S. Ramachandran, S. Jensen, and Y. Alhassid, Phys. Rev. A 112, 023316 (2025).

[2] For a 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, pp. 267 - 298.

[3]] S. Ramachandran, S. Jensen, and Y. Alhassid, in preparation (2026).