Exploring the Fermi polaron problem with canonical-ensemble quantum Monte Carlo

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The behavior of a mobile impurity that interacts strongly with a Fermi sea, first discussed by Landau, is of fundamental importance in quantum many-body physics. This system has been realized experimentally in ultra-cold atomic Fermi gases with tunable attractive short-range interactions. In the so-called unitary limit of infinite scattering length, there is a crossover from a dressed quasiparticle, known as the Fermi polaron, at low temperatures to a classical Boltzmann gas at high temperatures. As a function of the inverse scattering length at a low temperature, there is a transition from a Fermi polaron to a dressed molecule.

Theoretical explorations of the Fermi polaron have thus far relied mostly on uncontrolled approximations. We carried out controlled calculations of the Fermi polaron thermodynamics [1] using canonical-ensemble auxiliary-field Monte Carlo (AFMC) [2] methods on a discrete lattice and extrapolating to the continuum limit [3,4]. Our canonical-ensemble AFMC methods are particularly suitable for exploring the Fermi polaron by projecting on an N-particle Fermi sea of spin-up particles and on one spin-down particle. The spin-imbalanced Fermi gas has a Monte Carlo sign problem but we find it to be moderate at and beyond unitarity.

We present results for the energy gap and for the contact, a fundamental property of quantum many-body systems with short-range correlations. Our AFMC results for the temperature dependence of the contact at unitarity agree with recent experiments but we find discrepancies between theory and experiment in the dependence of the contact on the inverse scattering length.

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[3] S. Jensen, C. N. Gilbreth, and Y. Alhassid, Phys. Rev. Lett. 124 (2020) 090604.

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