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Some Exact Solutions in Polaron Physics and Polaron Interactions: A Few-Body Perspective

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Polaron quasiparticles—impurities interacting with a quantum medium—represent one of the earliest and most fundamental topics in condensed matter physics. A key feature of polaron physics is the interplay between few-body and many-body effects. In strongly interacting regimes where mean-field and perturbative methods often fail, polaron systems offer a unique opportunity for exact treatment: due to the negligible back-action of a single impurity on the background medium, polarons can often be described from a few-body perspective, sometimes allowing for exact solutions.

We begin by examining the exact solution of a heavy Fermi polaron, modelled as an infinitely massive impurity immersed in a non-interacting Fermi gas. We demonstrate how Ramsey spectroscopy—closely related to nuclear magnetic resonance (NMR)—can be used to probe the polaron dynamics. By extending this technique to the multidimensional regime, in analogy with multidimensional NMR, we uncover nonlinear nonequilibrium features in polaron dynamics.

We then generalize the exact solution to a heavy impurity immersed in a paired two-component Fermi gas across the BEC–BCS crossover. This system admits an exact description of polaron physics in the presence of superfluid correlations.

Finally, we consider heavy polarons in a quantum Hall fluid. Remarkably, exact solutions are obtained not only for single polarons, but also for systems with multiple interacting polarons, allowing the polaron-polaron interactions to be determined analytically.

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