Ultracold three-body recombination of fermionic atoms

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Three-body recombination, a three-body collision process in which two atoms combine to form a bound state and the third carries away the binding energy, is an important loss mechanism for Bose-Einstein condensates. This process is also important in nuclear physics and in the chemical dynamics of combustion and gas-phase systems. Only recently have nonperturbative, quantum-machanical investigations been carried out [1, 2, 3, 4]. Those investigations showed that the three-body recombination rate K_3 of identical, spin-polarized bosons depends only on the two-body s-wave scattering length a_s.

Meanwhile, many groups [5, 6, 7] are carrying out experiments with ultracold trapped fermions. A degenerate Fermi gas (DFG) is expected to exhibit interesting behavior in its thermodynamics [8], collision dynamics [9], and the scattering of light [10, 11]. The most intriguing prospect for a DFG is the potential to observe "Cooper" pairing, analogous to the Cooper pairing of electrons in a semiconductor. One of the limiting factors to such pairing is the loss of atoms by two-body or three-body inelastic collisions. To the best of our knowledge, ultracold three-body recombination of fermions has never been studied, in contrast to numerous theoretical investigations of boson recombination. So, we will present the first study on three-body recombination of ultracold fermions. In particular, a system of three identical spin-polarized fermions interacting via a sum of pairwise interactions will be considered.

Three-body recombination of bosons can be described in terms of the two-body s-wave scattering length a_s. In the case of fermions, however, the Pauli exclusion principle prohibits s-wave scattering of identical atoms, making p-wave collisions dominant at ultracold energies. When describing the three-body recombination of fermions, we use the the low-energy parameter V_p, the "p-wave scattering volume", defined by

$$V_p = -\lim_{k\to 0} \frac{\tan \delta_p(k)}{k^3}. \quad (1)$$

Here, $\delta_p(k)$ is the p-wave scattering phase shift and k is the wave number. In our previous study [12], we found that for three identical fermions the permutation symmetry suppresses recombination as E^2 near threshold. From this, by essentially dimensional analysis, we predict that K_3 scales as $|V_p|^{8/3}$. In contrast, the recombination rate for bosons scales generally as $|a_s|^4$. To examine quantitatively the behavior of K_3, we have performed nonperturbative calculations using the adiabatic hyperspherical representation.

We will present the results of our studies to date, including Figure 1. This figure shows the behavior of the three-body recombination rate K_3 as a function of the scattering volume V_p at the fixed collision energy $E = 5\mu$K. We will discuss the various features of this curve, explaining them in physical terms. For instance, the $|V_p|^{8/3}$ dependence predicted above is clearly seen as

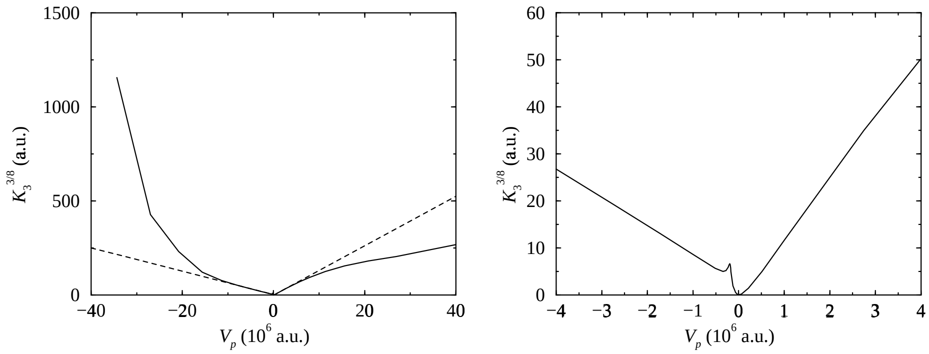

Figure 1: Left panel: Three-body recombination rate as a function of the scattering for a wide range of the scattering volume V_p at a fixed collision energy $E = 5\mu$K. The dotted line corresponds to the $|V_p|^{8/3}$ scaling. Right panel: Same as left panel, but with expanded V_p scale showing the scaling.

the straight lines in the plot of $K_3^{3/8}$ versus V_p. The physics of two-body resonances, Stuckelberg oscillations, and three-body tunneling will be invoked in the discussion. Further, implications for and comparisons with experiments will be presented.

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