Abstract

This work shows experiments exploring few-body quantum physics in the zero-energy limit. Three-body and four-body interactions are addressed. Experimental evidence for Efimov quantum states in an ultracold gas of Cs atoms and the observation of magnetically tunable inelastic collision resonances in an ultracold gas of Cs_2 dimers is presented.

We experiment on ^{133}Cs in the energetically lowest, low-field seeking hyperfine ground state at low magnetic fields trapped by far red-detuned optical dipole traps which are loaded from an optically pre-cooled atomic cloud. We can tune the two-body interaction strength via an entrance-channel dominated magnetic Feshbach resonance. We can prepare optically trapped samples of ultracold Cs_2 dimers by Feshbach association from an atomic Bose-Einstein condensate. Accurate measurements of the three-body loss rate coefficient are facilitated by the fact that spin-changing collisions are endothermic, meaning inelastic two-body losses are energetically suppressed.

In the limit of resonant two-body interaction a series of universal three-body bound states, called Efimov states, exists. Striking manifestations of Efimov states have been predicted for three-body recombination processes. We observe the rate of inelastic trap loss involving three Cs atoms and map out the dependence of the three-body loss rate coefficient α_{rec} on the scattering length a. To avoid undue thermal averaging and unitary limitation, we create thermal samples of a few nK by collapsing a Bose-Einstein condensate of Cs atoms. Our measurements concentrate on the universal regime of resonant two-body interaction. We recover the well-established universal a^4-scaling law for negative and positive, large values of the scattering length. Furthermore we observe a resonant enhancement of three-body losses in the region where $a < 0$, and a suppression of three-body losses in the region where $a > 0$. We attribute these features to the presence of Efimov quantum states. This is the first instant of experimental access to Efimov quantum states.

As first small step towards experimentally exploring four-body interactions, we observe the rate of inelastic binary collisions in an ultracold gas of Cs_2 dimers as a function of the magnetic field strength. By tuning the external magnetic field strength we vary the binding energy of the molecules on a scale corresponding to a few MHz and we transfer the molecules from the initial state into another molecular bound state by following the upper branch of an avoided level crossing. In this second molecular state two Feshbach-like collision resonances show up as strong inelastic loss features. We interpret these resonances as being induced by the presence of Cs_4 bound states, or tetramers, near the molecular scattering continuum.

Investigating few-body physics with ultracold atomic and molecular quantum gases is a newly emerging field of research. Universal aspects of three-body and four-body interactions might reveal universal effects in larger compounds. Understanding few-body systems is of great relevance to various fields of physics and future measurements will benefit from the exceptionally high degree of control over the internal and external degrees of freedom achievable in ultracold quantum gases.