ABSTRACT

The concept of universality states that physical systems, even if appearing completely different at first glance, exhibit the same behavior under certain conditions. Cesium is a prime candidate for exploring few-body physics in the regime of universal interactions due to its favorable scattering properties, which result from the existence of three broad and many narrow two-body scattering resonances. These so-called Feshbach resonances provide a large tunability of the effective two-body interaction strength.

This thesis presents experimental studies of universal three- and four-body phenomena performed in an ultracold quantum gas of cesium by trap-loss spectroscopy.

The main part of this thesis examines the Efimov scenario, which predicts the existence of an infinite series of universally related three-body bound states for resonant two-body interactions. For attractive effective interactions, these trimer states couple to the free atom continuum or, for repulsive ones, to the atom-dimer threshold. Both situations lead to an experimentally detectable enhancement of the particle loss, which is referred to as tri-atomic and atom-dimer Efimov resonance, respectively. We investigate the latter scenario in an ultracold sample of atoms and weakly bound dimers. These measurements yield the first evidence of an atom-dimer Efimov resonance. We observe a slight shift of the resonance position in comparison to what universal theory would lead us to expect. In another experiment, the properties of the three-body parameter, which incorporates all unknown short-range interactions in universal theories, are studied in an atomic cesium gas. For this, three-body losses are investigated in the vicinity of different Feshbach resonances covering a magnetic field range of about 800 G. We observe several Efimov features, including three tri-atomic Efimov resonances. The analysis of our findings shows that the three-body parameter stays essentially constant for the investigated scattering scenarios.

Utilizing an ultracold atom-dimer sample, we observe a magnetically controlled exchange process. This experiment represents the first demonstration of an elementary reaction process in the regime of universal interactions. Complete control is achieved by the magnetic tunability of the effective interaction strength.

Universal four-body processes in pure dimer and atom samples are another focus of research covered in this thesis. A collisional study based on universal dimers reveals a pronounced loss minimum. This phenomenon, which offers insight into an elementary four-body process, is still not completely understood. We extend our investigations by including non-universal dimer states and detect several narrow loss resonances, which point to the coupling of the dimers to complex molecular structures. Due to the shape of the resonances, we can conclude that these features are induced by tetramer states; so far, the properties of these states remain unknown.

A recent theoretical study suggests the existence of two universal four-body states accompanying each Efimov trimer state. To verify this scenario, we analyze four-body losses in an ultracold atomic sample, thereby identifying two resonances representing the first evidence for these universal four-body states. This result is in good agreement with the expectations from theory.