Abstract

Cesium is an outstanding candidate in the field of ultracold quantum gases as it provides a very rich molecular energy structure. Various Feshbach resonances are available to efficiently produce ultracold molecules. Moreover, these resonances serve as "entrance doors" into the complex molecular structure near threshold. In the context of this thesis, we have thoroughly explored the molecular quantum states at low magnetic fields using various techniques.

In our experiment, we use several magnetically tunable Feshbach resonances to create Cs_2 molecules from ultracold ^{133}Cs atoms. Up to 20000 molecules confined in a crossed CO_2-laser dipole trap can be prepared at temperatures of about 250 nK. We have developed elaborate methods to transfer molecules to various internal states, to clean the population in the optical trap from remaining atoms and from molecules in unwanted states, and to detect the molecular population via controlled dissociation. In particular, we have investigated states with high orbital angular momentum which so far have been unexplored. For these states direct Feshbach association is not possible because of negligible coupling to the atomic threshold.

We have explored ro-vibrational molecular quantum states using two different techniques. Magnetic moment spectroscopy is a versatile technique which has allowed to map out the molecular spectrum up to binding energies of $E_b = h \times 10\,\text{MHz}$ in a magnetic field range from 5 to 55 G. Using microwave spectroscopy, we have performed highly precise measurements of the binding energy of a particularly important s-wave state in an energy range $E_b < h \times 20\,\text{MHz}$. The microwave results show the transition into a weakly bound state with quantum-halo character. Precise knowledge about this s-wave state is important for applications related to the research of universal few-body quantum physics such as Efimov's effect.

As an example for coherent manipulations of the molecular states, we have realized a time-domain molecular 'Stückelberg interferometer'. A coherent superposition of two internal molecular states is achieved by means of an appropriately chosen magnetic field ramp over an avoided crossing. In a Ramsey-type interferometer scheme we observe macroscopic matter-wave interference between the two dimer states. As a first application, we have determined the precise position and the coupling strength of the avoided crossing in good agreement with theory.