Abstract

In this thesis I report on experiments with ultracold molecules and atom pairs in optical lattice potentials. We combine the capabilities of the optical lattices with two powerful "tools" used in atom physics: magnetic Feshbach resonances and two-color Raman transitions. We demonstrate a high degree of control of ultracold lattice gases on the quantum level by both realizing a coherent optical transfer between two molecular states, and by exploring a so far undiscovered "exotic" bound state, which is caused by the repulsive interaction between the atoms.

The starting point of the presented experiments is a pure quantum lattice gas of ultracold molecules. This molecular lattice gas is produced by first loading a Bose-Einstein condensate of ⁸⁷Rubidium atoms into a three-dimensional optical lattice. We can then efficiently convert the atoms in doubly occupied lattice sites into molecules by magnetoassociation across a Feshbach resonance. With this method the conversion is performed in a very controlled way and we create the molecules with almost unity efficiency in a well-defined quantum state.

In the first part of this thesis I report on the demonstration of a coherent optical transfer of a pure ensemble of ultracold molecules to a deeper bound molecular state via stimulated Raman adiabatic passage (STIRAP). The key idea of this method is to keep the molecules in a dark superposition state during the transfer. This state is decoupled from the light and thus losses due to spontaneous light scattering are suppressed. We are able to test interferometrically the coherence of this molecular quantum superposition state. These results represent an important step towards Bose-Einstein condensation of molecules in the vibrational ground state.

In the second part of this work I report on the discovery of a novel kind of bound object, consisting of two atoms which repel each other. We create the repulsively bound atom pairs by dissociating the molecules in the individual lattice sites with the help of a magnetic Feshbach resonance. This new type of bound object remains stable because the large repulsive interaction between the atoms cannot be converted into kinetic energy in the structured environment of an optical lattice where the phase space for the unbound constituents is strongly restricted. The lack of dissipation in optical lattices allows the pairs to be long-lived, and to undergo coherent dynamics on long timescales. Signatures of the pairs are also recognized in the characteristic momentum distribution and through spectroscopic measurements. We are able to consistently describe our results with the Bose-Hubbard model. This is of importance since this model is also the theoretical basis for many other strongly correlated condensed matter systems and quantum information.