Abstract

The combination of an ultracold gas with a periodic potential in the form of an optical lattice opens up the opportunity to study phenomena known from solid state physics in a clean and well isolated environment, with a high degree of control over both internal and external degrees of freedom. This thesis reports on the realization of a tunable quantum gas in an optical lattice, where the use of Cs atoms allows a precise control over the atom-atom interactions using a broad Feshbach resonance. In particular, it is possible to strongly suppress the interactions by tuning the scattering length close to zero.

In the framework of this thesis, a Cs BEC apparatus was constructed with the specific aim to perform experiments with optical lattices. The apparatus is an evolution of the first-generation Innsbruck Cs BEC apparatus. Instead of using a stainless steel vacuum chamber, the Cs atoms are trapped in a glass cell, which allows for fast and precise control over magnetic fields without disturbing eddy currents. The setup was designed to allow a large optical access, enabling the addition of an optical lattice, and is capable of producing a Cs BEC of up to $2 \cdot 10^5$ atoms every 10 s.

The control over atom-atom interactions is demonstrated in two sets of experiments studying the effect of interactions on a Bloch oscillating BEC. The atom-atom interactions lead to density-dependent phase shifts at the individual lattice sites and limit the number of Bloch oscillations one can observe. In the first set of experiments, we quantitatively characterize this dephasing as a function of the magnetic field and determine the point where atom-atom interactions are minimized. With interactions minimized, more than 20000 Bloch oscillations can be followed, corresponding to a coherent evolution over more than 10 s. The force inducing the Bloch oscillations can then be determined with better than 10^{-6} precision. Our technique to suppress interactions has potential applications for BEC atom interferometry, where phase shifts and decoherence due to interactions are a major problem.

In the second set of experiments, we observe and control matter wave interference that is driven by interparticle interactions. We show that interaction-induced phase shifts lead to the development of a regular interference pattern in the wave function of a Bloch oscillating BEC. The high degree of coherence in this process is demonstrated in a matter wave spin-echo type experiment, where the phase evolution of a dephased BEC is reversed by tuning the scattering length close to zero and applying an external potential, allowing us to recover the original BEC wave function.