New experiments with a BEC in an optical lattice

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A second BEC experiment has been set up in Oxford and we have recently observed Bose condensed clouds of ^{87}Rb in the $|F = 1, m_F = -1>$ state, trapped in a TOP magnetic trap. This apparatus will be used to observe the Feshbach resonances in the $|F = 1, m_F = +1>$, in a way similar to the experiment performed in a Bose-Einstein condensate of sodium atoms [1]. Such resonances have been predicted for ^{87}Rb atoms in the $|F = 1, m_F = +1>$ state for three different values of a dc magnetic field (383, 643 and 1018 G) [2]. We will load the BEC in a one-dimensional optical lattice obtained from a standing wave of light at 850 nm focused at a waist of 50 μm, turn off the magnetic trapping potential and drive spin flips to the $|F = 1, m_F = +1>$ state by means of rf transitions of the spin polarized atoms in the presence of a small bias field. Then, we will turn on a magnetic field and we will observe the predicted Feshbach resonances looking for a sudden decrease in the number of atoms for certain values of the magnetic field.

These Feshbach resonances should allow us to tune the strength of the interaction between the atoms from very low values (or even negative values that lead to a collapse of the condensate) to very high values where the interaction term becomes the dominant one in the Hamiltonian. This tuneability of the interactions (scattering length) will enable us to observe the phase coherence of the system decreasing until we achieve a transition to a Mott insulator phase.

To reach this peculiar quantum phase the relevant parameter is the ratio U/J of the repulsion energy between atoms in a lattice site and the strength of the tunnelling term between neighbouring sites. The transition occurs when this ratio is $U/J = z * 5.8$ [3], z being the number of next neighbours of a lattice site. For strong tunnelling such that the interaction is negligible the system is a superfluid, each single particle wavefunction is spread all over the lattice with a Poissonian number distribution. As the tunnelling strength decreases compared to the interaction term, the single particle wavefunctions become more and more localised. This feature allowed the observation of squeezed number states [4] with sub-Poissonian fluctuations in the number of atoms and a shorter-range phase coherence. In the strong interaction limit exact number states can be created during the Mott insulator transition, with zero coherence throughout the lattice.

Other experiments [5, 4] varied the parameter U/J by changing the depth of the optical lattice, i.e. modifying the tunnelling strength. Another possibility is to modify the interaction strength U that is proportional to the scattering length a of an atom. We will achieve this by exploiting the Feshbach resonances to change the scattering length thus tuning the strength of the interaction term.

Experiments using atoms in the number states created in a Mott insulator phase may lead to a better comprehension of fundamental limits of quantum mechanics and advances in quantum computation with neutral atoms.

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