Flat band modes and compact localised states using Bose-Einstein condensates with spin-orbit coupling in a 2D lattice

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ABSTRACT

Keywords: Bose-Einstein condensate, Spin-orbit coupling, Flat band, Compact localised state, Optical lattice

Introduction

A Bose-Einstein condensate (BEC) is a phase of matter in which a collection of bosons occupy the same mascroscopic quantum state. This occurs when the de Broglie wavelength approaches the interparticle spacing. At this point the wavefunctions of the particles overlap and the particles can be treated as a single classical field. BECs are ideal tools for exploring analogies to other physical systems, including condensed matter systems, because of the easily tunable parameters. In the realm of condensed matter physics, BECs can be used to provide insight into the superfluid-Mott insulator transition, topological insulators, and other quantum Hall effects.

Atomic species used in BEC experiments are neutral atoms, and thus not subject to electromagnetic forces in the same way as charged particles. This is ostensibly an impediment to the modelling of structures such as metals and ferromagnets, however, artificial gauge fields can be used to emulate electronic and spintronic effects. Spin-orbit coupling (SOC) is a simple example of an artificial gauge field that can be used to induce behaviours similar to those of charged particles. In SOC, the spin of a particle is coupled to its linear momentum, in analogy to the relativistic coupling of an electron's spin with orbital angular momentum in an atom. SOC was realised in 2011[1] where one dimensional SOC with pseudo-spine 1/2 bosons was achieved.

Optical lattices, normally created by the interference of multiple laser beams, are periodic microscopic potentials for atoms which are induced by the AC Stark effect. Optical lattices have been used as a realisation of the Bose-Hubbard model. SOC can be applied to atoms in optical lattices and give rise to many interesting effects. There have been a number of theoretical treatments of SOC on lattices, some of which predict the onset of topological insulators, materials that insulate in the bulk but conduct along surfaces.

In a lattice, The dispersion curve relates the particle energy to its wavevector across the Brillouin zone. Normally, there is a quadratic relationship between energy and momentum, however, there are configurations in which the relationship is dispersionless. In this case the curve is flat, a flat band (FB) mode,[2] and the energy does not change with momentum. A flat band in momentum space is conjugate to localisation in position space, and thus FB modes can give rise to compact localised states (CLS), in which the particles are localised to a single or a few lattice sites. Theoretical work has predicted flat band modes can be achieved in diamond lattices when treated with SOC[3]. In this work we test that hypothesis.

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Method

We create a BEC of about 10^4 ^{87}Rb atoms in an all-optical trap.[4] From here the atoms are transferred to a 2D pancake trap created by two 1064 nm beams intersecting at a shallow angle. These beams are red-detuned and thus attract the atoms from the dipole trap. Once the atoms are loaded into the 2D trap, a 532 nm laser is shaped by a spatial light modulator (SLM) to create an arbitrary 2D potential. This potential is blue-detuned and thus repulsive to the atoms. In this case the potential used is that of a diamond lattice (Figure 1).

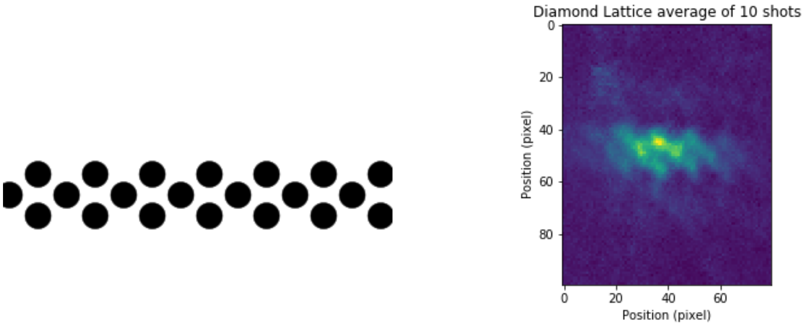

Figure 1. (a) The image projected by the SLM. (b) An average of 10 shots of the SLM image

The prediction that we are testing is that SOC will cause CLSs in a diamond lattice.

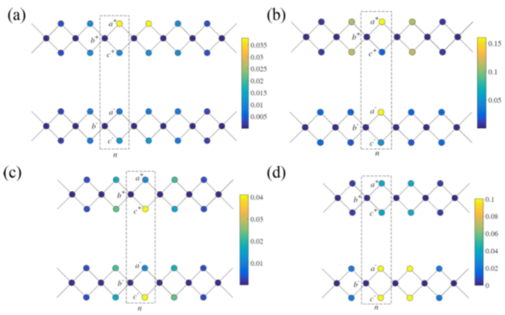

Figure 2. CLS in a diamond lattice

As can be seen in Figure 2, the density of the atoms is localised to particular lattice sites.

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