Abstract

Recently it was suggested to extend the dimension of optical lattices by using atomic internal degrees of freedom as an extra dimension [1]. Here we demonstrate that one can engineer a two-dimensional lattice with nonzero synthetic magnetic flux using atoms in a standard one-dimensional optical lattice [2]. The additional dimension appears due to laser-assisted transitions between the atomic sub-levels in the ground state manifold. The synthetic magnetic flux is generated by a combination of an ordinary tunnelling in the real space and laser-assisted transitions characterised by the complex amplitudes in the extra dimension. A distinctive feature of the proposed scheme is the sharp boundaries in the extra dimension, a feature that is difficult to implement for the atoms in optical lattices in the real-space. The boundaries of the extra dimension can be closed down using additional laser-assisted transitions. Closing the boundaries of the extra dimensions leads to a remarkably simple realisation of the fractional (Hofstadter butterfly-type) spectrum.


Optical lattices in extra dimensions

1D chain of atoms in real dimension

Raman transitions between magnetic sublevels

$\lambda$ - extra dimension

Tunneling in real dimension and Raman transitions in the extra dimension yield a 2D lattice involving real and extra dimensions.

Combination of real and extra dimensions yields strong and non-staggered magnetic flux $\gamma = k\alpha$ per 2D plaquette.

Sharp boundaries in extra dimension

Conducting edge states in extra dimension

Experiments

1D atomic gas

Lattice

Raman


• alkaline-earth-like $^{173}$Yb atoms
• synthetic dimension encoded in a subset of the $F = 5/2$ nuclear spin manifold
• Existence of edge states detected
• Observed edge-cyclotron orbits


• $^{87}$Rb BECs in the $F = 1$ ground state hyperfine manifold
• Directly imaged individual bulk and edge eigenstates
• Experimental observation of their edge localization and transverse skipping motion

Acknowledgements

J. R and G. J. acknowledges the financial support by the European Social Fund under the Global Grant measure

Edge states

Dispersion branches

(a) $\Omega_0 = 0.14t$

(b) $\Omega_0 = 0.5t$

Atoms with opposite spins move in opposite directions

Spin-independent potential (road block)

Spin-dependent potential (perturbation for $m = 1$)

Spin-dependent potential (perturbation for $m = 0$)

Scattering of edge state atoms by a short-range potential:

Black dashed line – spin-independent perturbation (road block).

Red dashed line – perturbation for $m = \pm 1$.

Blue line – perturbation for $m = 0$.

Closed boundaries

Various possibilities:

Combination of Raman and two-photon IR transitions

Connecting different $F$ manifolds via rf fields

Formation of Hofstadter butterfly using artificial dimensions