abstract

Topological materials are characterized by a number of exotic effects such as robust metallic states on the edges.
Due to these properties and their potential application in quantum information sciences, systems showing topological phenomena gained a lot of attention and are intensively studied both in theory and in experiment.
To realize such effects in well controllable environment, one can use systems of ultracold atoms.
Moving in periodic optical potential, ultracold atoms mimic behavior of electrons in solid state being at the same time easy to tune and probe.
They offer an ideal playground for studying and probing exotic phenomena.

First step to realize topological effects is to create non-trivial lattice geometries.
Then tunneling between the lattice sites must be properly engineered such that there are nonzero geometric phases associated with the particles.
To this end we study two species fermionic atoms trapped in different lattices of simple geometries.
Atoms are attractively interacting and in the considerations we include effects of higher bands.
We show that in certain regimes orbital effects such as interband tunneling can be dominant and give rise to the self-assembly of the atoms into non-trivial structures.

In the case of the trapping potential of square geometry, we use strongly interacting atoms.
We theoretically study regimes of tunable parameters in which interaction induced effects cause formation of two sublattices of the Lieb geometry.
Such geometry of the potential is associated with a band structure of topological properties.
We show emergence of pseudo-spin degrees of freedom and discussed how topological effects -- anomalous quantum Hall effect and quantum spin Hall effect -- can be realized in the system.

When it comes to weakly interacting systems, we propose to favor orbital effects by periodic driving of the trapping potential.
Changing parameters of such lattice shaking gives are control over tunneling rates.
We show that properly adjusted lattice shaking can give rise to topological effects in 1D system.
Namely, we show that in a simple sinusoidal lattice, one can induce formation of dimerized structure with staggered tunneling such that the system realizes Su-Schrieffer-Heeger and Rice-Mele models.
Emergent nature of the dimerized structure assures existence of defects which amount can be easily controlled in the experiments.
On such defects topologically protected localized modes associated with fractional fermionic number can arise.

Next, we investigate an elliptically shaken system of triangular geometry.
Again orbital effects dominate for properly chosen parameters and the atoms self-organize into a structure called the dice lattice.
Together with the emergence of this structure we observe appearance of effective staggered field that is non-Abelian in nature.
We can change the strength of the synthetic field and in this way influence energy band structure of the system.
Manipulating the parameters we can induce magnetization of the system and appearance of the anomalous and quantum anomalous Hall effects.

We show that orbital effects combined with strong interaction or properly adjusted shaking can be used to engineer topological effects in the systems of cold atoms.
Our findings show alternative method to realize exotic phenomena in ultracold atoms.
Moreover we emphasize the importance of orbital effects in certain regimes and their influence on the properties of the system.
The experimental advantage of the proposed method is the simplicity of the trapping potential, flexibility with choice of the components of the setup and presence of controllable defects that play significant role in topological phenomena.