Description for general public

Overview of atomic optics

Field of my research – atomic optics, is a branch of physics studying quantum nature of atomic gases, their interactions with each other and with external electromagnetic fields (especially light). It also develops techniques to control atoms, and cool them even to temperatures of order 0.0000001 Kelvin – nearly absolute zero. Such systems have wide range of applications. Easy control and study made them the best up to date realization of the quantum simulator. Idea of such a simulator dates back to eighties when it was reply for problems of solid state physics, as many theories describing solids on atomic scale could not be checked experimentally. In year 1982 Richard Feynman proposed that instead of trying to study systems hard to study one should try to create systems which obey the same physics but do not create so big problems in lab. Nowadays we can use ultracold atomic gases not only to simulate solid state systems, but also for example to model accretion of gas onto neutron star.

One of most important structures used in quantum simulation is optical lattice – artificial crystal. Superposition of two counterpropagating laser beams creates standing wave of light, light intensity changes periodically mimicking periodic structure of crystalline lattice. Ultracold atomic gas loaded into such lattice interacts with light and acts as electrons in solid state. Such a system is highly controllable – changing light intensity one can change depth of potential which in normal crystal is impossible.

Goal of the project

Aim of my project is to develop new methods of controlling ultracold atomic gases placed in bichromatic optical lattices (composed of two beams with different wavelengths). Studied methods will be based on fast time-periodic modulations of lattices and the main goal is to use them to describe setup for filter for energies of particles – system which let through only atoms with given energies and holds rest.

Such a system can be created using Anderson localization – phenomenon of localization of particles in disordered systems. Probability wave of particle scatters on randomly placed obstacles in such a way that it interferes destructively almost everywhere. Only in small area interference is constructive – this is a place of particle localization.

Disorder can be created in optical lattices in a few ways, one is to use two beams which ratio of wavelengths is not commensurate. In practice, it comes down to change of depth of sites. In fact, these changes are not random, it is rather quasi-disorder but it is enough to localize atoms. However in such system depending on parameters whether all particles are localized or none, so unfortunately this system cannot be used to create filter for energies.

Method that can help, is fast time-periodic modulation of system. This technique is used to generate many effects in cold atomic systems. Using it one can make the atom behave like it is in nearly infinitely deep lattice or if it has electric charge and move in magnetic field. All such effects are possible because when we do such fast periodic changes of system, probability wave of particle also changes but not quite periodically, there is some constant shift, which for longer times result in change of overall behavior.

Initial calculations show that when we modulate our lattice new effects appear, which probably allow creation of filter for energies. To confirm this and study detailed properties of such filter numerical calculations will be made – investigating dynamics of atoms in optical lattices analytically is usually impossible.

Reasons for choosing the research topic

Studying new procedures of modulation and determining what effects came from them, will broaden area in which ultracold atomic gases in optical lattices can be used as quantum simulators. Thanks to this, potentially it will be possible to realize experimentally models, which were so far described only theoretically. Filter for energies itself can be very useful in ultracold atoms labs. Especially due to high controllability. For example it can be source of atoms with precisely chosen energy to be used in interferometric experiments – thus increasing their accuracy. Other possibility is putting into filter cloud of atoms from other experiment and checking how many of them escapes for different settings – this will gave us information about energy distribution of atoms.