Description for general public

Topology is one of the most important disciplines of modern mathematics. In comparison with geometry, which is based on the concept of distance (metric), the topology describes the properties of the space which are independent from the metric. Instead of that topology examines quantities that are invariant under continuous transformation – topological invariants. An example of such a property is the so-called genus, which is the total number of holes in a space. Topological quantum systems have crucial properties related to the topology of the space of quantum states, the abstract space that describes the quantum system. Due to the global nature of topological invariant, any physical effect directly associated with them cannot be destroyed by local fluctuations. One of the first examples of topological effects is the Integer Quantum Hall effect. In a strong magnetic field in an effectively two-dimensional electron gas, the transverse conductivity (so-called Hall conductivity) is proportional to the an integer number, which is topological invariant known as the first Chern number. Such systems possesses localized edge states which conduct an electrical current without resistance, because of topological protection. These kinds of states are a general feature of topological structures and have many potential applications, especially in electronics (lossless current transport) or quantum computing (qubit protected by topology).

The main part of this project is examination of the effects associated with interactions between particles in two-dimensional crystalline systems, such as Chern insulators and topological insulators. These systems have conductive edge states, while in the bulk they are insulators. In topological insulator time reversal symmetry is preserved, in the opposite to the Chern insulators in which this symmetry is broken. In such systems, interactions lead to the emergence of highly correlated, noncompressible quantum liquids, which in this case are called fractional Chern insulators and fractional topological insulators. While in three spatial dimensions identical particles obey either bosonic or fermionic statistics, quasiparticles in such liquids can obey exotic fractional statistics. This kind of particle are called anyons. These liquid states compete with Wigner crystallization, the states of highly localized electrons that form a crystalline lattice. The project will investigate the transition between topological quantum liquids and Wigner crystals and analyze the properties of the anyons for different filling factors.

Electronic interactions in the quantum system can not only lead to quantum liquids with fractional statistics, but can also be responsible for changing its topology. This means that the topologically trivial system can become nontrivial as a result of interactions. This effect is expected to appear in twisted graphene bilayers and other atomically thin bilayer crystals. Graphene is the two-dimensional carbon crystal with a thickness of one atom. The discovery of graphene was honored with the Nobel Prize in 2010 years, and its properties in today's time are fairly well understood. Recently, it was shown that the properties of two layers of graphene, rotated with respect to each other by a small angle, are significantly different from the physics of a single layer. The twisted bilayer graphene and other bilayer crystals can host the nearly flat band for particular values of twist angles. This opens up a possibility to design new quantum systems with strong electron-electron interactions and in consequence appearance of new quantum phases.

In conclusion, the project is focused on investigation the effects of interactions in topological structures, in particular the topological properties of twisted two-dimensional crystals, fractional Chern insulators, fractional topological insulators and Wigner crystallization.