

Quench Dynamics of Topological Materials: Dynamical Phase Transitions and Entanglement

Quantum systems have many strange properties compared to the classical systems with which we are familiar in everyday life, some of the most famous examples being wave-particle duality and quantum teleportation, a result of entanglement. However the way in which quantum systems evolve in time can also lead to new and interesting physical phenomena. Here we focus on several such dynamical phenomena, namely quantum quenches and time crystals. The goal of this project is to understand how these sudden or periodic changes lead to new phases of matter. We will investigate the properties of these dynamical states, looking for new types of dynamical phases and ways in which they may be experimentally realised and observed.

The particular type of quantum systems we will consider are so called topological insulators. These are materials which do not conduct electricity in the bulk, but do on their edges or surfaces. The edge and surface currents are carried by special protected states which due to their topology are not easy to destroy, meaning that these currents are very robust to disorder and other perturbations. The role that the edge and surface states play in the dynamics of topological insulators is one of the main focuses of this project.

Suddenly changing, i.e. quenching, the properties of a quantum system leads to a situation where the quantum material is far from its thermal equilibrium, and can lead to transient phenomena such as new phase transitions occurring during the dynamics. It will be studied in detail in what way the edge and surface currents modify the dynamical phase transitions. These dynamical phase transitions differ fundamentally from the standard phase transitions that separate different states of matter. A famous example of a phase transition is water boiling, when it changes from liquid to vapour as the temperature is increased. Dynamical phase transitions however are a fundamentally new kind of transition which occurs as a function of time, not of temperature or any other parameter.

Entanglement is the long range quantum property that allows for quantum teleportation and gives rise to Einstein's "spooky action at a distance". During time evolution this entanglement grows and changes, and a particular role in the whole process is played by the surface and edge currents. We will study exactly how this entanglement is formed during the time evolution.

From this project we expect to gain a deeper understanding of the way in which topological insulators change in time subject to perturbations. This in turn will give us insight into potential new phases of matter which can be formed during time evolution, and the role played by the special edge and surface currents in the formation of new phases, or the development of correlations and entanglement in evolving quantum systems.