UNIVERSITEIT VAN AMSTERDAM

Symmetries and Topology in Quantum Baths
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Symmetries and Topology in Quantum Baths

An important part of condensed matter theory is building models of many-body quantum systems, in order to better understand the collective behavior of the particles that constitute them. In many of these models, it is assumed that the system is perfectly isolated from its environment, but this is not always true for their counterparts in the real world. For example, a quantum computer may work flawlessly on paper, but any realization will have to deal with environmental noise that can destroy the carefully prepared quantum superpositions on which the computer relies. That is why it is important to improve our theoretical understanding of the effects of noise on condensed matter systems.

Systems that are not completely isolated from their environment are known as dissipative or open systems. The environment can be modeled as a quantum bath that is coupled to the system, similar to a heat bath from the theory of thermodynamics. Although the model does not keep track of everything that happens inside the quantum bath, it provides a probabilistic description of the effect that the bath has on the system. In other words, it tells you the chance that the environment will have disturbed the system in a certain way at any point in time. The dynamics of such an open quantum system is no longer predicted by the Schrödinger equation, which determines the time evolution of an isolated quantum system, but by a generalization known as the Lindblad master equation. Because the description is probabilistic, the time evolution is irreversible and produces entropy, as information flows from the system into the bath and disappears. The effect of a bath coupled to a quantum system is therefore also known as dissipation.

In this Thesis, I study dissipation in a number of one-dimensional models from condensed matter physics. The main purpose is to see how the dissipation interacts with other properties, such as topological order and different types of symmetries. Topology is the study of objects that can be smoothly deformed into one another and its application to the electronic band structures of materials has led to a minor revolution in the field. So-called topological insulators and superconductors are exotic phases of matter characterized by perfectly conducting edge modes, that are protected from impurities or perturbations by the symmetries of the system. By changing some of the system parameters, these models can undergo a topological phase transition, in which the topological order changes and the edge modes vanish or appear. A simple one-dimensional example of a topological superconductor is the Kitaev chain. It is this model that I have studied in the presence of dissipation, hoping to find out what happens to the topological order.

The dissipative Kitaev chain is a non-interacting model, which means that almost any property can be calculated efficiently, even for a relatively large number of particles. For the type of dissipation that I considered, where every site of the chain is coupled to a quantum bath in the same manner, the edge modes in the topological phase decay over time. However, the way they decay can still tell us something about the topological order of the system. The dissipation also creates an intermediate region between the topological and trivial phases, in which the topological order is not well-defined. Finally, if you wait long enough, the dissipation causes a current to run through the system, which appears to be somewhat sensitive to the topological order. If we add periodic driving to the dissipative Kitaev chain, by switching the electric potential back and forth between two values, this creates even more interesting topological features. As a result of the driving, two different kinds of edge modes appear and it becomes possible for multiple modes to accumulate on each edge.

Finally, I investigate the effect of dissipation on interacting models and how symmetries might help us analyze this effect. The XXZ Heisenberg spin chain with dissipation --- a string of interacting quantum magnets, each one coupled to a bath --- serves as an example. While the dynamics of such a model are very difficult to compute, certain observables like the total magnetization of the spin chain behave in a peculiar way. By studying the symmetry properties of both the system and the bath, I show that the dissipation causes the expectation value of the magnetization to relax in a simple and coherent manner, only adding an overall damping factor to the dynamics of the isolated system.