EE4902 Mini-project Research statement

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August 11, 2022

Forrays into Disordered systems, the XY and the Clock model

The quantum clock model and XY model are vital tools to model superconductivity. These models describe a 2D lattice of spins with nearest neighbor interactions, with spins pointing in a discrete or continuous set of directions. Such models' phase diagram is rich with multiple phases; particularly, it has a vortex phase. Such vortices appear in various devices employing superconducting elements, which may or may not be desirable for their operation. The popularity of superconducting qubits has triggered a vast amount of research in vortices, and some groups are also trying to make qubits out of the vortex-antivortex pair. Understanding the phase diagram and quench behavior of the disordered XY model or the clock model for natural systems can enable greater control and perhaps even the ability to manipulate these vortices for various applications.

This project aims to study the effect of disorder on the phase diagram and the quench dynamics(response to sudden changes in temperatures and the nature of defects caused therein) of the system. Starting with the study of the theory of a clean clock model, I will attempt to analyze a model with disorder. Any deviation from regularity can be thought of as disorder in the model. These can be point defects that represent a vacancy in the crystal, anomalous bond strengths due to impurities or local stresses, or a stray magnetic field. I will look at columnar defects in bond strength; spins in a row will interact differently from those in a column. Heavy ion irradiation can introduce this defect in a high-Tc superconducting lattice. It pins the vortices allowing dissipationless current flow. In a disorder-free model, it has been shown that the number of vortices that remain after the system passes from the vortex phase to the disordered phase depend upon the critical exponents of the same phase transition in some regions of the phase diagram. It is not known if such behaviour is observed in the disordered clock or the XY model.

I plan to learn and apply the strong disorder renormalization group(SDRG) technique to analyze the disordered system. (SDRG) involves iteratively replacing local high-energy states; for example, an anomalously strong coupling between two spins will cause splitting much larger than that due to standard coupling between these and the other spins. It becomes possible to treat the two spins as a super spin in a magnetic field such that the energy scales are much lower than before. Repetition results in energy scales crossing the thermal energy scale at some point. Since, in this equivalent model, the thermal energy is more than the coupling strengths, all spins can be treated as independent, and the standard statistical mechanics can be used to derive the properties of the system. If time permits, I will try the same calculations with the XY model or perform numerical simulations using the Monte-Carlo method for the clock model to verify the results of my analysis.