Chapter 6

Summary and future plans

6.1 Summary

We extensively studied the quantum mechanical aspects of skyrmions and identified it's various properties in this thesis. We used quantities like scalar chirality, which is the quantum mechanical analogue to the classical topological charge, and topological entanglement entropy, which is the topological invariant part of a multi partite entanglement entropy, to identify the skyrmion order in various magnetic crystals. In a triangular lattice frustration is introduced by means of competing nearest neighbouring ferromagnetic interaction and anti ferromagnetic next nearest neighbouring interaction. Dzyaloshinskii-Moriya interaction introduces the broken inversion symmetry which mediates non-collinearity in magnetic ordering. We showed that this setup results into the formation of quantum skyrmion by the aid of scalar chirality. We noticed that strong next nearest neighbouring interactions causes the skyrmions to be more stable. We identified helical, skyrmionic and ferromagnetic ordering in this systme, A quench from skyrmion to a ferromagnet resulted in the observation of dynamic quantum phase transition. A quench from skyrmion to a helical phase does not show such DQPT. We studied different geometries and hamiltonians in order to account for the scaling and universality of this problem. In another attempt we introduced a topologically invariant entropy component which can be used to determine the phase boundaries in a precise manner. Topological entanglement entropy along with the scalar chirality identified the phase boundaries better. Also we proved that increasing the next nearest neighbouring antiferromagnetic exchange interacion improves the stability of skyrmion.

We studied the dynamic behaviour of the skyrmions by employing unitary evolution and monitoring various observables of interest. We were looking for the possible enhancement in entropy and entropy production rate due to the existence of dynamical quantum phase transition. By assessing the dynamical behaviour of various quantities we concluded that in the several skyrmion models we considered the DQPT does not aid in the enhancement of entorpy production. Neither could we find a one to one correspondane between entropy production rate and rate function. We observed that the topological entanglement entropy and magnetization behave differently when there is DQPT and when there is no DQPT.

Skyrmions are topologically protected stable solitons. This stability endows them with unexpected properties. These properties are key in the advancement of spintronics and quantum computing technologies. We looked for the practicality of using the topological protection and studied the thermodynamics of the system. We modelled a skyrmion made in a rectangular lattice having nearest neigbouring ferromagnetic exchange with an axial Heisenberg anisotropy and Dzyaloshinski Moriya interaction. The quantum lattice is surrounded by classical ferromagnetic vector magnetic moments. Here we identified the skyrmion and ferromagnetic phases with the aid of Topological index and winding parameter. The irreversible work calculated turned out to be zero for the skyrmion phase and we used this property to propose a heat engine using this skyrmion working substance. The proposed engine showed promising enhancement in efficiency. We also proposed that this skyrmion heat engine can be externally controlled by means of the technique of surface plasmon polaritons using laser interacting with free electrons in a metal dielectric interface and control the power output. This thesis explored various models for quantum skyrmions and gave new observables to quantify it. Identified application to quantum skyrmions.

6.2 Future plans

The experimental realization of skyrmion heat engine will help to reduce thermal throttling in spintronic devices. Skyrmion can be used to send quantum informations without loss due to its topological protection. Layers of skyrmions can be used like a quantum channel where one layer acts similar to a qubit. The effect of disorder on skyrmions is an intriguing thought to explore. The disorder has the tendancy to enhance localizations such as skyrmions.

Merons are intriguing topological entities similar to skyrmions. Unlike skyrmions, merons have half topological charge. As a natural extension to the current study we can look at the nanoscale merons and their quantum behaviours.