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ABSTRACT

Title: Topological Properties of some quantum systems

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In this dissertation, topological properties of four different systems have been described and evaluated. Simple Haldane-like model has been proposed on non-interacting fermionic systems formulated on the three-band stuffed honeycomb lattice and two-band depleted Lieb lattice in tight-binding regime. Interplay among the hopping parameters, complex phases and onsite energies has been found to generate intriguing topological phases and phase transitions. In another fermionic system considered on the four-band square-octagon lattice, the emergence of multiple topological phase transitions and generation of phases with higher Chern numbers have been shown to be induced by periodic irradiation. Furthermore, first and second order exotic topological phases has been identified and substantiated on a bosonic system of ferromagnetic Heisenberg model formulated on breathing kagome lattice, in the absence and presence of Dzyaloshinskii-Moriya (DM) interaction.

In the second chapter, stuffed honeycomb lattice has been probed, which interpolates between honeycomb, triangular and dice lattices. Complex phase coupled with NNN hopping and asymmetric onsite energy are introduced to break time reversal, chiral and particle-hole symmetries. Chern insulating (CI) and Chern semi-metallic (CSM) phases are produced with non-zero Chern numbers characterizing the bands. These are validated by the existence of edge states in open geometry and integer quantum hall (IQH) plateaus. Thus, addition of extra sublattice leads to novel CI phases with higher Chern numbers. To validate this, a stuffed square lattice is also considered. Spin-orbit coupling breaks the time reversal symmetry of up-spin and down-spin Hamiltonian to produce exotic Chern insulating phases with higher Chern numbers, which is cross-verified with the number of in-gap edge modes between the bulk bands.

In chapter three, square-octagon lattice is investigated which consists of square and octagonal plaquettes. The spin-1/2 V^{4+} ions of the anti-ferromagnetic spin-liquid CaV_4O_9 arrange themselves in square-octagon structure. The system shows trivial topology as it consists of quadratic band touching points and a pair of flat bands. When the effect of circularly polarized light is taken into consideration in the effective Hamiltonian using Floquet-Bloch theory, the energy spectrum becomes gapped. Simultaneously, the system becomes nontrivial as confirmed by the bands acquiring non-zero Chern numbers as well as the IQH plateaus and in-gap edge modes in the open geometry. Multiple and rapid topological phase transitions occur when the amplitude of incident light and the hopping strengths are varied.

In the following chapter, ferromagnetic (FM) Heisenberg Hamiltonian is formulated on breathing kagome lattice. Magnon dispersion relation is obtained by using linear

spin wave theory. As the flat upper band touches the middle band in four corners of the Brillouin zone, conventional first order topological phase is not possible. Considering a finite triangular replica of the system in 0 D, three states at the three corners of the triangle have been found, correlating with the edge mode pattern of 1D system. Set of polarization vectors has been defined which works as the topological invariant and characterizes this second order topological magnon insulating (SOTMI) phase. Moreover, DM interaction is added along NN bonds to open up the gap between upper bands. Three different first order topological magnetic insulating (TMI) phases are observed in the relevant parameter space. Simultaneous occurrence of first order and second order TMI phases are confirmed by calculating the respective topological invariants and edge (corner) geometry. Violation of the second order bulk-corner correspondence rule has been noted in some regions. Thermal hall conductivity is calculated for ease of experimental verification of TMI phases.

In the penultimate chapter, depleted Lieb lattice has been studied for occurrence of CI phases. This lattice is derived from Lieb lattice by depleting one of the sites. The two-band spectrum of depleted Lieb lattice shows one Dirac cone but does not retain the flat band of Lieb lattice. To break the time reversal and sublattice symmetries, complex phase coupled with NNNN hopping and staggered onsite energy are incorporated in the Hamiltonian. Existence of topological phase is confirmed by the analytical and numerical calculation of Chern numbers, edge geometry and IQH plateau. Additionally, bilayer version of this model is explored to find new topological phase in the extended parameter space. This four-band system was successfully able to produce CI phase with higher Chern numbers. Finally, a comprehensive discussion based on the results obtained in this investigation is presented in the last chapter.

This dissertation is based on the following four articles published in the international journals.

1. Nontrivial topological phases on the stuffed honeycomb lattice, *Arghya Sil and Asim Kumar Ghosh,* J. Phys.: Condens. Matter **32**, 025601 (2019).

2. Emergence of photo-induced multiple topological phases on square-octagon lattice, *Arghya Sil and Asim Kumar Ghosh,* J. Phys.: Condens. Matter **31**, 245601 (2019).

3. First and second order topological phases on ferromagnetic breathing kagome lattice, *Arghya Sil and Asim Kumar Ghosh,* J. Phys.: Condens. Matter **32**, 205601 (2020).

4. Topological phases of monolayer and bilayer depleted Lieb lattices, *Arghya Sil and Asim Kumar Ghosh,* J. Phys.: Condens. Matter **36**, 125401 (2024).

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