Preface

When a current-carrying conductor is placed in the external magnetic field, a transverse voltage appears perpendicular to both the external magnetic field and the current direction. This phenomenon is known as the Hall effect. In ferromagnetic material, E. Hall observed that the magnitude of the Hall effect becomes 10 times more pronounced compared to conventional semiconductor materials. This phenomenon is known as the anomalous Hall effect (AHE). The AHE in ferromagnetic materials is attributed to two distinct mechanisms; extrinsic and intrinsic mechanisms. The extrinsic mechanism takes contributions from skew scattering and side jump effects. Skew scattering refers to the asymmetric, spin-dependent scattering of electrons caused by spin-orbit coupled impurities within the host solid. The anomalous Hall resistivity (ρ_{AH}) stemming from skew scattering exhibits a linear relationship with the longitudinal resistivity (ρ_{xx}). In contrast, the side jump mechanism involves a transverse shift in electron coordinates during scattering with host impurities, resulting in the Hall resistivity. The ρ_{AH} varies quadratically with ρ_{xx} in the side jump mechanism. The intrinsic mechanism is free from any kind of scattering events and relies solely on the band structure of the material. Karplus and Luttinger (K-L) initially proposed that electrons in ferromagnetic materials acquire an anomalous velocity perpendicular to the magnetic field direction due to the spin-orbit coupled band structure. This theory was later revisited in the context of the Berry curvature of Bloch bands, which acts as a pseudo-magnetic field in momentum space, leading to the transverse motion of electrons. In the intrinsic mechanism, the ρ_{AH} varies quadratically with ρ_{xx}. The AHE finds its application in high-frequency Hall sensors, magnetic memory devices, spin-logic gates, spintronics, and more. In addition to the AHE, there are instances where additional Hall resistivity arises due to non-trivial spin structures such as skyrmions present in the system. When an electron traverses through these non-trivial spin configurations, it acquires real-space Berry curvature, causing it to deflect in the transverse direction and contributing to the Hall effect. This effect is known as the topological Hall effect (THE). The search for material with large Berry curvature near the Fermi energy is crucial for realizing the large transverse response. The topological semimetals, a category of the topological material can show the large Berry curvature in the material owing to the topological band structure near to the Fermi energy.

Heusler alloys have been diligently considered over the last decade for their wide range of properties such as ferromagnetic shape memory effects, spin gapless semi-conductivity, anomalous Hall and Nernst effect, thermoelectric effect, non-trivial spin texture such as skyrmions, topological effect, etc. These wide ranges of properties put forward the Heusler alloys for different technological applications. Among the Heusler alloys, Co-based Heusler alloys are the most salient candidates due to their large spin-polarization, high Curie temperature (T_c) well above the room temperature, and large anomalous transport response, which are the useful properties for the device applications. Several Co-based Heusler alloys have been identified as topological semimetals, characterized by the breaking of time-reversal symmetry, thus designated as magnetic topological semimetals. The advantage of the magnetic topological semimetal is that their topological properties can be controlled by an external magnetic field. The Co-based Heusler alloys also offer tunable electronic, magnetic, and topological properties, which are useful for attaining desired characteristics. Many Co-based Heusler alloys also crystallize into different types of disordered structures, therefore they provide a good platform to study the effect of disorder on AHE.

This thesis presents a detailed investigation of AHE and topological properties of the Co-based Heusler alloys through experimental and theoretical techniques. The thesis is divided into VIII chapters as follows-

- **Chapter 1** includes a detailed introduction covering the family of Hall effect, the origin of the anomalous Hall effect, topological materials, Heusler alloys, and the related subjects.

- **Chapter 2** includes a method of the synthesis process of the samples, a detailed discussion of the various components, and several characterization techniques e.g. the lab source and synchrotron X-ray diffraction measurements were performed for the structural analysis of samples. The energy-dispersive X-ray spectroscopy (EDX) measurement was done for the composition analysis. The magnetization measurements were performed using the Physical Properties Measurement System (PPMS) and the magnetotransport measurements were done using the Cryogen Free Measurement System (CFMS). A detailed method of the theoretical calculations specifically density functional theory and the Wannier interpolation is included in this chapter.

- **Chapter 3** provides a detailed study of AHE on the Co_2FeGe Heusler alloy via experiment and theoretical calculation. Co_2FeGe Heusler alloy was reported to exhibit anomalous Hall conductivity (AHC) due to the topological nodal lines. However, no experimental validation was present in the literature. Our experimental analysis gives the AHC of about 78.6 S/cm in this system. The Berry curvature calculation gives an AHC of about 77.29 S/cm due to gapped nodal lines, which is in good agreement with the experiment. This work can be found in Phys. Rev. B 104, 195108 (2021).

- **Chapter 4** provides the study of the effect of the antisite disorder on the AHE in Co_2FeAl Heusler alloy. Co_2FeAl Heusler alloy crystallizes in the B2 type structure, which provides an avenue to investigate the disorder effect on the AHE. The combined experimental and theoretical results establish that the antisite disorder can enhance the AHC of the system, which is in contrast to the prior studies suggesting that the disorder decreases the value of AHC in the system. This work can be found in Phys. Rev. B 105, 035124 (2022).

- **Chapter 5** includes the investigation of AHE in the NiCoMnGa quaternary Heusler alloy. This study emphasizes the effect of magnetization and topological band structure on the AHE in the ferromagnetic material. The magnetic moment of NiCoMnGa is close to the well-known Co_2MnGa Heusler alloy. The latter exhibits AHC of about 1200 S/cm due to nodal lines formed by the mirror symmetries of the system. Despite having a close magnetic moment to the Co_2MnGa, the NiCoMnGa shows AHC about 100 S/cm, because of the absence of the nodal lines in its inverse Heusler structure. This work can be found in Phys. Rev. B 106, 045131 (2022).

- **Chapter 6** provides a detailed theoretical study of AHE and anomalous Nernst effect (ANE) in the Cu_2CoSn Heusler alloy. Cu_2CoSn Heusler alloy was predicted as topological semimetal in the quantum material database, however, no detailed study of AHE was available in the literature. We found a large AHC of about 1000 S/cm and anomalous Nernst conductivity (ANC) of about 3.98 A-m/K for this system, comparable to the high AHC Co_2MnGa Heusler alloy. This work can be found in Appl. Phys. Lett. 123, 052402 (2023).

- **Chapter 7** involves the study of the topological Hall effect (THE) in the Co_2FeAl bulk centrosymmetric Heusler alloy. We found the signature of skyrmions in the Co_2FeAl through the magnetotransport measurement, ac-susceptibility measurement, and the micromagnetic simulation.
- **Chapter 8** provides the summary and suggestions for future work.