ABSTRACT

The Standard model(SM) is considered to be the most successful theory of particle physics to date. The path-breaking discovery of the Higgs boson at the large hadron collider(LHC) in the year 2012 has experimentally verified the SM. It can explain three of the four fundamental interactions of nature, namely electromagnetic interaction, weak nuclear interaction, and strong nuclear interaction except for gravity. The SM can explain the mass generation mechanism of almost all elementary particles. Despite its incredible success, there is quite a lot, that remains unexplained within the framework of SM, such as the smallness of neutrino mass, dark matter, baryon asymmetry of the universe(BAU), and lepton flavor violation, etc. Many fundamental theoretical problems like the strong CP problem, mass ordering problem, and flavor puzzles, etc, remain unaddressed within the framework of SM. Experimental evidence of neutrino mass and mixing from different relevant experiments gives enough motivation to study beyond standard model frameworks and address some of the unexplained phenomena in the SM.

The existence of neutrino mass and large mixing parameters are confirmed by the different atmospheric, solar, reactor, and long-baseline neutrino experiments like MINOS [28], T2K [27], Double Chooz [26], Daya Bay [35], RENO [25], etc. These experiments have accurately measured the neutrino oscillation parameters. We know that the absolute neutrino mass scale is still unperceived. However, the Planck experiment has given an upper bound on the sum of the light neutrino mass to be $\sum_i |m_i| < 0.23$ eV in 2012, and recently the bound has been constrained to $\sum_i |m_i| < 0.11$ eV [13]. In the present scenario, neutrino physics is in the precession era. Several BSM frameworks have been proposed to study the origin of small neutrino mass and mixing [57, 61, 60, 59, 66, 87, 67, 88]. The BSM physics also can be useful in explaining various phenomena like Baryon Asymmetry of the Universe (BAU) [179], Lepton Number Violation (LNV) [37], Lepton Flavour Violation (LFV) [206], the existence of dark matter [74].

One of the most important and open questions for particle physicists is, whether the neutrinos are four-component Dirac fermions or two-component Majorana fermions. This question is directly related to the lepton number conservation. Neutrinoless double beta decay(NDBD/$0\nu\beta\beta$) [37, 38] is one such process that arises in many BSM frameworks. It is a second-order and slow radioactive process that transforms a nuclide of atomic number Z into its isobar with atomic number Z+2, which violates the lepton number(LN) conservation. The main aim of the search for $0\nu\beta\beta$ decay is the measurement of the effective Majorana neutrino mass, which is a combination of the neutrino mass eigenstates and neutrino mixing matrix terms.

There is no experimental evidence of the NDBD to date. But, there are many new generations of experiments that are already running or about to run to explore effective neutrino mass along with decay rates of the NDBD process. The KamLANDZen [39] and GERDA [40] uses Xenon-136 and Germanium-76 nuclei. They have improved the lower bound of the half-life of the decay process. Incorporating the results from the first and second phases of the experiment, the KamLAND-Zen imposes the best lower limit on the decay half-life using Xe-136 as $T_{1/2}^{0\nu} > 1.07 \times 10^{26}$ yr at 90 percent confidence level(CL) and the corresponding upper limit of effective Majorana mass in the range $(0.06 - 0.165)$ eV.

Neutrino oscillation directly implies the lepton flavor violation for neutral leptons. So one can expect a similar kind of lepton flavor violating decays for charged lepton also . Theoretical and experimental manifestation of LFV [162–164] has been one of the most promising areas of research for a long. $\mu \to e\gamma$, $\mu \to 3e$, and $\mu \to e$ conversion in the nuclei are the most prominent low-energy LFV channels that are accessible in recent experiments. The exact mechanism of these decays are still not known to us. There are several present day and future generation experiment are dedicated to detect such kind of decays. The most stringent bounds on LFV come from the MEG experiment [41]. The limit on branching ratio for the decay of $\mu \to e\gamma$ from this experiment is Br($\mu \to e\gamma$)$< 4.2 \times 10^{-13}$. In case of $l_\alpha \to 3l_\beta$ decay constraints comes from SINDRUM experiment [42] is set to be $\mathrm{BR}(\mathrm{l}_\alpha \to 3\mathrm{l}_\beta) < 10^{-12}$.

Another motivation to go beyond the Standard Model (BSM) is to study the baryon asymmetry of the Universe (BAU). The Universe is matter dominated. This domination of matter over antimatter can be generated by the process of baryogenesis. In such process matter, antimatter asymmetry is produced by the out-of-equilibrium decay of heavy neutrino [189, 190]. There are various type of leptogenesis such as thermal, resonant, and vanilla leptogenesis which are widely used to produce observed BAU. In this thesis, we are explaining vanilla leptogenesis along with other neutrino phenomenology beyond standard model frameworks such as the radiative seesaw model. As discussed in many kinds of literature [189, 190], we now know that there exists a lower bound of about 10TeV for the lightest of the RHNs(M_{N_1}) in the radiative seesaw model considering the vanilla leptogenesis scenario [180, 110]. For a hierarchical mass of RHN, i.e $M_{N_1} << M_{N_2}, M_{N_3}$, the leptogenesis produced by the decay of N_2 and N_3 are suppressed due to the strong washout effects produced by N_1 or N_2 and N_3 mediated interactions [110]. Thereby, the lepton asymmetry is produced only by the virtue of N_1 decay and this is further converted into the baryon asymmetry of the Universe(BAU) by the electro-weak sphaleron phase transitions [111].

Dark matter is one of the most important questions for particle physicists which remained unexplained in the SM. It was first proposed by Fritz Zwicky back in 1933. After that many experimental observations such as gravitational lensing, galaxy rotation within galaxy clusters, cosmic microwave background, etc. confirmed that our present universe is made up of non luminous mysterious objects known as the Dark matter. Present experiment dedicated to the study of dark matter [13] confirms that 26.8% of the total energy density of the Universe is composed of DM. There are many BSM framework that tries to address the DM issues. In this thesis, we mainly address the sterile neutrino as a possible DM candidate and studied associated phenomenology.

Symmetry plays an important part in the field of particle physics, which can be used to explain different phenomena. The SM is a successful theory based on $SU(3)_c \times SU(2)_L \times U(1)_Y$ gauge group. Where, $SU(n)$ and $U(n)$ are abelian continuous symmetry. But, this one cannot accommodate neutrino mass and mixing. Using nonabelian discrete flavor symmetries in an extended SM framework can successfully produce neutrino mass and mixing. This is one of the motivations to use discrete flavor symmetry in our work within different BSM frameworks. Non-abelian discrete symmetries can control the flavor structure of a particular model. There are many models have been proposed which are successful in producing correct neutrino mixing. Discrete symmetries such as A_N, S_N, Z_N, etc are extensively used for model-building purpose.

In this thesis work, we have used A_4, Z_2 and Z_4 discrete symmetries to construct different neutrino mass models. These models are constructed and used to study phenomena like lepton number violation, lepton flavor violation, baryon asymmetry of the Universe, and dark matter in light of the latest experimental data, which remain unexplained in SM. The minimal left-right symmetric model, extended left-right symmetric model, and radiative seesaw model are the chosen frameworks for the phenomenological analysis in this thesis.

In chapter 1, we reviewed the SM and discussed the current status of experimental and theoretical advancement of neutrino physics. As our thesis is based on three different BSM frameworks namely, minimal eft right symmetric model, extended left-right symmetric model, and radiative seesaw model, so we have extensively discussed these frameworks in chapter 1. Different BSM phenomena like lepton number violation, lepton flavor violation, BAU, and dark matter are also introduced in this chapter. Lastly, we have discussed the discrete symmetry group A_4 in details.

In chapter 2, we have studied neutrinoless double beta decay (NDBD) and charged lepton flavor violation(CLFV) in a generic Left-Right symmetric model (LRSM). In this framework, type-I and type-II seesaw terms arise naturally. We have used $A_4 \times Z_2$ discrete flavor symmetry to realize the LRSM. Within the model, we have considered type-I and type-II dominant cases and analyzed the new physics contributions to the NDBD process coming from different particles of the LRSM. We tried to find the leading order contributions to the NDBD process in type-I and type-II dominant seesaws along with the decay rate of the process in our work. We have also studied different charged lepton flavor violating processes such as $\mu \to 3e$ and $\mu \to e\gamma$ and correlated with neutrino mass within the model.

In chapter 3, we have constructed a flavor symmetry-based extended left-right symmetric model(LRSM) with a dominant type-II seesaw mechanism and have explored the associated neutrino phenomenology. The particle content of the model includes usual quarks, and leptons along with additional sterile fermion per generation in the fermion sector while, the scalar sector contains Higgs doublets and scalar bidoublet. The realization of this extension of the LRSM is done by using $A_4 \times Z_4$ discrete symmetries. In this work, we have included the study of sterile neutrino dark matter(DM) phenomenology along with neutrinoless double beta decay within the framework.

In chapter 4, we have studied the scotogenic model proposed by Ernest Ma, which is an extension of the SM by three singlet right-handed neutrinos and a scalar doublet. This model proposes that the light neutrinos acquire a non-zero mass at a one-loop level. In this work, the realization of the scotogenic model is done by using discrete symmetries $A_4 \times Z_4$ in which the non-zero θ_{13} is produced by assuming a non-degeneracy in the loop factor. Considering different lepton flavor violating(LFV) processes such as $l_\alpha \longrightarrow l_\beta \gamma$ and $l_\alpha \longrightarrow 3l_\beta$, their impact on neutrino phenomenology is studied. We have also analyzed $0\nu\beta\beta$ and baryon asymmetry of the Universe(BAU) in this work.

And finally, we give the summary and conclusion in the **chapter 5**. We have also discussed the prospects of this work in this chapter.

Keyword: The Standard model(SM), Neutrino oscillation, left-right symmetric model(LRSM), Extended left-right symmetric model, Lepton flavor violation (LFV), lepton number viola-

tion (LNV), Baryon asymmetry of the Universe(BAU), Dark matter(DM), Discrete flavor symmetry