5
Conclusion and future prospectives:

In this chapter, we present the important conclusions drawn from the above phenomenological studies of neutrino physics in light of the latest neutrino and cosmological data. Our works primarily address the generation of neutrino mass in different BSM frameworks and connect it with various phenomena such as baryon asymmetry of the Universe, lepton number violation, lepton flavor violation, and dark matter. In this thesis, the generation of neutrino mass is studied in three different BSM frameworks namely, LRSM, extended LRSM, and radiative seesaw. We have tried to study these above-mentioned phenomena under a common framework with the application of discrete flavor symmetry. Discrete flavor symmetry constrains the parameter space of phenomenological parameters thereby making our models predictive. Discrete symmetries such as A_4,Z_2 and Z_4 are used in our works. In the following, we summarize the significant conclusions of the last three chapters of this thesis.

5.1 Conclusion

5.1.1 Chapter 2

The nature of the neutrinos and lepton flavor-violating processes are very well-motivated topics of research in the BSM realm. The issue related to the nature of neutrinos is directly linked to the process of NDBD, which violates the lepton number. The experimental detection of NDBD will confirm that the nature of neutrino is Majorana type. We have considered one very interesting BSM framework known as LRSM. LRSM is a very simple extension of the standard model gauge group where parity restoration is obtained at a high energy scale and the fermions are assigned to the gauge group $SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ which can be tested in present-day experiments. In this work, we have studied NDBD and charged lepton flavor violation(CLFV) in a generic LRSM. In this framework, type-I and type-II seesaw terms arise naturally. 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 LRSM. 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. We have contemplated the implications of NDBD in the LRSM framework which is realized through $A_4 \times Z_2$ flavor symmetric model. Because of the presence of new scalars and gauge bosons in this model, various additional sources would give rise to contributions to the NDBD process, which involves RH neutrinos, RH gauge bosons, scalar Higgs triplets as well as the mixed LH-RH contributions. We have realized LRSM for both type-I and type-II dominant cases. For a simplified analysis, we have ignored the left-right gauge boson mixing and heavy light neutrino mixing. We have assumed the extra gauge bosons and scalars to be of the order of TeV and evaluated all the contributions to the NDBD process under this simplified approximation. The evaluated results are validated with the experimental bounds provided by KamLAND-ZEN and GERDA experiment. In light of standard light neutrino contribution to the effective neutrino mass, we varied different neutrino oscillation parameters to check the viability of the model. Different neutrino oscillation parameters are analyzed with effective neutrino mass calculated from the model for type-II and type-I dominant cases. From these results, we can say that the parameters Majorana phase α, mixing angle θ_{23}, and CP-violating phase δ are well within the experimental limits. We have also checked the consistency of the model by investigating different LFV processes such as $\mu \to e\gamma$ and $\mu \to 3e$ in light of SINDRUM and MEG collaboration. We have also analyzed the branching ratios of these processes with the lightest neutrino mass for both type-I and type-II dominant cases considering both NH and IH. From the results, it can be inferred that the type-I dominant case is more consistent with the experimental bounds than the type-II dominant case.

5.1.2 Chapter 3

In this chapter, the LRSM is extended with a neutral sterile fermion per generation along with quark and leptons. The Scalar sector of this extension consists of Higgs bidoublet Φ, two scalar triplets Δ_L, Δ_R, and two doublets H_L,H_R. The B-L charge of Higgs bidoublet, scalar triplets, and doublets are 0,2 and -1 respectively. This kind of extension of LRSM is known as the extended LR model and the naturally arising seesaw from it is called the extended seesaw mechanism. We have studied a flavor symmetry-based extended LRSM with a dominant type-II seesaw mechanism and have explored the associated neutrino phenomenology. Realization of this extension of LRSM has been done by using $A_4 \times Z_4$ discrete symmetries. In this work, we have also included the study of sterile neutrino dark matter(DM) phenomenology along with NDBD within the framework. In this work, we extend the generic left-right symmetric model with an extra singlet fermion per generation. We have realized this extension with A_4 and Z_4 flavor symmetry considering the type-II dominance case. Because of the extension, there will be new physics contributions to the NDBD process and type-II dominance will constrain some of the contributions. We have computed all the mass matrices of light neutrino, heavy neutrino, and sterile neutrino using flavor symmetry which will constrain the model. Type-II dominance gives rise to large left-right mixing which is discussed in detail in our work. By estimating the contribution coming from light neutrinos, heavy neutrinos and, sterile neutrinos, it is seen that all the contributions coming from these exchanges are well within the experimental bound. The singlet fermion in the keV range can be a viable DM candidate in the model. We have extensively studied the sterile neutrino dark matter phenomenology. It has been found that the allowed mass range lies within $10-25$ keV in this model. We have found that the DM candidate can provide a significant contribution to the total relic abundance. We can conclude from the above-mentioned results that, the model under consideration is viable for studying neutrino as well as cosmological phenomenologies.

5.1.3 Chapter 4

In this chapter, we have studied the radiative seesaw model proposed by Ernest Ma, which is an extension of the Standard Model by three singlet right-handed neutrinos and a scalar doublet. This model proposes that the light neutrinos acquire a non-zero mass at the 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. As the loop factor, $r_i \propto \frac{1}{M_{N_i}}$, we have broken the degeneracy in the masses of the RHN with the implementation of a perturbation which further breaks the $\mu-\tau$ symmetry. We have taken four free parameters, $M_{N_1}, M_{N_2}, \eta_R^0$ and λ_5 whose values are mentioned above. By this choice of parameter space, we have shown its consistency with various experimental and cosmological bounds. The lightest of the RHN decays to produce lepton asymmetry which is further converted into BAU. Thus, the parameter space taken into account for the generation of the BAU is seen to follow the Planck limit for BAU. We can see from the results that the lightest active neutrino mass eigenvalue obtained from the model satisfies the Planck limit for BAU and consecutively obeys the Planck limit for the summation of light neutrino masses for NH/IH. Thus, the model is viable in connecting BAU and NDBD, also satisfying the bounds coming from neutrino oscillation data. We have also calculated the effective mass of the light neutrinos. The lightest active neutrino mass eigenvalue for both NH/IH is seen to satisfy the KamLAND-Zen limit for the effective mass of light neutrinos. Additionally to this, a contour plot co-relating the model parameters with BAU is also studied. The conclusion we can draw from it is that the parameter space obtained from the model falls within the experimental bounds, thereby constraining the Yukawa coupling matrix. Furthermore, we have computed the branching ratios, Br($\mu \to$ eγ) and Br($\mu \to$ 3e) of LFV decays along with the $\mu - e$ conversion ratio. We have studied the correlation between the branching ratios and the lightest neutrino mass eigenvalue and see that it also obeys the experimental upper bounds for the branching ratios. It is predicted well from the model that $l_\alpha \to l_\beta \gamma$ decay suppress the $l_\alpha \to 3l_\beta$ decay in case of both NH/IH. We can say that the results hardly show any change depending on the mass hierarchies. Overall, this realization of the Scotogenic model by discrete symmetries, with the considerations on the free parameters taken from various bounds is viable for studying neutrino as well as cosmological phenomenologies.

5.2 Future prospectives

This thesis work primarily focuses on developing models within different BSM frameworks using discrete flavor symmetry. We have included three beyond SM frameworks namely, LRSM, extended LRSM, and radiative seesaw in this thesis based on the drawbacks of the SM. Three chapters of this thesis address neutrino mass, mixing, and various phenomenologies such as LFV, LNV, BAU, and DM within the developed models.

However, there are many possibilities, that can be explored in this area. Realization of these models can be done with the help of modular symmetry, which reduces the number of free parameters of a particular model. More constrained and predictive models can be proposed with the application of modular symmetry which increases its viability. In the case of the work based on minimal LRSM, BAU can be addressed additionally. We can study DM phenomenology within the proposed flavor symmetric radiative seesaw model. Extended LRSM can be explored to connect neutrino physics and grand unified theories.