STUDIES ON NEUTRINO PHENOMENOLOGY IN THE CONTEXT OF NON-ABELIAN DISCRETE FLAVOR SYMMETRY

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Chapter 7

Conclusions and Future Outlook

The chapters explore fundamental concepts in particle physics, each addressing crucial phenomena related to neutrino masses, the matter-antimatter asymmetry, and the nature of dark matter. Together, they form a cohesive picture of how extensions to the Standard Model of particle physics may resolve some of the outstanding mysteries in the universe. Our investigation employed various seesaw models, including Inverse and Double Inverse seesaw frameworks.

Our main findings are summarized below, along with suggestions for future exploration.

7.1 Conclusions

7.1.1 Chapter 3

In this chapter, we proposed a $\Delta(54)$ flavor model, incorporating two SM Higgs bosons and a $Z_2 \otimes Z_3 \otimes Z_4$ symmetry to generate a neutrino mass matrix. Utilizing the Inverse Seesaw mechanism, our flavor-symmetric approach successfully reproduces neutrino masses and mixing, consistent with current neutrino oscillation data, including non-zero reactor angle (θ_{13}) and Dirac CP (δ_{CP}). Our model deviates from Tribimaximal Mixing (TBM) and predicts neutrino oscillation parameters in agreement with best-fit values obtained through χ^2 analysis. However, Inverted Hierarchy (IH) predictions disagree with experimental data. Normal Hierarchy (NH) predictions favor the lower octant of θ_{23}. Furthermore, we investigated the Jarlskog invariant and Neutrinoless Double Beta Decay (NDBD). The effective Majorana neutrino mass $|m_{ee}|$ is well within the sensitivity reach of the recent $0\nu\beta\beta$ experiments.

The consistency of the model predictions with the latest neutrino data implies that model may be tested in future neutrino oscillation experiments.

7.1.2 Chapter 4

In this chapter, we explored the $\Delta(54)$ flavor model with the double inverse seesaw model for Majorana neutrinos. Our flavor-symmetric approach reproduces neutrino masses and mixing, aligning with current neutrino oscillation data, including non-zero reactor angle (θ_{13}). Our model deviates from Tribimaximal Mixing (TBM) and predicts neutrino oscillation parameters consistent with best-fit χ^2 analysis. However, IH predictions disagree with experimental data, whereas NH predictions favors the upper octant.

Furthermore, we investigated the Jarlskog invariant parameter (J) and the Neutrinoless Double Beta Decay (NDBD) phenomenon within the framework of our $\Delta(54)$ flavor model. It is worthy to note that the effective Majorana neutrino mass denoted as $|m_{ee}|$, falls within the sensitivity range of Neutrinoless Double Beta Decay ($0\nu\beta\beta$) experiments. Future work is reserved for examining the model to explore phenomena such as Leptogenesis and Asymmetric Dark Matter.

7.1.3 Chapter 5

This chapter explores the $\Delta(54)$ flavor symmetry, with SM Higgs boson and $Z_2 \otimes Z_3 \otimes Z_4$ symmetry to generate a neutrino mass matrix. Our model employs the Inverse Seesaw (ISS) mechanism, providing a flavor-symmetric approach that accounts for solar mixing angle, upper octant atmospheric mixing angle, non-zero reactor angle, and CP violation. Predicted absolute neutrino masses satisfy cosmological bound $\sum_i m_i < 0.12$ eV. Neutrino oscillation parameter predictions align with best-fit χ^2 values, except for Inverted Hierarchy (IH) scenario discrepancies.

Furthermore, we investigated baryogenesis via flavoured resonant leptogenesis. The right-handed neutrinos are degenerate at the dimension 5 level, introducing a higher dimension term resulted in a tiny splitting. We have taken the splitting parameter, $d \approx 10^{-8}$ and thus, obtained a nonzero, resonantly enhanced CP asymmetry ($\epsilon_{i\alpha}$) from the out-of equilibrium decay of right-handed Majorana neutrinos. We determined the baryon-to-photon ratio (η_B) in the flavored resonant leptogenesis scenario using the values of the CP asymmetries. It was found that the model can explain the observed value of BAU with particular choice of RHN mass scale, $M_1 = 10TeV$ and mass splitting, $d \approx 10^{-8}$. Future work is reserved for examining the model to explore the Relic abundance of Dark Matter.

7.1.4 Chapter 6

This chapter presents a theoretical framework based on the $\Delta(54)$ flavor symmetry, generating neutrino mass matrices consistent with experimental neutrino data and cosmological constraints on relic abundance of dark matter and active neutrino-dark matter mixing angle. Incorporating the ISS mechanism enables a flavor-symmetric approach, accurately predicting CP violation, solar mixing angle, upper octant atmospheric mixing angle, and non-zero reactor angle. The model exhibits optimal agreement with experimental data in the normal hierarchy scenario, as confirmed by minimal χ^2 analysis. Conversely, the inverted hierarchy scenario fails to reproduce experimental findings.

We calculated the sterile neutrino mass which is a potential dark matter (DM) candidate and the active neutrino-DM mixing angle with the predicted model parameters. The non-resonant formation of sterile neutrinos and the corresponding limitations from Lyman-α have been taken into consideration in this study. The active neutrino-DM mixing angle is examined in relation to DM mass. It is found that the data points from our model prefers the Lyman-α range in the case of NH. The constraints for Ly-α is 10 keV. The lower bound for X-ray constraint is approximately 17 keV. We have shown a co-relation between dark matter mass and active-DM mixing angle. A very small region between 10 - 16 keV falls in the allowed parameter space for NH. We have shown the dark matter mass range which obeys the Planck limit for relic abundance of dark matter. We have larger number of points for in the allowed parameter space m_{DM} = 10 - 16 keV satisfying the Planck bound.

Future dark matter and neutrino oscillation experiments such as DUNE, JUNO, Daya Bay and Super-Kamiokande may test the model considering the predictions of the model align with the most recent neutrino data.

7.2 Future Outlook

The Standard Model limitations necessitate alternative approaches to understanding neutrino properties. We present the future outlook based on the findings from the previous chapters, outlining potential directions for further research and development in the study of neutrino masses, leptogenesis and dark matter. Overall, the research fields covered in this thesis provide numerous potential paths for further investigation, both theoretically and experimentally.

Future research directions, building upon these models, are discussed in this section.

- Future research in this area can focus on experimentally testing the predictions of the Inverse seesaw mechanism. With the introduction of light sterile neutrinos in this framework, upcoming neutrino experiments, such as those involving long-baseline oscillation studies or neutrinoless double-beta decay searches, could help determine the validity of the inverse seesaw model.

- Further investigation into the Double Inverse seesaw model could involve refining its predictions for lepton flavor violation and probing the possibility of new interactions at intermediate mass scales.

- For leptogenesis, one promising avenue for future research is the exploration of low-scale leptogenesis models that can be directly tested through experiments. This includes refining the parameter space where the baryon asymmetry of the universe (BAU) can be explained within low-energy frameworks, making it possible to connect the theoretical models to observable phenomena.

- The interplay between dark matter and leptogenesis presents an interesting theoretical landscape, where dark matter particles could play a role in generating the observed BAU. New models linking these phenomena in a unified framework may open up exciting possibilities for future theoretical and experimental studies.