PROCEEDINGS OF SCIENCE

Phenomenological aspects of A_5' modular symmetry on linear seesaw with leptogenesis

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In the linear seesaw framework, we analyse the implications of modular A_5' symmetry on neutrino oscillation phenomenology. To preserve the holomorphic aspect of the superpotential, we incorporate six heavy fermion superfields along with a pair of weightons to establish the well defined mass structure for the light active neutrinos as needed by the linear seesaw mechanism. Modular symmetry has the advantage of considerably reducing the need of flavon fields. Furthermore, the Yukawa couplings alter non-trivially under the flavour symmetry group and are described in terms of Dedekind eta functions, whose q expansion simplifies computations numerically. We show that the model framework meticulously accounts for all neutrino oscillation data. In addition, we investigate the implications of CP asymmetry resulting from the lightest heavy fermion decay in explaining the observed baryon asymmetry through leptogenesis.

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1. Introduction

Since, its debut in the early 1970s, the standard model (SM) has been used to classify many of the elementary particles that are now being seen. Despite its effectiveness, SM is unable to explain a large number of well-known events in particle physics, astrophysics, and cosmology. As an example, SM is unable to resolve the dilemma of neutrino physics. The most hot issue in science at the moment is neutrinos, which are believed to have a part in both the microscopic and macroscopic realms. One of the most important discoveries in neutrino physics is the flavour oscillations of neutrinos, which imply that neutrinos are hefty. Additionally, experimental data shows that the three neutrino framework is characterised by six distinct factors, three of which are mixing angles and two of which are mass squared differences and a CP phase. The CP violating phase has become the primary focus to be corrected in the near future despite the fact that it has not yet been demonstrated due to experimental limitations. The neutrinos' mass hierarchies, which are regarded to be significant in particle physics and cosmology, are still unknown in addition to the above. In the theoretical realm, we go beyond the standard model to explain neutrino phenomenology by introducing right-handed neutrinos and specific discrete and continuous symmetries to achieve the seesaw process. Many flavon fields are also needed to build the Lagrangian, which aids in symmetry breaking and defines a few additional terms needed depending on the kind of seesaw being used. However, flavon fields introduce non-renormalizable higher dimensional components into the picture, which decreases the model's predictability. Therefore, a new approach of modular symmetry [1] has recently been seen in myriad literature [2–6] whose soul aim is to transform the Yukawa couplings into modular forms and reduce the usage of flavon fields. One such kind being $\Gamma(5)' \approx A_5'$ which is a double cover [7] of the A_5 symmetry as discussed below.

2. Model Framework

The seesaw mechanism utilised here is linear seesaw [8], therefore, the extra particles are the RH and LH neutrinos along with other SM particles as presented in Table 1, where k_I being the modular weight. Therefore, we are able to write the relevant superpotential to retain the linear seesaw mass structure given below

Fields	e_R^c	μ_R^c	τ_R^c	L_L	N_R^c	S_L	$H_{u,d}$	ζ	ζ'
$SU(2)_L$	1	1	1	2	1	1	2	1	1
$U(1)_Y$	1	1	1	$-\frac{1}{2}$	0	0	$\frac{1}{2}, -\frac{1}{2}$	0	0
$U(1)_{B-L}$	1	1	1	-1	1	0	0	1	-1
A_5'	1	1	1	3	$3'$	$3'$	1	1	1
k_I	1	3	5	1	1	4	0	1	1

Table 1: The particle spectrum and their charges under the symmetry groups $SU(2)_L \times U(1)_Y \times U(1)_{B-L} \times A_5'$ while k_I represents the modular weight.

The complete superpotential is given by

$$\begin{aligned}\mathcal{W} &= A_{M_l}\left[(L_L l_R^c)_{\mathbf{3}} Y_{\mathbf{3}}^{k_Y}\right] H_d + \mu H_u H_d + G_d \left[(L_L N_R^c)_{\mathbf{5}} Y_{\mathbf{5}}^{(2)}\right] H_u + \\ & G_{ls}\left[(L_L S_L)_{\mathbf{4}} H_u \sum_{i=1}^{2} Y_{\mathbf{4},i}^{(6)}\right]\frac{\zeta}{\Lambda} + B_{rs}\left[(S_L N_R^c)_{\mathbf{5}} \sum_{i=1}^{2} Y_{\mathbf{5},i}^{(6)}\right]\zeta'. \end{aligned} \tag{1}$$

The neutrino mass matrix under linear seesaw in the flavor basis of (ν_L, N_R^c, S_L) is expressed as

$$\mathbb{M} = \begin{pmatrix} 0 & M_D & M_{LS} \\ M_D^T & 0 & M_{RS} \\ M_{LS}^T & M_{RS}^T & 0 \end{pmatrix} \tag{2}$$

The resulting light neutrino mass formula

$$m_\nu = M_D M_{RS}^{-1} M_{LS}^T + \text{transpose} \tag{3}$$

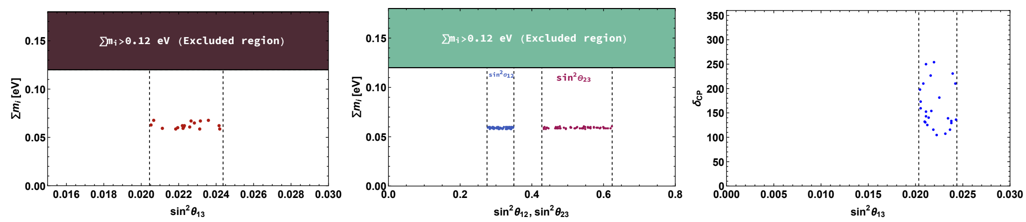

Figure 1: These plots express mixing angles $\sin^2\theta_{13}$ (left), ($\sin^2\theta_{12}$ and $\sin^2\theta_{12}$) (middle) versus Σm_i[eV], right plot shows relation between δ_{CP} with $\sin^2\theta_{13}$.

3. Leptogenesis

To account for leptogenesis satisfying Sakharov criteria [9], eqn.(4) introduces a higher-dimensional mass term for the Majorana fermion (N_R), resulting in a minor mass splitting between the heavy fermions, where α_R is the coupling constant.

$$\mathcal{W}_{M_R} = -G_R\left[\sum_{i=1}^{2} Y_{5,i}^{(4)} N_R^c N_R^c\right]\frac{\zeta'^2}{\Lambda}, \tag{4}$$

Boltzmann equations are expressed below in eqn. (5) which helps to get the correct lepton asymmetry

$$\begin{aligned}\frac{dY_{N^-}}{dz} &= -\frac{z}{sH(M_1^-)}\left[\left(\frac{Y_{N^-}}{Y_{N^-}^{\rm eq}}-1\right)\gamma_D + \left(\left(\frac{Y_{N^-}}{Y_{N^-}^{\rm eq}}\right)^2-1\right)\gamma_S\right], \\ \frac{dY_{B-L}}{dz} &= -\frac{z}{sH(M_1^-)}\left[\epsilon_{N^-}\left(\frac{Y_{N^-}}{Y_{N^-}^{\rm eq}}-1\right)\gamma_D - \frac{Y_{B-L}}{Y_\ell^{\rm eq}}\frac{\gamma_D}{2}\right].\end{aligned} \tag{5}$$

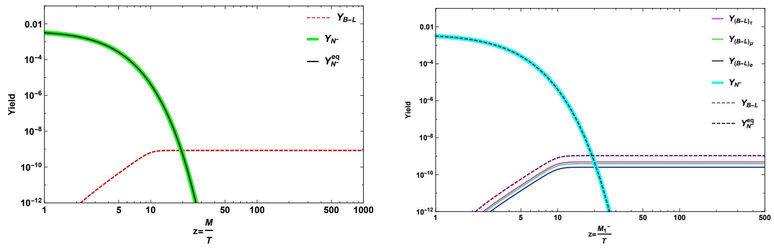

Figure 2: Left and right plot shows evolution of Y_{B-L} (dashed) as a function of $z = M_1^-/T$ for one flavor approximation and flavoured case respectively.

4. Conclusion

In this paper, we discuss the implementation of A'_5 modular symmetry to linear seesaw mechanism and are successful in matching the experimental results for neutrino phenomenology. Also, we have discussed leptogenesis yielding baryon asymmetry $\approx 10^{-10}$.

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