Neutrino masses in the flipped 341 model

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Introduction

Neutrino oscillations phenomenon reveals that contrary to the standard model predictions, the neutrinos have masses. This means that the standard model is just an approximate theory and can be classified as an effective field theory that one can go beyond to find answers to the existing unexplained problems.
The 341 model is one of the most interesting BSM models with a very rich phenomenology [1]. This model based on the gauge group $SU(3)_C \times SU(4)_L \times U(1)_X$ where the three quark generations belong to different $SU(4)_L$ representations, two with a left handed chirality Q_{iL} $(i = 1,2)$ lie in the fundamental representation 4, whereas , the third one Q_{3L} together with the three lepton generations $\psi_{\ell L} (\ell = e, \mu, \tau)$ have to transform under the conjugate fundamental representation $\bar{4}$ (or vice versa). The 341 model predicts the existence of many new particles like exotic fermions, heavy gauge and scalar bosons etc...
The flipped 341 model is a new anomaly free model without exotic electric charges where all the quark generations transform under the same representation while leptons are not. Besides many new particles, this model predicts the existance of ten neutral leptons, in our work, we are interested to generate their masses using seesaw mechanism. To generate the mixing between ν_e and $\nu_{\mu,\tau}$ that is required by the oscillation neutrinos we were obliged to introduce a one loop radiative correction.

Objectives

The goal of this work is to introduce a new anomaly-free model called the flipped 341 model and to generate masses for all neutral leptons that will play the role of light and heavy neutrinos where we use seesaw mechanism.

References

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The Flipped 341 Model

In general, one of the most important parameters to distinguish different 341 models are denoted as β and γ which define the electric charges of new particles through the following electric charge operator [2]:

$$Q = T_3 + \beta T_8 + \gamma T_{15} + X \quad (1)$$

In our model, we have $\beta = \frac{1}{\sqrt{3}}$ and $\gamma = -\frac{2}{\sqrt{6}}$, thus, the fermion content in the flipped 341 model is [2]:

$$\psi_e = \begin{pmatrix} \Sigma^+ & \frac{\Sigma^0}{\sqrt{2}} & \frac{\nu_e}{\sqrt{2}} & \frac{\beta^+}{\sqrt{2}} \\ \frac{\Sigma^0}{\sqrt{2}} & \Sigma^- & \frac{e^-}{\sqrt{2}} & \frac{\beta^0}{\sqrt{2}} \\ \frac{\nu_e}{\sqrt{2}} & \frac{e^-}{\sqrt{2}} & E_e^- & \frac{N_e^0}{\sqrt{2}} \\ \frac{\beta^+}{\sqrt{2}} & \frac{\beta^0}{\sqrt{2}} & \frac{N_e^0}{\sqrt{2}} & \sigma^+ \end{pmatrix}_{(1,10,0)} , \quad (2)$$

$$\psi_\alpha = \begin{pmatrix} \nu_\alpha \\ \ell_\alpha \\ E_\alpha^- \\ N_\alpha^0 \end{pmatrix}_{(1,4,-\frac{1}{2})} , \widetilde{\psi} = \begin{pmatrix} \widetilde{e}^- \\ \widetilde{\nu} \\ \widetilde{N}^0 \\ \widetilde{E}^- \end{pmatrix}_{(1,\bar{4},-\frac{1}{2})} , \quad (3)$$

$$\psi_i = \begin{pmatrix} d_i \\ u_i \\ U_i \\ D_i \end{pmatrix}_{(3,\bar{4},\frac{1}{6})} , \quad (4)$$

where $\alpha = \mu, \tau$ and $i = 1, 2, 3$, the symbol $\sim$ refers to the quantum numbers of the $SU(3)_C$, $SU(4)_L$ and $U(1)_X$ respectively. In the flipped 341 model, all quark families transform under the same representation, while, lepton generations are not. Right-handed quarks transform as singlets under $SU(4)_L \otimes U(1)_X$. In order to generate masses for all particles one has to have four scalar fields $\phi_{1,\ldots,4}$ and two new scalar matrices S and S' [2]. In our model, there are 10 colorless neutral fields $\nu_{\alpha=\mu,\tau}$, $N^0_{\beta=\mu,\tau}$, ν_e, β^0, N^0_e, $\widetilde{\nu}^0$, Σ^0 and $\widetilde{N}$ which represent light and heavy neutrinos where their masses will be a mixture of a type-II and type-III seesaw mechanism contribution.

Neutrinos masses

In the basis ($\nu_{\alpha=\mu,\tau}$, $N^0_{\beta=\mu,\tau}$, ν_e, β^0, N^0_e, $\widetilde{\nu}^0$, Σ^0 , $\widetilde{N}^0$), the mass matrix M can be written in the following form [2]:

$$M = \begin{pmatrix} N_{\alpha\beta}^{4\times4} & 0^{4\times6} \\ 0^{6\times4} & V^{6\times6} \end{pmatrix} . \quad (5)$$

The matrix M can be block-diagonalized into two blocks, the sub-matrices 4×4 and 6×6 that are denoted by $N_{\alpha\beta}$ and V respectively.
Using seesaw approximation, from the matrix $N_{\alpha\beta}$, we get four eigenvalues, two of them represent light neutrino masses m_{ν_μ}, m_{ν_τ} and the others are heavy neutrino masses $m_{N^0_\mu}$,$m_{N^0_\tau}$, their expressions are given respectively by [2]:

$$m^N_{\alpha\beta} \simeq y''_{\alpha\beta} v_{\sigma'}, \quad (6)$$

$$m^\nu_{\alpha\beta} \simeq y''_{\alpha\beta} v_{\triangle'} - \frac{v_\phi^2}{2v_{\sigma'}} y''_{\alpha\beta} (y''_{\alpha\beta})^{-1} (y''_{\alpha\beta})^\dagger . \quad (7)$$

From the matrix V, we get six eigenvalues, they represent two heavy sterile neutrino masses m^{Σ^0} and $m^{\widetilde{N}^0}$ and four light neutrino masses m_{ν_e}, $m_{N^0_e}$, $m_{\widetilde{\nu}}$ and m_{β^0} given by $m_{\nu'}$ where their masses resulted as a mixture of a type-II and type-III seesaw mechanism contribution.

$$m^{\Sigma^0} \simeq \frac{y'}{\Lambda} v_\sigma v_{\sigma'}, \quad (8)$$

$$m^{\widetilde{N}^0} \simeq \widetilde{W} v_\sigma, \quad (9)$$

$$m^{\nu'} \simeq m' - m M'^{-1} m^T \quad (10)$$

where Λ represents a new physics or cutoff scale that defines the effective interaction. Notice the existence of light sterile neutrinos β^0, N^0_e and $\widetilde{\nu}$. Reference [3] discussed the possible existence of sterile neutrinos in the eV-scale. Moreover, there are some indications from LSND and miniBoone for an eV mass sterile neutrino [2].
Oscillation neutrinos requires the mixing between ν_e and $\nu_{\mu,\tau}$, To generate this mixing we consider loop contributing to the neutrino mass matrix M (see Figure 1).

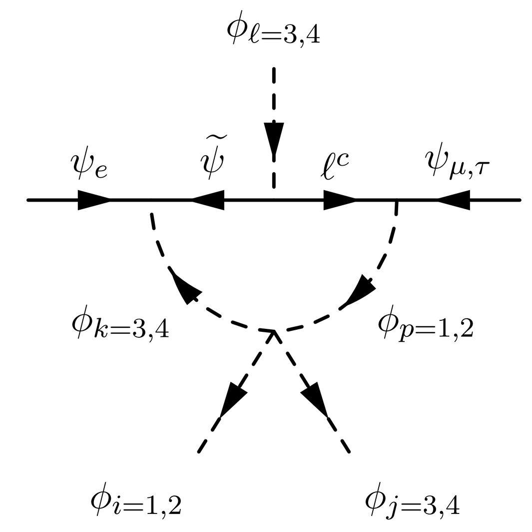

Figure 1: Loop diagram responsible for the mixing of ν_e with ν_μ and ν_τ [2].

At one loop level, the mass matrix M has a new form [2]:

$$\mathcal{M} = \begin{pmatrix} M_1^{(6\times6)} & M_2^{(6\times4)} \\ M_2^{\mathrm{T}(4\times6)} & S^{(4\times4)} \end{pmatrix} . \quad (11)$$

From the mass matrix $\mathcal{M}$ and by using the seesaw approximation, all neutral leptons gain their masses. Notice that the smallness of the active neutrino masses $m^{\nu_{e,\mu,\tau}}$ arises from the inverse powers of the heavy VEVs and Λ and from their linear dependence on the light VEVs $v_\triangle, v_{\triangle'}, v_H, v_\phi$.

Conclusion

As a result, we get:
Conclusion (I): The three light neutrino masses are generated.
Conclusion (II): Light sterile neutrinos exist.
Conclusion (III): The remaining sterile neutrino masses must be heavy.

Future Research

The flipped 341 model predicts the existence of new heavy neutral gauge bosons Z' and Z'', The non-universal coupling of those gauge bosons with leptons leading to the appearance of the flavor changing neutral current. In our future direction, We will discuss this FCNC in the lepton sector.

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