# Dirac Neutrino Mass Generation by Type II Seesaw Mechanism

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## Abstract

In this work we show a study of the generation of neutrino masses is carried out from the Seesaw type II Mechanism for Dirac neutrinos. These mechanisms not only explain the mass of the neutrino but also its small value compared to charged quarks and leptons. Therefore, a model is proposed to obtain the small neutrino masses by extending the visible content of the Standard Model (SM) with a hidden sector composed of a scalar singlet $S$ and three right-handed singlet neutrinos $(\nu_{R_1}, \nu_{R_2}, \nu_{R_3})$. These right-handed neutrinos are charged under a new symmetry $U(1)_{B-L}$. In addition, it is necessary to add a heavy scalar doublet to play the role of messenger between the visible sector (SM) and the hidden sector.

## Introduction

An important question concerning the physics of neutrinos is their nature i.e are they Dirac or Majorana particles. Therefore, there is a possibility that neutrinos are their own antiparticles since they do not have an electrical charge. Also, one of the most interesting problems with SM is the masslessness of neutrinos, which is contradicted by the experimental evidence. It has been established that neutrinos have a small mass, but different from zero, therefore the first experimental proof of a new physics beyond the Standard Model is generated.

In this work, the visible content of the standard model is extended with a hidden sector, $SU(3)_c \otimes SU(2)_L \otimes U(1)_Y \otimes U(1)_{B-L}$, which is prescribed by a local abelian gauge symmetry $U(1)_{B-L}$. The $B-L$ models, in which the difference between the number of baryons and leptons is measured, are extensions of the Standard Model that could provide mass to neutrinos in addition to explaining the nature of dark matter , which frame two of the most relevant problems in physics.

## Model

The field content of the $SU(2)_L \otimes U(1)_Y \otimes U(1)_{B-L}$ that we propose in this work is determined in Table 1. Where $L$ represents a left lepton doublet, $\phi$ the Higgs doublet, $\nu_R$ the right-handed singlet neutrinos, $S$ the Higgs singlet and $\eta$ the heavy scalar doublet.

| **Fields** | $SU(2)_L$ | $U(1)_Y$ | $U(1)_{B-L}$ |
|---|---|---|---|
| $(\nu_R)^\dagger_i$ | **1** | 0 | +4 |
| $(\nu_R)^\dagger_3$ | **1** | 0 | −5 |
| $L^{(n)}$ | **2** | $-\frac{1}{2}$ | −1 |
| $\eta$ | **1** | $\frac{1}{2}$ | −3 |
| $S$ | **1** | 0 | −3 |
| $\phi$ | **2** | $\frac{1}{2}$ | 0 |

Table 1:The field content related to the generation of the Dirac neutrino masses, where $i = 1, 2$ and $n$ represents the family index. The other particles of the Standard Model are singlets under $U(1)_{B-L}$

The Higgs Lagrangian for the tree-level diagram shown in figure (1) is given by:

$$\mathcal{L}_{\text{Higgs}} = (D_\mu\phi)^\dagger(D^\mu\phi)+(D_\mu\eta)^\dagger(D^\mu\eta)+(D_\mu S)^\dagger(D^\mu S)-V_I \quad (1)$$

where,

$$V(v_\phi, v_S, v_\eta) \subseteq -\mu^2_\phi v^2_\phi-\mu^2_S v^2_S+M^2_\eta\eta^2+\lambda_\phi v^4_\phi+\lambda_S v^4_S+\lambda_\eta v^4_\eta \quad (2)$$

$$\lambda_{\phi-S}(v^2_\phi)(v^2_S)+[\lambda_{\phi-\eta}+\lambda_7](v^2_\phi)(v^2_\eta)+\lambda_{\eta-S}(v^2_S)(v^2_\eta)+\rho[v_S v_\eta v$$

Here $v^2_\phi \equiv \langle\phi^\dagger\phi\rangle$, $v^2_\eta \equiv \langle\eta^\dagger\eta\rangle$ and $v^2_S \equiv \langle S^* S\rangle$ represent the scalar VEVs. Considering the condition of the minimum and assuming that $M_\eta > 0$

$$M^2_\eta \gg v(\text{VEVs})$$

we obtain,

$$v_\eta \approx \rho\frac{v_\phi v_S}{2M^2_\eta} \quad (3)$$

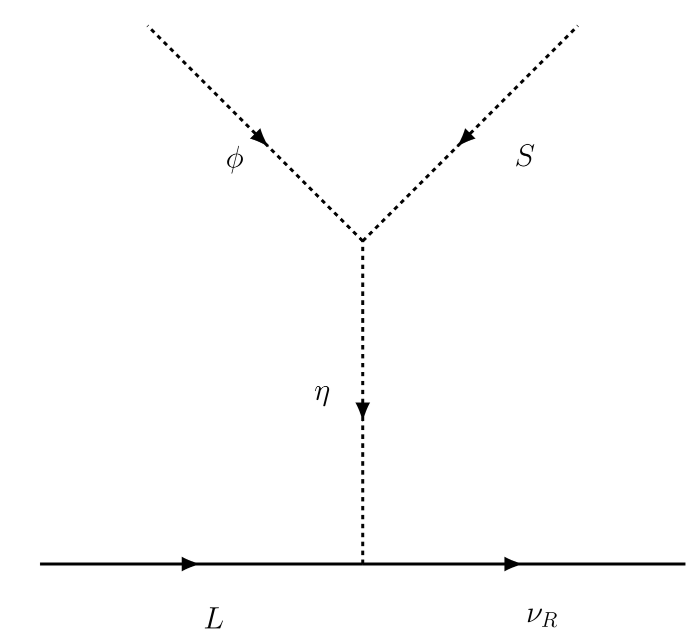


Figure 1:Neutrino mass generation in the Seesaw Dirac type II mechanism. Here the family indices have been supressed

We can thus write down the relevant interaction Lagrangian for generating the Dirac neutrino masses. It involves the messenger scalars $\eta$, the SM-like doublet $\phi$ and the singlet scalar $S$,

$$\mathcal{L}_Y \supset -\sum_{n,m}^{e,\mu,\tau} y_{nm}(\nu_{n_R})^\dagger(L_m)\cdot\eta + \rho S\eta^\dagger\phi + \text{h.c} \quad (4)$$

where $y_{nm}$ is the Yukawa coupling.

$$\mathcal{L}^\nu_{\text{masa}} = (\,(\nu_{e_R})^\dagger\ (\nu_{\mu_R})^\dagger\ (\nu_{\tau_R})^\dagger)M^\nu \begin{pmatrix}\nu_{e_L}\\ \nu_{\mu_L}\\ \nu_{\tau_L}\end{pmatrix} + \text{h.c} \quad (5)$$

The Dirac neutrino mass matrix is defined as follows:

$$M^\nu_{mn} = -\frac{v_\eta}{\sqrt{2}}y_{mn} \quad (6)$$

From (3),

$$M^\nu_{mn} = -y_{mn}\frac{\rho v_\phi v_S}{2\sqrt{2}M^2_\eta} \quad (7)$$

Introducing a large mass value for the $M^2_\eta$ term in the equation (7) gives a light value for the neutrino masses $M_{mn}$; Therefore it is concluded that the **type II Seesaw mechanism** generates light neutrinos by introducing heavy Higgs.

We pass to the mass states through the diagonalization of the $M^\nu$ matrix, assuming that the neutrinos transform from the interaction representation, that is, the flavor representation to the mass representation.

$$M^\nu_{\text{diag}} = U^\dagger M^\nu V\,, \quad (8)$$

Finally the mass Lagrangian of the neutrinos is obtained,

$$\begin{aligned}\mathcal{L}^\nu_{\text{masa}} &= \sum_i m_i\nu^\dagger_i\gamma^0\nu_i \\ &= m_1\overline{\nu}_1\nu_1 + m_2\overline{\nu}_2\nu_2 + m_3\overline{\nu}_3\nu_3\,. \end{aligned} \quad (9)$$

## Conclusion

Introducing a large mass value for the $M^2_\eta$ term gives a light value for the neutrino masses $M_{mn}$; Therefore it is concluded that the **type II Seesaw mechanism** generates light neutrinos by introducing heavy Higgs.

A new framework for the generation of Dirac neutrino masses is presented. This is achieved by extending the visible content of the Standard Model with a hidden sector that has a new symmetry $U(1)_{B-L}$ and is composed of three right singlet neutrinos and one Higgs scalar singlet, $S$.

The masses of the neutrinos that we have obtained with the Seesaw type II mechanism is proportional to the expected vacuum value of the heavy Higgs scalar doublet $v_\eta$.

## References

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