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RADIATIVE NEUTRINO MASS FROM GAUGE LEPTON NUMBER VIOLATION

Sofiane M. Boucenna
Instituto de Física Corpuscular (CSIC-Universitat de València)
Apdo. 22085, E-46071 Valencia, Spain.

Abstract

We propose a new radiative mechanism for neutrino mass generation based on the $SU(3)_c \otimes SU(3)_L \otimes U(1)_X$ electroweak gauge group. Lepton number is spontaneously broken in the gauge sector only. As a result light Majorana masses arise from neutral gauge boson exchange at the one-loop level. In addition to the isosinglet neutrinos which may be produced at the LHC through the extended gauge boson *portals*, the model contains new quarks which can also lie at the TeV scale and provide a plethora of accessible collider phenomena.

1 Introduction

The origin of neutrino mass and mixing, required in order to account for neutrino oscillation data ^{1, 2)}, poses one of the biggest challenges in particle

physics. While charged fermions must be Dirac particles, neutrinos are generally expected to be Majorana fermions ³⁾, breaking lepton number and inducing neutrinoless double beta decay ⁴⁾.

Another important challenge is the origin of the number of families. We know that three different flavors exist, i.e. states with the same gauge quantum numbers but different mass. But we do not know why nature replicates, nor why the masses of the three generations of Standard Model quarks and leptons are so different, nor why they mix in the way they do (flavor problem).

In ⁵⁾ we considered an alternative approach to neutrino mass generation at accessible scales and "explaining" the number of families. The model is based on the $SU(3)_c \otimes SU(3)_L \otimes U(1)_X$ (3-3-1) electroweak gauge structure and is consistent only if the number of families equals the number of quark colors ^{6, 7)}, giving a reason for having three species of fermions. This feature follows from gauge anomaly cancellation and characterizes 331 models, including other variants e.g. ^{8, 9, 10, 11, 12, 13)}.

2 The model

We start from the $SU(3)_c \otimes SU(3)_L \otimes U(1)_X$ gauge framework suggested in ^{6, 7)}. We concentrate on the electroweak part of the model. The left-handed leptons are assigned to the anti-triplet representation of $SU(3)_L$

$$\psi_L^\ell = \begin{pmatrix} \ell^- \\ \nu_\ell \\ N_\ell^c \end{pmatrix}_L, \quad (1)$$

where $\ell = 1, 2, 3 \equiv e, \mu, \tau$. In addition to the new two-component neutral fermions present in the lepton triplet $N_L^c \equiv (N^c)_L \equiv (\nu_R)^c$ where $\psi^c = C\bar{\psi}^T$ and C is the charge conjugation matrix, we introduce new sequential lepton-number-carrying gauge singlets $S = \{S_1, S_2, S_3\}$ sequentially ^{14, 15, 16, 17, 18)}. The matter content of the model is summarized in Tab. 1.

With the above \mathcal{L} assignment the electric charge and lepton number are given in terms of the $U(1)_X$ generator X and the diagonal generators of the $SU(3)_L$ as $Q = T_3 + \frac{1}{\sqrt{3}}T_8 + X$ and $L = \frac{4}{\sqrt{3}}T_8 + \mathcal{L}$

In order to spontaneously break the weak gauge symmetry, we introduce three scalar anti-triplets $\phi_1 \sim (\mathbf{3}^*, +2/3)$ and $\phi_{2,3} \sim (\mathbf{3}^*, -1/3)$. Note that the third component of ϕ_3 carries two units of lepton number. Following the

	ψ_L^ℓ	ℓ_R	$Q_L^{1,2}$	Q_L^3	\hat{u}_R	\hat{d}_R	S	ϕ_1	ϕ_2	ϕ_3
$SU(3)_c$	1	1	3	3	3	3	1	1	1	1
$SU(3)_L$	3S	1	3	3S	1	1	1	3S	3S	3S
$U(1)_X$	$-\frac{1}{3}$	-1	0	$+\frac{1}{3}$	$+\frac{2}{3}$	$-\frac{1}{3}$	0	$+\frac{2}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$
\mathcal{L}	$-\frac{1}{3}$	-1	$-\frac{2}{3}$	$+\frac{2}{3}$	0	0	1	$+\frac{2}{3}$	$-\frac{4}{3}$	$+\frac{2}{3}$

Table 1: Matter content of the model, where $\hat{u}_R \equiv (u_R, c_R, t_R, t'_R)$ and $\hat{d}_R \equiv (d_R, s_R, b_R, d'_R, s'_R)$ (see text).

notation of ⁷⁾ we have the following vacuum expectation values (VEVs)

$$\langle \phi_1 \rangle = \begin{bmatrix} k_1 \\ 0 \\ 0 \end{bmatrix}, \langle \phi_2 \rangle = \begin{bmatrix} 0 \\ 0 \\ n_1 \end{bmatrix}, \langle \phi_3 \rangle = \begin{bmatrix} 0 \\ k_2 \\ n_2 \end{bmatrix}, \quad (2)$$

where the k_1 and k_2 VEVs are at the electroweak scale and correspond to the VEV of the $SU(2)_L \subset SU(3)_L$ doublets. The VEVs n_1 and n_2 are isosinglet VEVs that characterize the $SU(3)_L$ breaking scale. Note that while ϕ_3 takes VEV in both electrically neutral directions, the second VEV of ϕ_2 is neglected, so that lepton number is broken only by $SU(2)_L$ singlets. This pattern gives the simplest consistent neutrino mass spectrum, avoiding the linear seesaw contribution ^{19, 20)}.

There are in total nine electroweak gauge bosons, four of which are charged, while five are electrically neutral, namely W^3, W^6, W^8, B and one neutral boson, unmixed if CP is conserved W^7 .

3 Neutrino masses

Turning to the lepton sector, the Yukawa terms are

$$\mathcal{L}_{\text{leptons}} = y_{ij}^\ell \overline{\psi_L^i} l_R^j \phi_1 + y_{ij}^a \psi_L^{iT} C^{-1} \psi_L^j \phi_1 + y_{ij}^s \overline{\psi_L^i} S^j \phi_2 + \text{h.c.}$$

where contraction of the flavor indices $i, j = 1, 2, 3$ is assumed. Here y^ℓ and y^s are arbitrary matrices while y^a is antisymmetric. The charged lepton mass matrix is just $M_\ell = y^\ell \langle \phi_1^0 \rangle$ and can be made diagonal in the usual way. Note that, thanks to an auxiliary parity symmetry, ϕ_3 does not couple to leptons.

The tree level neutrino mass matrix in the basis (ν_L, N^c, S) is given by

$$M_\nu = \begin{pmatrix} 0 & m_D & 0 \\ & 0 & M \\ & & 0 \end{pmatrix}, \quad (3)$$

where $m_D = k_1 y^a$, and $M = n_1 y^s$. Note that lepton number conservation forbids the Majorana mass entry for S . We denote the corresponding eigenstates as ν_1, ν_2, ν_3 . The heavy states form Dirac pairs with masses M_{D_i} ($i = 1, 2, 3$). On the other hand the state ν_1 is massless because of lepton number conservation in Eq. (3). This holds at tree level. However lepton number is broken spontaneously by $n_2 \neq 0$ and as a result induces light neutrino masses radiatively, as illustrated by the diagram in Fig. 1 (left). Indeed, the interplay of the intra-multiplet gauge boson exchange connecting ν to N^c with the gauge boson mixing implies that lepton number is necessarily violated in the neutral fermion sector. As a result the massless neutrino is not protected and radiative corrections involving the gauge bosons will yield a *calculable* Majorana mass term as depicted in the diagram of Fig. 1 and given by

$$m_{\nu_{\text{light}}} \simeq \frac{g^2 \epsilon \beta}{16\pi^2} M_D \frac{m_{Z'}^2}{M_D^2 + m_{Z'}^2} \log \frac{m_{Z'}^2}{M_D^2}, \quad (4)$$

where g is a simple function of gauge coupling constants g_1 and g_2 and ϵ is the mixing of W^6 with W^3, W^8 and B . Note that the contribution proportional to ϵ^2 and β^2 vanish as expected.

Fig. 1 (right) shows the correlation between the light neutrino mass scale and the Z' mass for various values of the Dirac mass M_D , parametrized by the Yukawa coupling y^a . For definiteness we fix the n_2 VEV, responsible for the masses of the new iso-singlet colored states at 1 TeV and 10 TeV. Increasing n_2 would push up the Z' mass and, assuming Yukawas of order one, would increase the exotic quark masses.

4 Conclusion

In summary, we have proposed a new mechanism to generate neutrino mass based on the $SU(3)_L \otimes U(1)_X$ gauge symmetry. At tree level neutrinos are massless because of lepton number conservation. Gauge interactions violate lepton number and lead to a Majorana mass term for light neutrinos at one-loop level. In contrast to most neutrino mass generation schemes, such as the

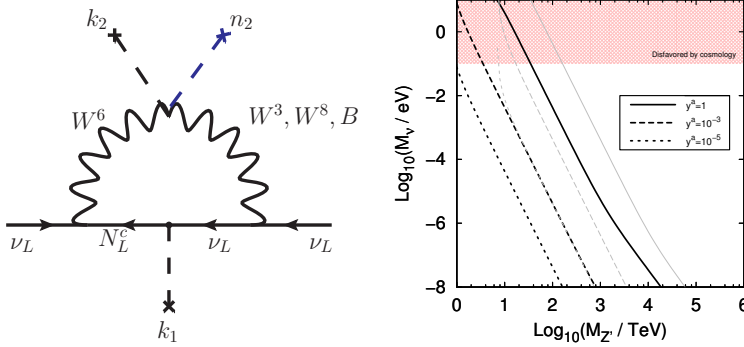


Figure 1: LEFT: Gauge boson exchange diagram for radiatively induced Majorana neutrino mass in the flavor basis. RIGHT: Neutrino mass versus Z' scale for various values of the Dirac mass parameter M_D . Solid, dashed and dot-dashed lines correspond to $y^a = 1, 10^{-3}$ and 10^{-5} respectively. $g_1 = 0.6$ and $k_2 = 90 \text{ GeV}$ and the scale of the new colored states (n_2) is fixed at 1 TeV (thick lines) and 10 TeV (thin lines).

seesaw mechanism, where the neutrino mass comes from Yukawa couplings, here it arises directly from gauge boson exchange as seen in Fig. 1 (left) and Eq. (4). All neutrino species are massive, and their splittings and mixing parameters can be fitted to the oscillation data. Moreover, if light enough, the new exotic colored states would also be produced at the LHC and induce gauge-mediated flavor-changing neutral currents, e.g. $b \rightarrow s\mu^+\mu^-$ (22) providing a double test.

References

1. J. Beringer et al. (Particle Data Group), Phys.Rev. **D86**, 010001 (2012).
2. D. Forero, M. Tortola, and J. W. F. Valle, Phys.Rev. **D86**, 073012 (2012), [arXiv:1205.4018](#).
3. J. Schechter and J. W. F. Valle, Phys. Rev. **D22**, 2227 (1980).
4. J. Schechter and J. W. F. Valle, Phys. Rev. **D25**, 2951 (1982a).
5. S. M. Boucenna, S. Morisi, and J. W. F. Valle, To appear in Phys. Rev. D, [arXiv:1405.2332](#).

6. M. Singer, J. Valle, and J. Schechter, Phys.Rev. **D22**, 738 (1980).
7. J. W. F. Valle and M. Singer, Phys. Rev. **D28**, 540 (1983).
8. R. Foot, H. N. Long, and T. A. Tran, Phys.Rev. **D50**, 34 (1994)
9. P. H. Frampton, Phys. Rev. Lett. **69**, 2889 (1992).
10. F. Pisano and V. Pleitez, Phys.Rev. **D46**, 410 (1992)
11. H. N. Long, Phys.Rev. **D53**, 437 (1996)
12. M. Tully and G. C. Joshi, Phys.Rev. **D64**, 011301 (2001)
13. P. V. Dong, H. T. Hung and T. D. Tham, Phys. Rev. D **87**, 115003 (2013).
14. R. N. Mohapatra and J. W. F. Valle, Phys. Rev. **D34**, 1642 (1986).
15. J. Bernabeu et al., Phys. Lett. **B187**, 303 (1987).
16. M. Dittmar, A. Santamaria, M. C. Gonzalez-Garcia, and J. W. F. Valle, Nucl. Phys. **B332**, 1 (1990).
17. G. C. Branco, M. N. Rebelo, and J. W. F. Valle, Phys. Lett. **B225**, 385 (1989).
18. N. Rius and J. W. F. Valle, Phys. Lett. **B246**, 249 (1990).
19. E. Akhmedov et al., Phys. Lett. **B368**, 270 (1996a) and Phys. Rev. **D53**, 2752 (1996b)
20. M. Malinsky, J. C. Romao, and J. W. F. Valle, Phys. Rev. Lett. **95**, 161801 (2005).
21. H. Georgi and S. L. Glashow, Phys.Rev. **D6**, 429 (1972).
22. A. J. Buras, F. De Fazio and J. Girrbach, JHEP **1402**, 112 (2014) [arXiv:1311.6729 [hep-ph], arXiv:1311.6729].