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Nuclear and Particle Physics Proceedings 267–269 (2015) 370–375

www.elsevier.com/locate/nppp

The assignment of Lepton number and neutrino masses in 3-3-1 models

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Abstract

The assignment of lepton number its violation and its relation to neutrino masses is investigated in several versions of the $SU(3)_c \otimes SU(3)_L \otimes U(1)_x$ model. Spontaneous and explicit violation and conservation of the lepton number are considered. For a particular model, the Majoron is gauged away, providing in this way the longitudinal component to a now massive gauge field.

Keywords:
Neutrino, Majoron, Lepton Number, Masses to neutrinos

1. Introduction

Recent experimental results have confirmed that neutrinos oscillate [1, 2, 3, 4, 5] which implies that at least two of them have small but non zero masses. An alternative to generate neutrino masses is violates lepton number L by two units, generated via non renormalizable operators of the form $(\bar{\psi}^c_{lL}\tilde{\phi}^*)(\tilde{\phi}^\dagger\psi_{l'L})$ to Standard Model (SM), where $\psi_{lL} = (\nu_l, l^-)^T_L$, and $\phi = (\phi^+, \phi^0)$ is the SM Higgs doublet and $\tilde{\phi} = i\sigma_2\phi^*$. This dimension five operator is able to generate type I, type II and type III seesaw mechanisms by using for heavy fields an $SU(2)_L$ singlet fermion, triplet scalar and triplet fermion respectively (in this regard, see Ref. [6, 7]).

The mechanism of coupling two standard model lepton doublets with a Higgs triplet Δ which in turn develops non zero Vacuum Expectation Values (VEV), breaking in this way the lepton number spontaneously, implies in turn the existence of a Majoron [8], particle ruled out experimentally by the Z line shape measurements [9, 10] (a singlet Majoron may still survive but with large constraints [11, 12]).

The variant Zee mechanism [13, 14] can be implemented, when the L=2 Lorentz scalar $\psi_{lL}C\psi_{l'L}$ (with C the charge conjugation matrix) is coupled to an $SU(2)_L$ charged singlet h^+ with L= -2, introducing next a new scalar doublet ϕ' and breaking the L symmetry explicitly in the scalar potential with a term of the form $\phi\phi' h^+$. In this way, neutrino Majorana masses are generated by one loop quantum effects and the unwanted Majoron is not present.

The second Higgs doublet ϕ' can be avoided by introducing instead a double charged Higgs singlet k^{++} which couples to the single charged one by the trilinear coupling $k^{++}h^-h^-$ and to the right handed charged leptons singlets l^-_R via a term of the form $l^-_R C l'^-_R k^{++}$, generating in this way Majorana small masses via two loop quantum effects by what is known as the Zee-Babu mechanism [15, 16].

This situation motivates us to perform an extensive analysis of the lepton number symmetry in the most relevant 3-3-1 models. In particular, we are interested in the gauging away mechanism of the Majoron.

This paper is organized as follows: in Sec. 2 we review the charge assignment and the gauge boson content

http://dx.doi.org/10.1016/j.nuclphysbps.2015.11.002
2405-6014/

of the 3-3-1 models in general, in Sec. 3 the four possibilities for lepton number violation in the context of the minimal version of the 3-3-1 model are presented, in Sec. 4 we classify all the 3-3-1 models without exotic electric charges. Then in Sec. 5 we do the general analysis for the 8 different 3-3-1 models without exotic electric charges with 3 families and we analyze for the so called 3-3-1 model with exotic electrons. and finally, our conclusions are presented in Sec. 6.

2. 3-3-1 Models

Some interesting extensions of the SM are based on the local gauge group $SU(3)_c \otimes SU(3)_L \otimes U(1)_x$ (3-3-1 for short) in which the weak sector of the SM is extended to $SU(3)_L \otimes U(1)_x$. Several models for this gauge structure have been constructed so far.

For the 3-3-1 models, the most general electric charge operator in the extended electroweak sector is

$$Q = a\lambda_3 + \frac{1}{\sqrt{3}} b\lambda_8 + xI_3, \tag{1}$$

where $\lambda_\alpha, \ \alpha = 1, 2, \ldots, 8$ are the Gell-Mann matrices for $SU(3)_L$ normalized as $\mathrm{Tr}(\lambda_\alpha\lambda_\beta) = 2\delta_{\alpha\beta}$ and $I_3 = Dg(1,1,1)$ is the diagonal 3×3 unit matrix. $a = 1/2$ if one assumes that the isospin $SU(2)_L$ of the SM is entirely embedded in $SU(3)_L$; b is a free parameter which defines the different possible models, and the x values are obtained by anomaly cancellation. For A^α_μ,the 8 gauge fields of $SU(3)_L$, $x = 0$ and thus we may write:

$$\sum_\alpha \lambda_\alpha A^\alpha_\mu = \sqrt{2} \begin{pmatrix} D^0_{1\mu} & W^+_\mu & K^{(b+1/2)}_\mu \\ W^-_\mu & D^0_{2\mu} & K^{(b-1/2)}_\mu \\ K^{-(b+1/2)}_\mu & K^{-(b-1/2)}_\mu & D^0_{3\mu} \end{pmatrix}, \tag{2}$$

where $D^0_{1\mu} = A^3_\mu/\sqrt{2} + A^8_\mu/\sqrt{6}$, $D^0_{2\mu} = -A^3_\mu/\sqrt{2} + A^8_\mu/\sqrt{6}$, and $D^0_{3\mu} = -2A^8_\mu/\sqrt{6}$. The upper indices on the gauge bosons stand for the electric charge of the particles, some of them being functions of the b parameter.

3. The Minimal Model

In Ref. [17, 18] it has been shown that, for $b = 3/2$, the following fermion structure is free of all the gauge anomalies: $\psi^T_{lL} = (\nu^0_l, l^-, l^+)_L \sim (1,3,0)$, $Q^T_{iL} = (d_i, u_i, X_i)_L \sim (3,3^*,-1/3)$, $Q^T_{3L} = (u_3, d_3, Y) \sim (3,3,2/3)$, where $l = e, \mu, \tau$ is a family lepton index, $i = 1,2$ for the first two quark families, and the numbers after the similarity sign means 3-3-1 representations. The right handed fields are $u^c_{aL} \sim (3^*,1,-2/3)$, $d^c_{aL} \sim (3^*,1,1/3)$, $X^c_{iL} \sim (3^*,1,4/3)$ and $Y^c_L \sim (3^*,1,-5/3)$, where $a = 1,2,3$ is the quark family index and there are two exotic quarks with electric charge $-4/3$ (X_i) and other with electric charge 5/3 (Y). This version is called *minimal* in the literature, because its lepton content is just the one present in the SM.

For this model, the minimal scalar content required to break the symmetry, giving a realistic mass spectrum, consists of three triplets and one sextet: $\eta^T = (\eta^0, \eta^-_1, \eta^+_2) \sim (1,3,0)$, $\rho^T = (\rho^+, \rho^0, \rho^{++}) \sim (1,3,1)$, $\chi^T = (\chi^-, \chi^{--}, \chi^0) \sim (1,3,-1)$, and

$$S = \begin{pmatrix} \sigma^0_1 & s^+_1 & s^-_2 \\ s^+_1 & s^{++}_1 & \sigma^0_2 \\ s^-_2 & \sigma^0_2 & s^{--}_2 \end{pmatrix} \sim (1,6^*,0). \tag{3}$$

The scalars have Yukawa couplings to the leptons and quarks as follows:

$$\mathcal{L}^l_1 = h^\eta_{ll'}\eta\psi_{lL}C\psi_{l'L} + h^s_{ll'}\psi_{lL}SC\psi_{l'L}. + h.c., \tag{4}$$

$$\begin{aligned} \mathcal{L}^q_1 &= h^u_{ia}Q^T_{iL}\rho C u^c_{aL} + h^d_{ia}Q^T_{iL}\eta C d^c_{aL} \\ &+ h^X_{ij}Q^T_{iL}\chi C X^c_{jL} + h^d_{3a}Q^T_{3L}\rho^* C d^c_{aL} \\ &+ h^u_{3a}Q^T_{3L}\eta^* C u^c_{aL} + h^Y Q^T_{3L}\chi^* C Y^c_L + h.c., \end{aligned} \tag{5}$$

with vacuum expectation values (VEV) given by $\langle\eta^0\rangle = v_1$, $\langle\rho^0\rangle = v_2$, $\langle\chi^0\rangle = v_3$, $\langle\sigma^0_1\rangle = v_4$ and $\langle\sigma^0_2\rangle = v'_4$.

One of the main characteristics of this model is the fact that the lepton number L is not a good quantum number because both, the charged lepton and its antiparticle are in the same multiplet; as a consequence, L does not commute with the electroweak extended gauge symmetry.

The assignment of L starts with the SM assignments [19]

$$\mathrm{L}(l^-_L,\ \nu_{lL}) = -\mathrm{L}(l^+_L) = 1,$$
$$\mathrm{L}(u_{aL},\ u^c_{aL},\ d_{aL},\ d^c_{aL},\ W^\pm_\mu,\ D^0_{1\mu},\ D^0_{2\mu},\ D^0_{3\mu}) = 0;$$

then, looking to the Yukawa interactions of the SM particles and imposing L=0 in the covariant derivative implies

$$\mathrm{L}(K^{++},\ K^+,\ Y_L,\ X^c_{iL}) = -2$$
$$\mathrm{L}(K^{--},\ K^-,\ X_{iL},\ Y^c_L) = 2.$$

For the scalars, L is assigned by inspection of the Yukawa coupling constants and one finds

$$\mathrm{L}(\chi^-,\ \chi^{--},\ s^{--}_2) = 2,$$
$$\mathrm{L}(\eta^+_2,\ \rho^{++},\ \sigma^0_1,\ s^+_1,\ s^{++}_1) = -2,$$
$$\mathrm{L}(\eta^0,\ \eta^-_1,\ \chi^0,\ \rho^+,\ \rho^0,\ \sigma^0_2,\ s^-_2) = 0.$$

Notice that X_i and Y are bi-leptoquarks and K^+, K^-, K^{++} and K^{--} are bi-lepton gauge bosons.

Finally, the physical gauge bosons related to the neutral currents of the model have L=0.

It is interesting to notice that the above lepton numbers of the individual components of each multiplet can be written as [20]

$$\mathrm{L} = \frac{2\lambda_8}{\sqrt{3}} + \mathcal{L} I_3, \tag{6}$$

where $\mathcal{L}$ is a global symmetry of the Lagrangian which is not broken by the VEV, and is related to the following assignment: $\mathcal{L}(\psi_{lL}) = 1/3$, $\mathcal{L}(Q_{iL}) = 2/3$, $\mathcal{L}(Q_{3L},\ \eta,\ S,\ \rho) = -2/3$, $\mathcal{L}(\chi) = 4/3$, $\mathcal{L}(X^c_{iL}) = -2$, $\mathcal{L}(Y^c_L) = 2$, and $\mathcal{L}(u^c_a,\ d^c_a,\ A_{\alpha\mu}) = 0$.

The former analysis shows that since $\mathrm{L}(\eta^0,\ \chi^0,\ \rho^0,\ \sigma^0_2) = 0$, the only place where the L number can be spontaneously violated is in σ^0_1, but it may be explicitly violated in the scalar potential. As a matter of fact, a term like

$$\begin{aligned} V_{LV} &= f_1 \eta S \eta + f_2 S S S + \kappa_1 (\chi^\dagger \eta)(\rho^\dagger \eta) \\ &+ \kappa_2 \eta^\dagger S \chi \rho + \kappa_3 \chi \rho S S + h.c., \end{aligned} \tag{7}$$

explicitly violates $\Delta\mathcal{L} = \Delta\mathrm{L}=\pm 2$ when all the VEV are zero, leaving λ_8 unbroken. Then, the four possibilities of lepton number violation in the context of this model are thus:

(1) $V_{LV} = 0$ and $\langle S \rangle = 0$. This is the minimal 3-3-1 Pisano-Pleitez-Frampton model where total lepton number is conserved and neutrinos are massless particles. Consecuently, this version of the model is in conflict with the existence of massive neutrinos.

(2) $V_{LV} = 0$ but $\langle \sigma^0_1 \rangle \neq 0$. In this case the lepton number is spontaneously broken leading to a triplet Majoron. This case has been analyzed in Ref [21].

(3) $V_{LV} \neq 0$ and $\langle \sigma^0_1 \rangle = 0$. L is violated explicitly and non zero masses for neutrinos can be generated from quantum corrections.

(4) The case for $V_{LV} \neq 0$ and $\langle \sigma^0_1 \rangle \neq 0$ is also possible, with a rich phenomenology which may include a light pseudo Goldstone Majoron [22].

4. 3-3-1 Models Without Exotic Electric Charges

If one wishes to avoid exotic electric charges as the ones present in the minimal model, one must choose $b = 1/2$, in Eq. (1). Following [23, 24] we can find six sets of fermions which contain the antiparticles of the charged particles which are

- $S_1 = [(\nu^0_\alpha, \alpha^-, E^-_\alpha); \alpha^+; E^+_\alpha]_L$ with quantum numbers $(1, 3, -2/3); (1, 1, 1)$ and $(1, 1, 1)$ respectively.
- $S_2 = [(\alpha^-, \nu_\alpha, N^0_\alpha); \alpha^+]_L$ with quantum numbers $(1, 3^*, -1/3)$ and $(1, 1, 1)$ respectively.
- $S_3 = [(d, u, U); u^c; d^c; U^c]_L$ with quantum numbers $(3, 3^*, 1/3)$; $(3^*, 1, -2/3)$; $(3^*, 1, 1/3)$ and $(3^*, 1, -2/3)$ respectively.
- $S_4 = [(u, d, D); u^c; d^c; D^c]_L$ with quantum numbers $(3, 3, 0)$; $(3^*, 1, -2/3)$; $(3^*, 1, 1/3)$ and $(3^*, 1, 1/3)$ respectively.
- $S_5 = [(e^-, \nu_e, N^0_1); (E^-, N^0_2, N^0_3); (N^0_4, E^+, e^+)]_L$ with quantum numbers $(1, 3^*, -1/3)$;$(1, 3^*, -1/3)$ and $(1, 3^*, 2/3)$ respectively.
- $S_6 = [(\nu_e, e^-, E^-_1); (E^+_2, N^0_1, N^0_2); (N^0_3, E^-_2, E^-_3); e^+; E^+_1; E^+_3]_L$ with quantum numbers $(1, 3, -2/3)$; $(1, 3, 1/3)$; $(1, 3, -2/3)$; $(111), (111)$; and (111) respectively.

The different anomalies for these six sets are [23] found in Table I.

TABLE I.
Anomalies for 3-3-1 fermion fields structures

Anomalies	S_1	S_2	S_3	S_4	S_5	S_6
$[SU(3)_C]^2 U(1)_X$	0	0	0	0	0	0
$[SU(3)_L]^2 U(1)_X$	$-2/3$	$-1/3$	1	0	0	-1
$[Grav]^2 U(1)_X$	0	0	0	0	0	0
$[U(1)_X]^3$	10/9	8/9	$-12/9$	$-6/9$	6/9	12/9
$[SU(3)_L]^3$	1	-1	-3	3	-3	3

With this table, anomaly-free models, without exotic electric charges can be constructed for one, two or more families.

As noted in Ref. [23], there are eight three-family models that are anomaly free, which are:

- Model A: with right-handed neutrinos
  $3S_2 + S_3 + 2S_4$.
- Model B: with exotic electrons
  $3S_1 + 2S_3 + S_4$
- Model C: with unique lepton generation one (three different lepton families)
  $S_1 + S_2 + S_3 + 2S_4 + S_5$
- Model D: with unique lepton generation two
  $S_1 + S_2 + 2S_3 + S_4 + S_6$
- Model E: hybrid one (two different lepton structures)
  $S_3 + 2S_4 + 2S_5 + S_6$
- Model F: hybrid two
  $2S_3 + S_4 + S_5 + 2S_6$

- Model G: carbon copy one (three identical families as in the SM)
  $3(S_4 + S_5)$
- Model H: carbon copy two
  $3(S_3 + S_6)$

5. The Neutral Sector

To present the kind of analysis we are aimed to, let us concentrate on Model D to start with.

The lepton fields for this particular model are included in the structure $S_1 + S_2 + S_6$ which contains 21 two component spinors, including seven neutral Weyl states. Let us write them in the following way:

$$
\begin{aligned}
\psi_{1L} &= (\nu_1, l_1^-, E_0^-)_L \sim (1,3,-2/3),\\
l_{1L}^+ &\sim (1,1,1), \quad E_{0L}^+ \sim (1,1,1)\\
\psi_{2L} &= (l_2^-, \nu_2, N_0^0)_L \sim (1,3^*,-1/3), \quad l_{2L}^+ \sim (1,1,1),\\
\psi_{3L} &= (\nu_3, l_3^-, E_1^-)_L \sim (1,3,-2/3),\\
l_{3L}^+ &\sim (1,1,1), \quad E_{1L}^+ \sim (1,1,1)\\
\psi_{4L} &= (E_2^+, N_1^0, N_2^0)_L \sim (1,3,1/3),\\
\psi_{5L} &= (N_3^0, E_2^-, E_3^-)_L \sim (1,3,-2/3), \quad E_{3L}^+ \sim (1,1,1),
\end{aligned}
$$

with the 3-3-1 quantum numbers given in parenthesis.

The minimal scalar content required to break the symmetry, giving a realistic mass spectrum, consists now of only three triplets [25, 26]:

$$
\begin{aligned}
\rho^T &= (\rho_1^0, \rho_2^+, \rho_3^+) \sim (1,3^*,2/3),\\
\eta^T &= (\eta_1^-, \eta_2^0, \eta_3^0) \sim (1,3^*,-1/3),\\
\chi^T &= (\chi_1^-, \chi_2^0, \chi_3^0) \sim (1,3^*,-1/3),
\end{aligned} \tag{8}
$$

with VEV given by $\langle\rho^0\rangle^T = (v_1, 0, 0)$, $\langle\eta^0\rangle^T = (0, v_2, 0)$, and $\langle\chi^0\rangle^T = (0, 0, V)$.

The mass matrix for the neutral sector in the basis $(\nu_1, \nu_2, \nu_3, N_0^0, N_1^0, N_2^0, N_3^0)$ is now of the form:

$$
M_n = \begin{pmatrix}
0 & 0 & 0 & 0 & A & -a & 0\\
0 & 0 & 0 & 0 & M & 0 & 0\\
0 & 0 & 0 & 0 & B & -b & 0\\
0 & 0 & 0 & 0 & 0 & M & 0\\
A & M & B & 0 & 0 & 0 & G\\
-a & 0 & -b & M & 0 & 0 & -d\\
0 & 0 & 0 & 0 & G & -d & 0
\end{pmatrix}, \tag{9}
$$

where the M value is related to a GUT mass scale coming from the bare mass term $\psi_{2L}C\psi_{4L} + h.c$; A, B and C are mass terms at the TeV scale V, and a, b and c are mass terms at the electroweak scale $v \sim v_1 \sim v_2$. The diagonalization of the former mass matrix produces two Dirac massive spinors with masses at the GUT scale and three Weyl massless states that we can associate with the detected solar and atmospheric oscillating neutrinos.

So, up to this point the model has the potential to be consistent with the neutrino phenomenology. But the question is if the three Weyl states remain massless or if they may pick up small radiative masses in the context of the model, or a simple extension of it, something out of the reach of the analysis presented here.

5.1. General analysis for 3 families

Analysis similar to the previous one have been carried through for the neutral fermion sector of the eight anomaly-free lepton structures enumerated in Sec. 4. The results are presented in Table II.

TABLE II : Tree level neutrinos sectors

Model	Number of Weyl neutral states	Massless Weyl states	Dirac States at the EW scale
A:	6	2	2
B:	3	3	0
C:	8	0	3
D:	7	3	0
E:	14	0	3
F:	13	0	1
G:	12	0	3
H:	15	0	4

According to this Table, only models B and D fulfill the natural condition of having 3 tree-level zero mass neutrinos, which may pick up non zero masses via radiative corrections, with or without the adition of new ingredients. Some other structures may become realistic if new fields are added, and/or if some Yukawa coupling constants are fine tuned to very small values, and/or if discreet symmetries which forbids Yukawa terms are imposed, etc..

Let us see this in the following example.

5.2. The 3-3-1 model with exotic electrons

To see what kind of new ingredients are needed in order to provide masses to the neutral fields in these 3-3-1 models without exotic electric charges, let us briefly view the situation for model B which was introduced in the literature for the first time in Ref. [27]. The neutral fermion sector for this model has been studied in some detail in Refs. [28, 29], but the approach here is simpler.

The anomaly free fermion structure for this model is [27]:

$$
\begin{aligned}
\psi_{lL}^T &= (\nu_l^0, l^-, E_l^-)_L \sim (1,3,-2/3),\\
l_L^+ &\sim (1,1,1), \quad E_{lL}^+ \sim (1,1,1),\\
Q_{iL}^T &= (d_i, u_i, U_i)_L \sim (3,3^*,1/3),\\
Q_{3L}^T &= (u_3, d_3, D) \sim (3,3,0),\\
u_{aL}^c &\sim (3^*,1,-2/3), \quad U_{iL}^c \sim (3^*,1,-2/3),\\
d_{aL}^c &\sim (3^*,1,1/3), \quad D_L^c \sim (3^*,1,1/3),
\end{aligned}
$$

where $l = e, \mu, \tau$ is a lepton family index, E_l^- stands for three exotic electron fields, $i = 1, 2$ for the first two quark families, $a = 1, 2, 3$ is again the quark family index, and there are two exotic quarks with electric charge 2/3 (U_i) and other one with electric charge $-1/3$ (D). This model does not contain right handed neutrino fields.

The gauge boson and scalar sectors for this model are exactly the same ones that for the model with right handed neutrinos [25]; but the big differences are that now, the lepton number L is a good quantum number of the model and the gauge bosons does not carry lepton number at all, neither the exotic quarks. The scalars (η, ρ, χ) introduced have also L=0, the lepton number cannot be broken spontaneously and, as a consecuence, the neutrinos remain massless even with the inclussion of the radiative corrections.

In what follows and in order to simplify matters and make this model more predictable, we consider only the set of two scalar triplets χ and ρ instead of the set of three triplets proposed in the original paper [27], or the much more complex structure introduced in Ref. [28]. Also, let us take the VEV to be $\langle\chi\rangle^T = (0, v, V)$ and $\langle\rho\rangle^T = (v_1, 0, 0)$. The Yukawa couplings of the leptons to this scalars are now

$$\mathcal{L}_2^l = \sum_{l,l'} [(\psi_{lL}^T.\chi) C (h_{ll'}^e l_L'^+ + h_{ll'}^E E_{l'L}^+)] + h.c., \quad (10)$$

which for $l, l' = e, \mu, \tau$ saturates all the entries of the 6×6 charged lepton mass matrix and allows tree-level masses only for charged leptons, eventhough there are in (10) external legs with neutrino fields of the form $\nu_{lL}^0 \chi_1^- C (h_{ll'}^e l_L'^+ + h_{ll'}^E E_{l'L}^+) + h.c.$. The possible inclusion of the scalar η does not change this situation at all.

Masses for neutrinos can be obtained only by enlarging the model. For this purpose one can introduce a new scalar triplet $\phi = (\phi_1^{++}, \phi_2^+, \phi_3^+) \sim (1, 3, 4/3)$ which couples to the spin 1/2 leptons via a term in the Lagrangian of the form

$$\begin{aligned} \mathcal{L}_3^l &= \epsilon_{nmp} \sum_{l,l'} h_{ll'}^\nu \phi^n \psi_{lL}^m C \psi_{l'L}^p + h.c., \quad (11) \\ &= \sum_{ll'} h_{ll'}^\nu [\phi_1^{++} (l_L^- E_{l'L}^- - l_L'^- E_{lL}^-) \\ &+ \phi_2^+ (E_{lL}^- \nu_{l'L} - E_{l'L}^- \nu_{lL}) \\ &+ \phi_3^+ (\nu_{lL} l_L'^- - \nu_{l'L} l_L^-)] + h.c., \end{aligned}$$

which implies lepton number values L$(\phi_1^{++}, \phi_2^+, \phi_3^+) = -2$ in order to have it conserved in $\mathcal{L}_3^l$. Notice that the expression above also provides several external legs with neutrino fields which can be used to generate masses to the neutral fermions via quantum effects.

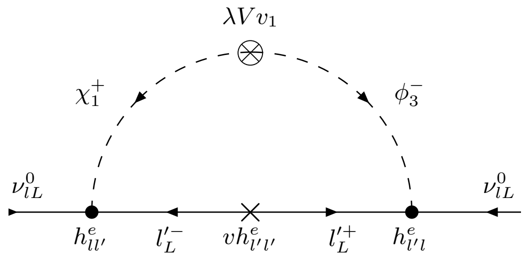

Figure 1: Generation of the neutrino masses via the one loop radiative mechanism in the 3-3-1 model with exotic electrons.

Since $\langle\phi\rangle = (0, 0, 0)$, the new scalar fields are not able to break spontaneously the lepton number. But the point is that the lepton symmetry is now explicitly broken in the Lagrangian by a term in the scalar potential of the form $\lambda(\phi.\chi)(\rho^*.\chi)$ which violates lepton number by two units and turns on the Zee radiative mechanism in the context of this 3-3-1 model with exotic electrons. As a matter of fact, all the previous ingredients allow us to draw the diagram in Figure 1 in the context of the field structure presented so far.

Although the scalar sector has three independent fields (χ, ρ, ϕ), its VEV structure is simpler that the one proposed in the original paper [27].

Neutrino masses in the context of the model analyzed in this section, were studied for the first time in Ref. [30]. The main difference between that paper and this one is that in Ref. [30], and in order to implement the Zee-Babu mechanism [13, 15] for generating neutrino mass terms, a double charged Higgs scalar $SU(3)_L$ singlet $k^{++} \sim (1, 1, 2)$ was used instead of our ϕ scalar triplet, which is the new and main ingredient of our analysis. So, both papers address to the same problem from two different points of view.

6. Conclusions

The main motivation of our study was to investigate the neutrino mass spectrum in the framework of the local gauge structure $SU(3)_c \otimes SU(3)_L \otimes U(1)_x$.

Summarizing: we have carried out an extensive analysis of the lepton number symmetry in the context of the best known versions of the 3-3-1 model. In some of these models, one explicitly find the quite unusual situation of the gauging away of the would be Majoron, providing in this way the longitudinal polarization component to a new massive gauge field.

This rare but quite unusual mechanism, is related to the fact that the lepton number generator L is connected with the λ_8 generator of $SU(3)_L$, as shown in Eq. (6).

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