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Mass Generation of the Scalars Bosons in a Left-Right Symmetric Model with two Bidoublets

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Abstract.
The search for new Physics justified by new discoverys, motivate among others, the realization of new models called Extensions of the Standard Model (ESM) which must include at low energy the Standar Model. (SM) The electroweak symmetry group $SU(2)_L \otimes U(1)_Y$ to the gauge group with left-right symmetry $SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L} \otimes \mathcal{P}$, represents one of the minimal extensions of the SM, in which $\mathcal{P}$ is a parity discrete symmetry such that left-right coupling constants satisfied $g_L = g_R$, and according to the hierarchy in the symmetry breaking (conditions that must be met by the vacuum expectation values introduced in the model) allow to obtain the SM. The aim of this work is to identify the Higgs boson of the SM, considering a more general scalar potential that must respect all the symmetries (local gauge invariant, discrete symmetries and Lorentz invariant) established in the model. We will take into account those previous works about the hierarchy conditions and certain approximations that must satisfy the vacuum expectation values for obtain greater simplicity in the caculations of scalar masses of the model.

1. Introduction

The SM of Particle Physics is divided in two parts according to the interaction under study, the electroweak and strong interaction, the former was elaborated by Weimberg Salam and Glashow [1] it associates to each known particle a quantum field performing their interactions. All the predicted particles by the SM have been observed experimentally being the final discovery the Higgs boson in 2012 by ATLAS [2] and CMS [3]. Despite of the SM sucess the theory not explain certain facts [4]. In the SM neutrinos are not massive, however the experiments have showed that neutrinos would posses a tiny mass, allowing the oscillations phenomena [5]. From the scalar fields point of view, it is possible to obtain more than one scalar higgs, extending the scalar sector of the SM with symmetry $SU(2)_L \otimes U(1)_Y$ [6], adding one more $SU(2)_R$ symmetry [7] or enlarging the symmetry group to $SU(3)_L \otimes U(1)_{B-L}$ [8]. It is logical suppouse that one of them is the scalar higgs boson, recently discovered with an order of mass 125.10 ± 0.14 GeV [9].

The aim of this work has as objetive to calculate the spectrum mass of the scalar sector of the one SM extension mentioned above: $SU(2)_R \otimes SU(2)_L \otimes U(1)_{B-L} \otimes \mathcal{P}$ ([10],[11]). This class of symmetric models left right (SMLR) preserve parity at high energies, obtainig the breakdown of this symmetry at low scale [12] as consecuence among others, neutrino would adquire a tiny

mass [5] or to have the possibility to explain dark matter [4] ie neutrino sterile [13].
In the present model all fermions are Dirac type particles including the neutrinos whose coupling with the neutral bosons vectors were giving in a previous work [14]. The scalar sector is constituting, in its minimal version, by two bidoublets Φ_1 and Φ_2, which give mass to all massive particles of the model through spontaneous symmetry breaking. Additionally, the model present from the initio parity symmetrie $\mathcal{P}$ which together with the left right symmetry of the gauge groups $SU(2)_R \otimes SU(2)_L$ let the model be left right symmetric, in consequence at high energies the couplings constants g_L and g_R are equals $g_L = g_R$ [14]. After the spontaneous symmetry breaking (SSB), the SMLR model must recover the electroweak SM $SU(2)_L \otimes U(1)_Y$. In this work we don't take into account the others sectors of the model as: leptonic, bosonic and yukawa sectors, because we are concern in describe with detail the scalar sector. It is important emphazise, in this work all the vacuum expectation values (VEV) $k_1, k_1^{'}, k_2, k_2^{'}$ v_L y v_R are reals because the subject of soft and spontaneous CP violations [15], [16] will be discused in other work. This expection values must satisfied the hierarchy conditions $v_R >> X$ being X any VEVs different of v_R. In the second section a summary of the model is presented, considering the scalar multiplets in each sector of the model and its respectives couplings with leptons, vectorial bosons and scalar itself. The vectorial boson sector was develop previously [14]. In the third section, the constrains equations are obtained, wich will let to calculate the scalar physical mass of the particles of the model. In the fourth section, the physical scalar neutral, as well as simply charged scalar bosons are calculated¸ using the previous constraints equations, obtaining in consequence, the lighter of them wich must be the higgs boson of the SM. In fifth section, a detailed fenomenological analysis is realized, identifiying the higgs boson of the SM. Finally in the sixth section the conclusions are discussed.

2. The Symmetric Model Left Right

2.1. Leptonic Sector

The left right leptons are represented by doublets in the fundamental representations of the local gauge groups $SU(2)_L$ and $SU(2)_R$:

$$\begin{array}{l} L_l \equiv \frac{1}{2}(1-\gamma_5)\begin{pmatrix} \psi_{\nu_l} \\ \psi_l \end{pmatrix} = \begin{pmatrix} \nu_e \\ e^- \end{pmatrix}_L ; \\ \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix}_L ; \begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix}_L \sim (\mathbf{2}_L, \mathbf{1}_R, -1) \\ R_l \equiv \frac{1}{2}(1+\gamma_5)\begin{pmatrix} \psi_{\nu_l} \\ \psi_l \end{pmatrix} = \begin{pmatrix} \nu_e \\ e^- \end{pmatrix}_R ; \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix}_R ; \\ \begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix}_R \sim (\mathbf{1}_L, \mathbf{2}_R, -1); \end{array} \tag{1}$$

the numbers between parentheses represents the third component of isospin left right $T_{3L}(T_{3R})$, and the hypercharge quantum number $B-L$ respectively [17]. This are related through the Gellman-Nishijima formula:

$$Q = T_{3L} + T_{3R} + \frac{B-L}{2}. \tag{2}$$

In the SM the hypercharge quantum number was an arbitrary parameter without physical

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meaning but relationated with the electric charge through eq(2), currently the hypercharge is realtionated with the barion number and lepton number by $Y = B - L$.

2.2. Scalar Sector

The scalar sector consist in two bidoublets with transformation $(\mathbf{2}, \mathbf{2}, 0)$:

$$\Phi_1 = \begin{pmatrix} \phi_1^0 & \eta_1^+ \\ \phi_1^- & \eta_1^0 \end{pmatrix}, \; \Phi_2 = \begin{pmatrix} \phi_2^0 & \eta_2^+ \\ \phi_2^- & \eta_2^0, \end{pmatrix}, \tag{3}$$

the electric charge assignment shown in (3), is analized in [18].
The bidoublet ϕ_1 gives mass to the known leptons (neutrinos included) and the other one ϕ_2 generate quark masses. The doublets $\chi_L \sim (\mathbf{2}, \mathbf{1}, +1)$ and $\chi_R \sim (\mathbf{1}, \mathbf{2}, +1)$ are introduced not only to complete the hierarchy in the spontaneous symmetry breaking towards $U(1)_Q$ final local gauge invariance of the model, is not also to respect the left right symmetry. This parity symmetry becomes breaking explicitly when the neutral component of the doublet χ_R adquire a non zero expectation value, it to say $v_R \neq 0$.

$$\chi_L = \begin{pmatrix} \chi_L^+ \\ \chi_L^0 \end{pmatrix}, \quad \chi_R = \begin{pmatrix} \chi_R^+ \\ \chi_R^0 \end{pmatrix}, \tag{4}$$

The higgs sector is different for each model, depending of the scalar number multiplets involved, with this scalars we build the most general potencial that respect the local symmetry of the model, in our case we use the potential proposed in [14]

$$V \;=\; V^{(2)} + V^{(4a)} + V^{(4b)} + V^{(4c)} + V^{(4d)} + V^{(4e)}, \tag{5}$$

where:

$$\begin{aligned}
V^{(2)} &= \frac{1}{2}\sum_{i=1,2}^{2}\left[\mu_{ii}^2\, Tr(\Phi_i^\dagger\Phi_i) + H.c.\right] \\
&+ \mu_{LR}^2\left(\chi_L^\dagger\chi_L + \chi_R^\dagger\chi_R\right) \\
V^{(4a)} &= \frac{1}{2}\sum_{i=1,2}^{2}\left[\lambda_{ii} Tr(\Phi_i^\dagger\Phi_i)^2 + H.c.\right], \\
V^{(4b)} &= \frac{1}{2}\sum_{i=1,2}^{2}\lambda'_{ii}\left(Tr\Phi_i^\dagger\Phi_i\right)^2, \\
V^{(4c)} &= \rho_{12}\, Tr\left(\Phi_1^\dagger\Phi_1\Phi_2^\dagger\Phi_2\right), \\
V^{(4d)} &= \frac{1}{2}\left[\sum_{i=1,2}^{2}(\Lambda_{ii}\, Tr\Phi_i^\dagger\Phi_i(\chi_L^\dagger\chi_L\chi_R^\dagger\chi_R)\right. \\
&+ \overline{\Lambda}_{ii}(\chi_L^\dagger\Phi_i\Phi_i^\dagger\chi_L + \chi_R^\dagger\Phi_i\Phi_i^\dagger\chi_R) + \\
&+ \left.\overline{\Lambda}'_{ii}(\chi_L^\dagger\tilde{\Phi}_i\tilde{\Phi}_i^\dagger\chi_L + \chi_R^\dagger\tilde{\Phi}_i\tilde{\Phi}_i^\dagger\chi_R))\right], \\
V^{(4e)} &= \lambda_{LR}\left[(\chi_L^\dagger\chi_L)^2 + (\chi_R^\dagger\chi_R)^2\right].
\end{aligned} \tag{6}$$

It is observed many free parameters introduced in the potential which will be vinculated trough constraints equations.

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We assign to neutral scalar fields its respective VEV, which are responsible of the content particle mass

$$< \Phi_1 >= \frac{1}{\sqrt{2}} \begin{pmatrix} k_1 & 0 \\ 0 & k_1' \end{pmatrix}, \quad < \Phi_2 >= \frac{1}{\sqrt{2}} \begin{pmatrix} k_2 & 0 \\ 0 & k_2' \end{pmatrix}, \tag{7}$$

and

$$\langle \chi_L \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v_L \end{pmatrix}, \quad \langle \chi_R \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v_R \end{pmatrix}. \tag{8}$$

These VEVs are considered reals because we are not interested for the moment in the subject of CP violation [15].

2.3. Bosonic Sector

As any extension of the SM this model propose the existence of the seven vectorial bosons as follows: a neutral non massive vectorial boson, the photon A_μ, two neutral massive vector bosons Z_L, Z_R and four massive charged bosons $W_L^\pm$, $W_R^\pm$. The development of this sector will de work in a future article.

3. Constraints Equations

The Constraints equations are obtained when the potential it is minimized around the vacuum expectation values through the spontaneous symmetry breaking, i.e:

$$\frac{\partial V}{\partial \phi_i}|_{\phi = \langle \phi \rangle} = 0, \tag{9}$$

where $\langle \phi \rangle$ is any expectation value:k_1, k_2, k_1', k_2', v_L y v_R.

From the condition (9) it is obtained the following constrains equations:

$$\begin{aligned}
(a) \quad & k_1\mu_{11}^2 + (\lambda_{11} + \lambda_{11}')k_1^3 + \lambda_{11}'k_1k_1'^2 \\
+ \quad & \frac{k_1}{2}(v_L^2 + v_R^2)(\Lambda_{11} + \overline{\Lambda}_{11}') + \frac{1}{2}k_1k_2^2\rho_{12} = 0, \\
(b) \quad & k_1'\mu_{11}^2 + (\lambda_{11} + \lambda_{11}')k_1'^3 + \lambda_{11}'k_1'k_1^2 \\
+ \quad & \frac{k_1'}{2}(v_L^2 + v_R^2)(\Lambda_{11} + \overline{\Lambda}_{11}) + \frac{1}{2}k_1'k_2'^2\rho_{12} = 0, \\
(c) \quad & k_2\mu_{22}^2 + (\lambda_{22} + \lambda_{22}')k_2^3 + \lambda_{22}'k_2k_2'^2 \\
+ \quad & \frac{k_2}{2}(v_L^2 + v_R^2)(\Lambda_{22} + \overline{\Lambda}_{22}') + \frac{1}{2}k_2k_1^2\rho_{12} = 0, \\
(d) \quad & k_2'\mu_{22}^2 + (\lambda_{22} + \lambda_{22}')k_2'^3 + \lambda_{22}'k_2'k_2^2 \\
+ \quad & \frac{k_2'}{2}(v_L^2 + v_R^2)(\Lambda_{22} + \overline{\Lambda}_{22}) + \frac{1}{2}k_2'k_1'^2\rho_{12} = 0, \\
(e) \quad & \mu_{LR}^2\, v_L + \lambda_{LR}\, v_L^3 + \frac{v_L}{2}\Big(k_1'^2(\Lambda_{11} + \overline{\Lambda}_{11}) + k_2'^2 \times \\
& (\Lambda_{22} + \overline{\Lambda}_{22}) + k_1^2(\Lambda_{11} + \overline{\Lambda}_{11}') + k_2^2(\Lambda_{22} + \overline{\Lambda}_{22}')\Big) \\
& = 0,
\end{aligned} \tag{10}$$

$$(f) \qquad \mu_{LR}^2 v_R + \lambda_{LR} v_R^3 + \frac{v_R}{2}\Big(k_1'^2(\Lambda_{11}+\overline{\Lambda}_{11}) + k_2'^2 (\Lambda_{22}+\overline{\Lambda}_{22}) + k_1^2(\Lambda_{11}+\overline{\Lambda}'_{11}) + k_2^2(\Lambda_{22}+\overline{\Lambda}'_{22})\Big) = 0.$$

This equations represents the constraints that must satisfy the VEVs as well as the potential parameters due to the Higgs mechanims, this relations will permit us to calculate the mass matrices for all particle of the model in particular the photon of zero mass.
The possibility of that some VEV remain zero (not breaking) will be studied.

4. Mass Matrices of the Exotic Scalar Bosons

Proceeding to the symmetry breaking we expand the zero charge scalar fields around its respective VEVs:

i) For bi-doublets:

$$\begin{aligned} \Phi_1 &= \begin{pmatrix} \frac{1}{\sqrt{2}}(k_1 + H_{1a} + i\,I_{1a}) & \eta_1^+ \\ \phi_1^- & \frac{1}{\sqrt{2}}(k_1' + H_{2a} + i\,I_{2a}) \end{pmatrix}, \\ \Phi_2 &= \begin{pmatrix} \frac{1}{\sqrt{2}}(k_2 + H_{1b} + i\,I_{1b}) & \eta_2^+ \\ \phi_2^- & \frac{1}{\sqrt{2}}(k_2' + H_{2b} + i\,I_{2b}) \end{pmatrix}, \end{aligned} \tag{11}$$

ii) For doublets:

$$\begin{aligned} \chi_L &= \begin{pmatrix} \chi_L^+ \\ \frac{1}{\sqrt{2}}(v_L + H_{1L} + i\,I_{1L}) \end{pmatrix}, \\ \chi_R &= \begin{pmatrix} \chi_R^+ \\ \frac{1}{\sqrt{2}}(v_R + H_{1R} + i\,I_{1R}) \end{pmatrix}, \end{aligned} \tag{12}$$

In this model do not exist double charge scalar fields because we do not have scalar triplets multiplet which would take us to massive neutrinos through see-saw mechanism [19][20].

4.1. Single Charged Scalar Fields

The mass matrices are obtained from the quadratic terms in the density lagrangian after the symmetry breaking. In the case of the scalar fields the general expression form of mass terms is show as follows [21].

$$\sum_{i,j} \frac{\partial^2 V}{\partial\phi_k \partial\phi_i}|_{\phi=\langle\phi\rangle} \, (T^a)_{ij} \, \langle\phi_j\rangle = 0, \tag{13}$$

where the T^a are the generators of the summetry group. The quadratic mass matrix becomes:

$$\mathcal{M}_{ij}^2 = \frac{\partial^2 V}{\partial\phi_k \partial\phi_i}|_{\phi=\langle\phi\rangle}. \tag{14}$$

We write this quadratic mass term in the base of the scalars single charged fields: η_1^+, ϕ_1^-, η_2^+, ϕ_2^-, χ_L^+ y χ_R^+.

$$\mathcal{M}^2_{SC} = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{16} \\ a_{21} & a_{22} & \cdots & a_{26} \\ \vdots & \vdots & \ddots & \vdots \\ a_{61} & a_{62} & \cdots & a_{66}, \end{pmatrix} \tag{15}$$

where:

$$\begin{aligned}
a_{11} &= \frac{\rho_{12}(k_2'^2 - k_2^2)}{2} - \frac{1}{2}(v_L^2 + v_R^2)(\Lambda_{11} + \overline{\Lambda}'_{11}) \\
&+ k_1'^2\lambda_{11} \\
a_{12} &= a_{21} = 0, \\
a_{13} &= a_{31} = \frac{\rho_{12}k_1k_2}{2}, \\
a_{14} &= a_{41} = a_{15} = a_{51} = 0, \\
\\
a_{16} &= a_{61} = 0, \\
a_{22} &= \frac{\rho_{12}(k_2^2 - k_2'^2)}{2} - \frac{1}{2}(v_L^2 + v_R^2)(\Lambda_{11} + \overline{\Lambda}_{11}) \\
&+ k_1^2\lambda_{11}, \\
a_{23} &= a_{32} = 0, \\
a_{24} &= a_{42} = \frac{\rho_{12}k_1'k_2'}{2}, \\
a_{25} &= a_{26} = a_{52} = a_{62} = 0, \\
\\
a_{33} &= \frac{\rho_{12}(k_1'^2 - k_1^2)}{2} - \frac{1}{2}(v_L^2 + v_R^2)(\Lambda_{22} + \overline{\Lambda}'_{22}) \\
&+ k_2'^2\lambda_{22} \\
a_{34} &= a_{43} = a_{35} = a_{53} = 0, \\
a_{36} &= a_{63} = 0, \\
a_{44} &= \frac{\rho_{12}(k_1^2 - k_1'^2)}{2} - \frac{1}{2}(v_L^2 + v_R^2)(\Lambda_{22} + \overline{\Lambda}_{22}) \\
&+ k_2^2\lambda_{22} \\
a_{45} &= a_{46} = a_{54} = a_{64} = 0, \\
\\
a_{55} &= -\frac{1}{2}k_1'^2(\Lambda_{11} + \overline{\Lambda}_{11}) - \frac{1}{2}k_2'^2(\Lambda_{22} + \overline{\Lambda}_{22}) \\
&- \frac{1}{2}k_1^2(\Lambda_{11} + \overline{\Lambda}'_{11}) - \frac{1}{2}k_2^2(\Lambda_{22} + \overline{\Lambda}'_{22}), \\
a_{56} &= a_{65} = 0, \\
a_{66} &= -\frac{1}{2}k_1'^2(\Lambda_{11} + \overline{\Lambda}_{11}) - \frac{1}{2}k_2'^2(\Lambda_{22} + \overline{\Lambda}_{22}) \\
&- \frac{1}{2}k_1^2(\Lambda_{11} + \overline{\Lambda}'_{11}) - \frac{1}{2}k_2^2(\Lambda_{22} + \overline{\Lambda}'_{22}),
\end{aligned} \tag{16}$$

.

In the elaboration of this matrix we are used the constraints equations given in (10) because these equations minimize the number of free parameters.

The next step is to diagonalize this quadratic mass matrix, nonetheless as this matrix elements are so extensive, then we will use some aproximations given in the literature[14]:

$$k_1 \approx k_1' \approx 0, \;\; k_2 \approx k_2', \;\; v_L = 0. \tag{17}$$

These relations of the VEVs was showed in the previous article [14] where the hierarchy that these VEVs must satisfy are: $v_R \gg k_1, k_2, k_1', k_2', v_L$, this aproximations (17) are justified by the constraints equations, where we observe that to put $v_L = 0$ don't affect any knowing lagrangian sector because this doublet χ_L don't interactue whit the known leptons. For this reason this scalar is candidate to be dark matter, therefore with the approximations given in (17) we have the new matrix:

$$\mathcal{M}^2_{Cf} = \begin{pmatrix} e_{11} & 0 & 0 & 0 & 0 & 0 \\ 0 & e_{22} & 0 & 0 & 0 & 0 \\ 0 & 0 & e_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & e_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & e_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & e_{66} \end{pmatrix}, \tag{18}$$

where the diagonal elements of the matrix are:

$$\begin{aligned} e_{11} &= -\frac{v_R^2}{2}(\Lambda_{11} + \overline{\Lambda}'_{11}), \\ e_{22} &= -\frac{v_R^2}{2}(\Lambda_{11} + \overline{\Lambda}_{11}), \\ e_{33} &= k_2^2\,\lambda_{22} - \frac{v_R^2}{2}(\Lambda_{22} + \overline{\Lambda}'_{22}), \\ e_{44} &= k_2^2\,\lambda_{22} - \frac{v_R^2}{2}(\Lambda_{22} + \overline{\Lambda}_{22}), \\ e_{55} &= e_{66} = -k_2^2\,(2\Lambda_{22} + \overline{\Lambda}_{22} + \overline{\Lambda}'_{22}) \end{aligned} \tag{19}$$

As it is a diagonal matrix then the proper values are those elements of the diagonal, therefore, theses values of mass (their squares) are given by:

$$\begin{aligned} m^2_{H_1^+} &= -\frac{v_R^2}{2}(\Lambda_{11} + \overline{\Lambda}'_{11}), \\ m^2_{H_2^-} &= -\frac{v_R^2}{2}(\Lambda_{11} + \overline{\Lambda}_{11}), \\ m^2_{H_3^+} &= k_2^2\,\lambda_{22} - \frac{v_R^2}{2}(\Lambda_{22} + \overline{\Lambda}'_{22}), \\ m^2_{H_4^-} &= k_2^2\,\lambda_{22} - \frac{v_R^2}{2}(\Lambda_{22} + \overline{\Lambda}_{22}), \\ m^2_{H_5^+} &= m^2_{H_6^+} = -k_2^2\,(2\Lambda_{22} + \overline{\Lambda}_{22} + \overline{\Lambda}'_{22}) \end{aligned} \tag{20}$$

It is observed from theses results that the simples scalar charged fields becomes massive particles. It is known that when we break the major symmetry group to a less symmetry

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group this is achived through the neutral scalars fields because they permit the electric charge conservation during the breaking, and as consequence appears the goldstone bosons

From the equations given in (20) and the fact that the hierarchy of VEVs must satisfy: $v_R >> X$ where X is any other expectation value we deduce:

$$\begin{aligned} \Lambda_{11} + \overline{\Lambda}'_{11} &< 0, \qquad \Lambda_{11} + \overline{\Lambda}_{11} < 0, \\ \Lambda_{22} + \overline{\Lambda}'_{22} &< 0, \qquad \Lambda_{22} + \overline{\Lambda}_{22} < 0, \\ 2\Lambda_{22} + \overline{\Lambda}_{22} + \overline{\Lambda}'_{22} &< 0. \end{aligned} \tag{21}$$

These inequalities are additionals constraint that must comply the parameters of the scalar sector. Also it is observed there exist two simply charged particles with the same mass (strictly speaking its quadratic mass), $m^2_{H_5^+}$, $m^2_{H_6^+}$.
Finally we obtains their masses from (20)

$$\begin{aligned} m_{H_1^+} &= v_R\sqrt{-\frac{1}{2}(\Lambda_{11} + \overline{\Lambda}'_{11})}, \\ m_{H_2^-} &= v_R\sqrt{-\frac{1}{2}(\Lambda_{11} + \overline{\Lambda}_{11})}, \\ m_{H_3^+} &= \sqrt{k_2^2\,\lambda_{22} - \frac{v_R^2}{2}(\Lambda_{22} + \overline{\Lambda}'_{22})}, \\ m_{H_4^-} &= \sqrt{k_2^2\,\lambda_{22} - \frac{v_R^2}{2}(\Lambda_{22} + \overline{\Lambda}_{22})}, \\ m_{H_5^+} &= m_{H_6^+} = k_2\sqrt{-\left(2\Lambda_{22} + \overline{\Lambda}_{22} + \overline{\Lambda}'_{22}\right)} \end{aligned} \tag{22}$$

Approximating the mass of the scalars $m_{H_3^+}$ and $m_{H_4^-}$ for the values of v_R great comparing with the others VEVs, we obtain.

$$\begin{aligned} m_{H_3^+} &\approx v_R\sqrt{\frac{-(\Lambda_{22} + \overline{\Lambda}'_{22})}{2}} - \frac{k_2^2\,\lambda_{22}}{v_R\sqrt{-2(\Lambda_{22} + \overline{\Lambda}'_{22})}} \\ &+ \mathcal{O}(1/v_R^3), \\ m_{H_4^+} &\approx v_R\sqrt{\frac{-(\Lambda_{22} + \overline{\Lambda}_{22})}{2}} - \frac{k_2^2\,\lambda_{22}}{v_R\sqrt{-2(\Lambda_{22} + \overline{\Lambda}_{22})}} \\ &+ \mathcal{O}(1/v_R^3). \end{aligned}$$

It can be deducted from these results given in (22, 21).

$$m_{H_1^+},\ m_{H_2^+},\ m_{H_3^+},\ m_{H_4^+} > m_{H_5^+}, \tag{23}$$

4.2. Neutral Scalar Fields (Real Part)
To find the masses of these fields it will be considered the quadratic terms in the scalar potential in relation to: H_{1a}, H_{1b}, H_{2a}, H_{2b}, H_{L1} y H_{R1}. They represent the base in which they were constructed the matrix od the neutral scalar fields (Hermitian Fields Operators).

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$$\mathcal{M}_h^2 = \begin{pmatrix} b_{11} & b_{12} & \cdots & b_{16} \\ b_{21} & b_{22} & \cdots & b_{26} \\ \vdots & \vdots & \ddots & \vdots \\ b_{61} & b_{62} & \cdots & b_{66}, \end{pmatrix} \tag{24}$$

where the matrix elements are of the form:

$$\begin{aligned}
b_{11} &= k_1^2\left(\lambda_{11}+\lambda'_{11}\right) \\
b_{12} &= b_{21} = \frac{1}{2}\rho_{12}k_1k_2, \\
b_{13} &= b_{31} = \lambda'_{11}k_1k'_1, \\
b_{14} &= b_{41} = 0, \\
b_{15} &= b_{51} = \frac{k_1v_L(\overline{\Lambda}_{11}+\overline{\Lambda}'_{11})}{2} \\
\\
b_{16} &= b_{61} = \frac{k_1v_R(\overline{\Lambda}_{11}+\overline{\Lambda}'_{11})}{2}, \\
b_{22} &= k_2^2\left(\lambda_{22}+\lambda'_{22}\right) \\
b_{23} &= b_{32} = 0, \\
b_{24} &= b_{42} = \lambda'_{22}k'_1k'_2, \\
b_{25} &= b_{52} = \frac{k_2v_L(\overline{\Lambda}_{22}+\overline{\Lambda}'_{22})}{2}, \\
b_{26} &= b_{62} = \frac{k_2v_R(\overline{\Lambda}_{22}+\overline{\Lambda}'_{22})}{2}, \\
\\
b_{33} &= k_1'^2\left(\lambda_{11}+\lambda'_{11}\right) \\
b_{34} &= b_{43} = \frac{1}{2}\rho_{12}k'_1k'_2, \\
b_{35} &= b_{53} = \frac{k'_1v_L(\overline{\Lambda}_{11}+\overline{\Lambda}'_{11})}{2}, \\
b_{36} &= b_{63} = \frac{k'_1v_R(\overline{\Lambda}_{11}+\overline{\Lambda}'_{11})}{2}, \\
b_{44} &= k_2'^2\left(\lambda_{22}+\lambda'_{22}\right) \\
b_{45} &= b_{54} = \frac{k'_2v_L(\overline{\Lambda}_{22}+\overline{\Lambda}'_{22})}{2}, \\
b_{46} &= b_{64} = \frac{k'_2v_R(\overline{\Lambda}_{22}+\overline{\Lambda}'_{22})}{2}, \\
b_{55} &= \lambda_{LR}\,v_L^2, \\
b_{56} &= b_{65} = 0, \\
b_{66} &= \lambda_{LR}\,v_R^2,
\end{aligned} \tag{25}$$

Similar to the before case, the simply charged fields were used in the constraint equations with the finality to express in the more simply form the matrix elements. It will be noted the importance of the constraint equations not only to obtain relations in the constraint equations but also to make more simply the calculus.

Continuing with the approximations given in (17) with the finality of simplify the calculus, we rewrite this matrix in its new form:

$$\mathcal{M}_H^2 = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & c_{22} & 0 & c_{24} & 0 & c_{26} \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & c_{42} & 0 & c_{44} & 0 & c_{46} \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & c_{62} & 0 & c_{64} & 0 & c_{66}, \end{pmatrix} \tag{26}$$

where:

$$\begin{aligned} c_{22} &= b_{22} = k_2^2\left(\lambda_{22}+\lambda'_{22}\right), \\ c_{24} &= c_{42} = k_2^2\lambda'_{22}, \\ c_{26} &= c_{62} = b_{26} = b_{62} = \frac{k_2 v_R(\overline{\Lambda}_{22}+\overline{\Lambda}'_{22})}{2}, \\ c_{44} &= k_2'^2\left(\lambda_{22}+\lambda'_{22}\right), \\ c_{46} &= c_{64} = \frac{k_2 v_R(\overline{\Lambda}_{22}+\overline{\Lambda}'_{22})}{2}, \\ c_{66} &= b_{66} = \lambda_{LR}\, v_R^2 \end{aligned} \tag{27}$$

The matrix (26) is symmetric and real, it can be find an orthogonal matrix that diagonalize this matrix, however it is possible to obtain the exact eigenvalues without to assistance of the orthogonal matrix. Therefore procceding to diagonalize we obtain the following mass values, taking into account the approximations given in (17)(quadratic values):

(i) Non massive Fields:

$$m_{H_1}^2 = m_{H_2}^2 = m_{H_3}^2 = 0 \tag{28}$$

It is observed the existence of three Higgs Neutral Fields, without mass

(ii) Massive Fields:

$$\begin{aligned} m_{H_4}^2 &= \frac{1}{2}\left[k_2^2(\lambda_{22}+2\lambda'_{22}) + \lambda_{LR}v_R^2 - \sqrt{\Delta}\right], \\ m_{H_5}^2 &= k_2^2\,\lambda_{22}, \\ m_{H_6}^2 &= \frac{1}{2}\left[k_2^2(\lambda_{22}+2\lambda'_{22}) + \lambda_{LR}v_R^2 + \sqrt{\Delta}\right], \end{aligned} \tag{29}$$

where:

$$\begin{aligned} \Delta &= \left[\lambda_{LR}v_R^2 - k_2^2(\lambda_{22}+2\lambda'_{22})\right]^2 \\ &+ 2k_2^2\, v_R^2\left(\overline{\Lambda}_{22}+\overline{\Lambda}'_{22}\right)^2 \end{aligned} \tag{30}$$

From the above results we can identify the less massive neutral Goldstone boson as the Higgs boson of the Standar Model (SM). In additions to the expressions given in (29) it can be said that the λ_{22} must be positive, as it was observed in the last section, realizing the following condition:

$$m_{H_6}^2 \gg m_{H_4}^2, m_{H_5}^2,$$

for the values of $v_R \gg X$, where X represents any VEV different to v_R.

4.3. Neutral Scalar Fields (Imaginary Part)
Now considering the imaginary components of the Higgs Fields, the matrix representation of the quadratic contributions is showed as follow:

$$\mathcal{M}_{SI}^2 = \begin{pmatrix} n_{11} & 0 & \cdots & 0 \\ 0 & n_{22} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & n_{66} \end{pmatrix}, \tag{31}$$

where we observe that this matrix result in a diagonal matrix without take into account the constraints equations, moreover its matrix diagonal elements (exact results) are written as:

$$\begin{aligned}
n_{11} &= \frac{1}{4}(v_R^2 + v_L^2)(\overline{\Lambda}'_{11} + \Lambda_{11}) + \frac{k_1'^2 \lambda'_{11}}{2} \\
&+ \frac{k_2^2 \rho_{12}}{4} + \frac{k_1^2}{2}(\lambda'_{11} + \lambda_{11}) + \frac{\mu_{11}^2}{2} \\[2ex]
n_{22} &= \frac{1}{4}(v_R^2 + v_L^2)(\overline{\Lambda}'_{22} + \Lambda_{22}) + \frac{k_2'^2 \lambda'_{22}}{2} \\
&+ \frac{k_1^2 \rho_{12}}{4} + \frac{k_2^2}{2}(\lambda'_{22} + \lambda_{22}) + \frac{\mu_{22}^2}{2} \\[2ex]
n_{33} &= \frac{1}{4}(v_R^2 + v_L^2)(\overline{\Lambda}_{11} + \Lambda_{11}) + \frac{k_1^2 \lambda'_{11}}{2} \\
&+ \frac{k_2'^2 \rho_{12}}{4} + \frac{k_1'^2}{2}(\lambda'_{11} + \lambda_{11}) + \frac{\mu_{11}^2}{2} \\[2ex]
n_{44} &= \frac{1}{4}(v_R^2 + v_L^2)(\overline{\Lambda}_{22} + \Lambda_{22}) + \frac{k_2^2 \lambda'_{22}}{2} \\
&+ \frac{k_1'^2 \rho_{12}}{4} + \frac{k_2'^2}{2}(\lambda'_{22} + \lambda_{22}) + \frac{\mu_{22}^2}{2} \\[2ex]
n_{55} &= \frac{k_1'^2}{4}(\overline{\Lambda}_{11} + \Lambda_{11}) + \frac{k_2'^2}{4}(\overline{\Lambda}_{22} + \Lambda_{22}) \\
&+ \frac{k_1^2}{4}(\overline{\Lambda}'_{11} + \Lambda_{11}) + \frac{k_2^2}{4}(\overline{\Lambda}'_{22} + \Lambda_{22}) \\
&+ \frac{\mu_{LR}^2}{2} + \frac{\lambda_{LR}}{2} v_L^2,
\end{aligned} \tag{32}$$

$$
\begin{aligned}
n_{66} &= \frac{k_1'^2}{4}(\overline{\Lambda}_{11} + \Lambda_{11}) + \frac{k_2'^2}{4}(\overline{\Lambda}_{22} + \Lambda_{22}) \\
&+ \frac{k_1^2}{4}(\overline{\Lambda}'_{11} + \Lambda_{11}) + \frac{k_2^2}{4}(\overline{\Lambda}'_{22} + \Lambda_{22}) \\
&+ \frac{\mu_{LR}^2}{2} + \frac{\lambda_{LR}}{2}v_R^2
\end{aligned}
$$

This matrix is expressed in the base: $\{I_{1a}, I_{1b}, I_{2a}, I_{2b}, I_{L1}, I_{R1}\}$; as this matrix is diagonal, automatically we obtain the mass values (their squares) of these fields:

$$
\begin{aligned}
m_{H_{I_1}}^2 &= n_{11}, \quad m_{H_{I_2}}^2 = n_{22}, \quad m_{H_{I_3}}^2 = n_{33}, \\
m_{H_{I_4}}^2 &= n_{44}, \quad m_{H_{I_5}}^2 = n_{55}, \quad m_{H_{I_6}}^2 = n_{66}
\end{aligned} \tag{33}
$$

However when we consider the constraints equations it is noted that these fields non adquire mass, it is to say:

$$
m_{H_{I_1}}^2 = m_{H_{I_2}}^2 = m_{H_{I_3}}^2 = m_{H_{I_4}}^2 = m_{H_{I_5}}^2 = m_{H_{I_6}}^2 = 0. \tag{34}
$$

Here it is not necessary use the approximations of the (17) equation. Then we can say that it is obtain six Goldstone Bosons.

5. Identifying the Goldstone Boson of ME

With the mass quadratic terms obtained for the neutral real Higgs Fields, equations (29), approximating for higher values of v_R in the calculus of their masses, we write:

$$
\begin{aligned}
m_{H_4} &\approx k_2\sqrt{\lambda_{22} + \lambda'_{22} + \lambda'^2_{22} - \frac{(\overline{\Lambda}'_{22} + \Lambda_{22})^2}{2\lambda_{LR}}} \\
&+ \mathcal{O}(1/v_R^2) \\
m_{H_5} &= k_2\sqrt{\lambda_{22}} \\
m_{H_6} &\approx v_R\sqrt{\lambda_{LR}} + \mathcal{O}(1/v_R)
\end{aligned} \tag{35}
$$

The only exact mass value is that one of the scalar boson m_{H_5}, this is not necessarily the Higgs Boson of the SM, due to the great quantities parameters to describe the model, in special in the scalar and Yukawa sectors [14], exist the possibility that m_{H_4} be the Higgs Boson of the SM ($=$ 125 GeV)[2].
When we consider $v_R \to \infty$, but finite, the masses of m_{H_4} y m_{H_6} approximates to:

$$
\begin{aligned}
m_{H_4} &\approx k_2\sqrt{\lambda_{22} + \lambda'_{22} + \lambda'^2_{22} - \frac{(\overline{\Lambda}'_{22} + \Lambda_{22})^2}{2\lambda_{LR}}} \\
m_{H_6} &\approx v_R\sqrt{\lambda_{LR}}.
\end{aligned} \tag{36}
$$

It is observed that the parameter λ_{LR} has a defined sign (positive), observing $m_{H_6} \gg m_{H_4},\ m_{H_5}$, as was noted before.
It can be considered the following analysis

- If $m_{H_6} > m_{H_4} > m_{H_5}$, then m_{H_5} would be the Higgs boson of the SM.
  In accordance to the Particle Data Group (PDG) [9]: $M_{Higgs} = 125.10 \pm 0.14$ GeV. Therefore, making the comparison:

$$M_{Higgs} = 125.10 = M_{H_5} = k_2 \sqrt{\lambda_{22}} \tag{37}$$

  It will mentioned before that to SM scales, it's to say, energies around the vectorial neutral boson mass Z^0, the parameter k_2 can take the maximum value of 246 GeV [9], then we obtain the following condition for λ_{22}:

$$\lambda_{22} \geq 0.259 \tag{38}$$

- If $m_{H_6} > m_{H_5} > m_{H_4}$
  In this case m_{H_4} would be the Higgs boson of the SM, then comparing we would have the condition

$$k_2 \sqrt{\lambda_{22} + \lambda'_{22} + \lambda'^2_{22} - \frac{(\overline{\Lambda}'_{22} + \Lambda_{22})^2}{2\lambda_{LR}}} = 125.10. \tag{39}$$

  As we mentioned to energies scale of the SM, the maximum value that can take k_2 is 246 GeV, obtaining.

$$\lambda_{22} + \lambda'_{22} + \lambda'^2_{22} - \frac{(\overline{\Lambda}'_{22} + \Lambda_{22})^2}{2\lambda_{LR}} \geq 0.067. \tag{40}$$

The results showed in the relations (38) and (40) complement each other with that obtained in the constraints equations and they are usefull in the fenomenological calculus. Remenber that in accordance to the bibliography, see [22], first we break the symmetry through the VEV v_R with value around the one TeV (in general $v_R > 1$ TeV). Recently an anomaly shift mass of W boson was discovery in CDF-II experiment, in this sense this model could explain this result [23].

6. Conclusions

The objetive of this work was to identify the Higgs boson of the SM, as well as to calculate the masses of the others scalars. This was obtained considering certain additional conditions that must accomplished the correspondent parameters. In accordance with the obtained results the model in consideration present (only in the scalar sector) three massive neutral Higgs scalar bosons and three neutral non massive, six massive simply charged particles and its respective non physical and non massive particles (imaginary components of the neutral fields) all they due to the spontaneous symmetry breaking. It can be say from the before obtained that the non physical particles represent six Goldstone bosons which will be adsorved to give mass to the vectorial bosons of the model: $W_L^{\pm}$, $W_R^{\pm}$, Z_L, Z_R, (fulfilling the Goldstone theorem). The case of the vectorial boson that carries the electromagnetic force, the photon, continue being non massive particle as it must be for the model to be consistent. It is necessary to be mentioned that in some extension of the SM they differ only in the scalar sector, everything else as leptonic and quark sector becomes equal, it is due to the phenomenology in study. This sector let us to study the problem of neutrino mass and W anomaly mass.

We observe that the higger massive boson is m_{H_6}, as a consequence of its direct dependence with v_R because this is the VEV more greather (in TeV) , for example if $\lambda_{LR} = 16$ and $v_R = 1$ TeV then: $m_{H_6} = 4$ TeV.

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