Volume 7 Number 0403 **ISSN 1979-3898**

Journal of
THEORETICAL AND COMPUTATIONAL
STUDIES

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J. Theor. Comput. Stud. **7** (2008) 0403
Received: May 30th, 2008; Accepted for publication: August 30th, 2008

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JOURNAL OF THEORETICAL AND COMPUTATIONAL STUDIES

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ISSN 1979-3898

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Minimal Left-Right Symmetry Model of Electroweak Interaction

A. Damanik[a,b], M. Satriawan[b], A. Hermanto[b], P. Anggraita[c]

[a] *Department of Physics, Faculty of Mathematics and Natural Sciences, Sanata Dharma University, Kampus III USD Paingan, Maguwoharjo, Sleman, Yogyakarta, Indonesia*

[b] *Department of Physics, Gadjah Mada University, Yogyakarta, Indonesia*

[c] *National Nuclear Energy Agency (BATAN), Jakarta, Indonesia*

ABSTRACT : Using two primary doublets and one induced bidoublet Higgs fields as a result of the interactions of the two doublets, we evaluate the predictive power of the left-right symmetry model based on $SU(2)_L \otimes SU(2)_R \otimes U(1)$ gauge group to the gauge bosons masses, leptons masses, and the structure of electroweak interactions. Parity violation in the weak interaction at low energy can be understood as due to the very large of m_{W_R} compared to m_{W_L}. The model can also produces the lepton masses in agreement qualitatively with the experimental facts by taking the value of coupling constant $G^* = 0$ and $p \ll s$.

KEYWORDS : Left-right symmetry model, doublet Higgs, bidoublet Higgs

E-MAIL : d.asan@lycos.com

Received: May 30th, 2008; Accepted for publication: August 30th, 2008

1 INTRODUCTION

Even though the Glashow-Weinberg-Salam (GWS) model for electroweak interaction based on $SU(2)_L \otimes U(1)_Y$ gauge group very successful phenomenologically [1, 2, 3], but many fundamental problems i.e. the responsible mechanism for generating the neutrino masses, the domination of the V-A over V+A interactions at low energy, and the responsible mechanism for the doublet lepton up-down mass difference could not be explained by GWS model. The need for the extension of the GWS model comes from the conclusion that the neutrinos have a mass as a direct implication of the detected neutrino oscillations phenomena for both solar and atmospheric neutrinos [4, 5, 6, 7, 8, 9, 10].

Many theories or models have been proposed to extend the GWS model. One of the interesting models is the Left-Right symmetry model based on $SU(2)_L \otimes SU(2)_R \otimes U(1)$ gauge group proposed by many authors [11, 12, 13, 14, 15, 16, 17]. In this paper, we use the left-right symmetry model based on $SU(2)_L \otimes SU(2)_R \otimes U(1)$ gauge group with two doublets and one bidoublet Higgs fields (as a result of the two doublets interaction) to break the $SU(2)_L \otimes SU(2)_R \times U(1)$ gauge group down to $U(1)em$. The lepton fields to be represented as doublet of an SU(2) for both left and right fields to make the full sense of the left-right symmetry model.

The paper is organized as follows: in section 2 we present our main assumptions for the left-right symmetry model, in section 3 we evaluate the gauge bosons masses, in section 4 we evaluate the leptons masses, and finally in section 5 we give a conclusion.

2 THE MODEL

In our model, the left-right symmetry model for electroweak interaction based on the $SU(2)_L \otimes SU(2)_R \otimes U(1)$ gauge group with the assumptions and the particles assignment as follows,

1. Two primary Higgs fields are doublet of SU(2)

$$X_L = \begin{pmatrix} a^+ \\ b^0 \end{pmatrix}, X_R = \begin{pmatrix} c^+ \\ d^0 \end{pmatrix}. \qquad (1)$$

2. The secondary bidoublet Higgs field could be produced from the interaction of the two primary Higgs fields, that is,

$$\phi = \begin{pmatrix} p^0 & q^+ \\ r^- & s^0 \end{pmatrix}, \qquad (2)$$

3. The leptons fields are doublet of SU(2) for both left and right fields,

$$\psi_L = \begin{pmatrix} \nu \\ e^- \end{pmatrix}_L, \psi_R = \begin{pmatrix} \nu \\ e^- \end{pmatrix}_R. \qquad (3)$$

4. Both leptons and gauge bosons masses are generated via symmetry breaking when Higgs fields develop its vacuum expectation values similar to the symmetry breaking in the GWS model.

By applying the above assumptions and particles assignment, we could break the left-right symmetry model based on $SU(2)_L \otimes SU(2)_R \otimes U(1)$ down to $U(1)em$ directly as shown schematically below,

$$\begin{array}{c} SU(2)_L \otimes SU(2)_R \otimes U(1) \\ \Downarrow \\ U(1)_{em} \end{array}$$

The vacuum expectation values of two doublets and one bidoublet Higgs could contribute to the gauge bosons masses. Meanwhile, the leptons masses (Yukawa term) only come from the vacuum expectation value of bidoublet Higgs, because the leptons fields to be doublet of $SU(2)$, then only the Yukawa term with bidoublet Higgs satisfies gauge invariance. Thus, the complete Lagrangian density could be read,

$$\begin{aligned} L = &-\frac{1}{4}W_{\mu\nu L}.W^{\mu\nu L} - \frac{1}{4}W_{\mu\nu R}.W^{\mu\nu R} \\ &-\frac{1}{4}B_{\mu\nu}B^{\mu\nu} \\ &+\bar{\psi_L}\gamma^\mu(i\partial_\mu - g\frac{1}{2}\tau.W_{\mu L} - g'\frac{Y}{2}B_\mu)\psi_L \\ &+\bar{\psi_R}\gamma^\mu(i\partial_\mu - g\frac{1}{2}\tau.W_{\mu R} - g'\frac{Y}{2}B_\mu)\psi_R \\ &+|(i\partial_\mu - g\frac{1}{2}\tau.W_{\mu L} - g'\frac{Y}{2}B_\mu)X_L|^2 \\ &+|(i\partial_\mu - g\frac{1}{2}\tau.W_{\mu R} - g'\frac{Y}{2}B_\mu)X_R|^2 \\ &+Tr|(i\partial_\mu - g\frac{1}{2}\tau.W_{\mu L})\phi - g\frac{1}{2}\phi\tau.W_{\mu R} \\ &-g'\frac{Y}{2}B_\mu\phi|^2 - V(X_L, X_R, \phi) - (G\bar{\psi_L}\phi\psi_R \\ &+G^*\bar{\psi_L}\tau_2\phi^*\tau_2\psi_R + H.c.), \end{aligned} \qquad (4)$$

where $g = g_L = g_R$ are the $SU(2)$ couplings, g' is the $U(1)$ coupling, γ^μ are the Dirac matrices, τ's are the Pauli spin matrices, $V(X_L, X_R, \phi)$ is the Higgs potential, Y is the hypercharge ($Y = B - L$), and G is the Yukawa coupling.

The electric charge operator Q satisfies the relations,

$$Q = T_{3L} + T_{3R} + \frac{Y}{2}, \qquad (5)$$

where T_{3L} and T_{3R} are the third components the weak isospin generator $T_i = \frac{\tau_i}{2}$. According to the Eqs. (4) and (5), the Higgs fields have the following quantum numbers,

$$X_L\left(\frac{1}{2}, 0, 1\right), X_R\left(0, \frac{1}{2}, 1\right), \phi\left(\frac{1}{2}, \frac{1}{2}, 0\right), \qquad (6)$$

and the leptons fields transform as,

$$\psi_L\left(2, 0, 0\right), \psi_R\left(0, 2, 0\right), \qquad (7)$$

under $SU(2)$.

3 THE GAUGE BOSONS MASSES

From Eq. (4), we can see that the relevant gauge boson mass terms as follow,

$$\begin{aligned} L_b = &|(-g\frac{1}{2}\tau.W_{\mu L} - g'\frac{Y}{2}B_\mu)X_L|^2 \\ &+|(-g\frac{1}{2}\tau.W_{\mu R} - g'\frac{Y}{2}B_\mu)X_R|^2 \\ &+Tr|(-g\frac{1}{2}\tau.W_{\mu L})\phi - g\frac{1}{2}\phi\tau.W_{\mu R} \\ &-g'\frac{Y}{2}B_\mu\phi|^2. \end{aligned} \qquad (8)$$

By substituting the vacuum expectation values of the Higgs fields,

$$\langle X_L\rangle = \begin{pmatrix} 0 \\ b \end{pmatrix}, \ \langle X_R\rangle = \begin{pmatrix} 0 \\ d \end{pmatrix},$$

$$\langle\phi\rangle = \begin{pmatrix} p & 0 \\ 0 & s \end{pmatrix}, \qquad (9)$$

into Eq.(8), we then obtain,

$$\begin{aligned} L_b = &\frac{g^2}{4}(b^2 + p^2 + s^2)[(W^1_{\mu L})^2 + (W^2_{\mu L})^2] \\ &+\frac{g^2}{4}(d^2 + p^2 + s^2)[(W^1_{\mu R})^2 + (W^2_{\mu R})^2] \\ &+\frac{b^2}{4}(gW^3_{\mu L} - g'B_\mu)^2 + \frac{d^2}{4}(gW^3_{\mu R} - g'B_\mu)^2 \\ &+g^2 ps(W^1_{\mu L}W^{\mu R1} + W^2_{\mu L}W^{\mu R2}) \\ &+\frac{g^2}{2}(p^2 + s^2)W^3_{\mu L}W^{\mu R3} \\ &+\frac{g^2}{4}(p^2 + s^2)(W^3_{\mu L})^2 \\ &+\frac{g^2}{4}(p^2 + s^2)(W^3_{\mu R})^2. \end{aligned} \qquad (10)$$

By defining,

$$W_\alpha^{\pm} = \frac{1}{\sqrt{2}}\left(W^1_{\mu\alpha} \mp iW^2_{\mu\alpha}\right),$$

$$Z_{\mu\alpha} = \frac{gW^3_{\mu\alpha} - g'B_{\mu\alpha}}{\sqrt{g^2+g'^2}}, \qquad (11)$$

$$A_{\mu\alpha} = \frac{g'W^3_{\mu\alpha} + gB_{\mu\alpha}}{\sqrt{g^2+g'^2}}, Z^{'}_{\mu\alpha} = W^3_{\mu\alpha}, \qquad (12)$$

where $\alpha = L, R$ and,

$$\begin{aligned} m_{W_L} &= g\sqrt{b^2+p^2+s^2}, \\ m_{W_R} &= g\sqrt{d^2+p^2+s^2}, \\ m_{Z_L} = \frac{b\sqrt{g^2+g'^2}}{2}&,\ m_{Z_R} = \frac{d\sqrt{g^2+g'^2}}{2}, \\ m_{Z^{'}_L} = m_{Z^{'}_R} &= \frac{g\sqrt{p^2+s^2}}{2},\ m_A = 0, \\ m_x = m_{x'} = g\sqrt{2ps}&,\ m_y = g\sqrt{p^2+s^2}, \end{aligned} \qquad (13)$$

then Eq.(10) reads,

$$\begin{aligned} L_b = \frac{1}{2}m^2_{W_L}W^+_{\mu L}W^-_{\mu L} &+ \frac{1}{2}m^2_{W_R}W^+_{\mu R}W^{\mu R-} \\ +\frac{1}{2}m^2_{Z_L}Z_{\mu L}Z^{\mu L} &+ \frac{1}{2}m^2_{Z_R}Z_{\mu R}Z^{\mu R} \\ +\frac{1}{2}m^2_A A_\mu A^\mu &+ \frac{1}{2}m^2_{Z^{'}_L}Z^{'}_{\mu L}Z^{'\mu L} \\ +\frac{1}{2}m^2_{Z^{'}_R}Z^{'}_{\mu R}Z^{'\mu R} &+ \frac{1}{2}m^2_x W^+_{\mu L}W^{\mu R-} \\ +\frac{1}{2}m^2_{x'}W^-_{\mu L}W^{\mu R+} &+ \frac{1}{2}m^2_y Z^{'3}_{\mu L}Z^{'\mu R3}. \end{aligned} \qquad (14)$$

From Eq. (14) we can see that after the symmetry breaking take place we have nine massive gauge bosons and one (photon) is massless. Thus, following the procedure of symmetry breaking in the standard model of electroweak interaction and put the value of $b = d$, from Eq. (13) one can see that the resulted gauge bosons masses for both left and right bosons are equal. To make the left-right symmetry model relevant to the electroweak phenomena, many authors [14, 15, 16] have taken the value of $b << d$. The difference values of the b and d can be associated with the parity violation. In this scheme, the domination of the V-A interaction over V+A interaction for charged current at low energy could be understood as an implication of the very massiveness of the m_{W_R} compared to m_{W_L}.

4 THE LEPTONS MASSES

As long as we know, for leptons masses there is no experimental fact to force us for choosing a one kind of multiplet Higgs in the Yukawa term except dictated by the requirement of the Lagrangian density must be gauge invariance. But, in the boson mass sector, the representation of the Higgs fields to be $SU(2)$ doublet theoretically supported by experimental fact. Thus, we could use the bidoublet Higgs field for generating the leptons masses.

Following GWS model, the leptons masses in our model also arise from the symmetry breaking. The lepton mass term is the Yukawa term in Eq. (4), that is,

$$\begin{aligned} L_l &= G\bar{\psi}_L\left\langle\phi\right\rangle\psi_R \\ &+G^*\bar{\psi}_L\tau_2\left\langle\phi^*\right\rangle\tau_2\psi_R + H.c. \end{aligned} \qquad (15)$$

By inserting the vacuum expectation value of bidoublet Higgs, for the first generation we then obtain the masses: $m_{\nu_e} = Gp + G^*s$ and $m_e = Gs + G^*p$ for neutrino and electron respectively. Thus, in this model the neutrino and the electron (charge lepton) masses values are equal which is contrary to experimental facts ($m_\nu << m_l$). But, our model can still predict the experimental facts qualitatively by taking the value of $G^* = 0$ and $p << s$. The reponsible mechanism which put the value of $G^* = 0$ is the remain problem in the left-right symmetry model if we want to make this model in agreement with the experimental facts in the lepton sector.

5 CONCLUSION

Using the minimal content of the particles (two primary doublets Higgs, one induced bidoublet Higgs (secondary Higgs), and two lepton fields) in the left-right symmetry model based on $SU(2)_L \otimes SU(2)_R \otimes U(1)$ gauge group, we then can explain the domination of the V-A interaction over V+A interaction at low energy due to the very massiveness of the m_{W_R}. The neutrino and the electron masses arise naturally, but for obtaining the leptons masses (neutrino and electron) phenomenologically, we must put the value of $G^* = 0$ and $p \ll s$. The mechanism which makes the $G^* = 0$, in order to make the model can predict the lepton masses, is still a problem for the left-right symmetry model.

ACKNOWLEDGMENTS

The first author would like to thank to the Graduate School of Gadjah Mada University Yogyakarta where he is currently a graduate doctoral student, the Dikti Depdiknas for a BPPS Scholarship Program, and the Sanata Dharma University Yogyakarta for granting the study leave and opportunity.

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