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LOW MASS PARITY RESTORATION, WEAK INTERACTION PHENOMENOLOGY AND GRAND UNIFICATION *

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ABSTRACT

The question of low energy restoration of parity is examined using a left-right asymmetric model implied by the gauge group $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ with $g_L > g_R$, both from a phenomenological point of view and also exploiting the possibility that such an asymmetry may be a consequence of two-stage symmetry breaking of $SU(2)_R$ allowed in the SU(16) grand unification scheme. We carry out all the charged and neutral current tests with somewhat increased errors of the measured values of neutral current parameters. The phenomenological asymmetric model passes all the tests permitting $1 \leq (g_L/g_R)^2 \leq 2$ and $0.23 \leq \sin^2\theta_w \leq 0.29$, where the case $g_L/g_R = 1$ corresponds to the symmetric model investigated by Rizzo and Senjanovic. Whereas low-energy parity restoration and low mass gauge bosons may be possible in the symmetric model, the phenomenological asymmetric model allows a low mass right-handed charged gauge boson (86-230 GeV) and a low mass neutral boson (190-455 GeV), in addition to the two gauge bosons of first generation, but no parity restoration. It is shown that all the results of analysis of the phenomenological asymmetric model, for the case of no mixing between the left- and right-handed charged gauge bosons still hold true in the case where the left-right asymmetry arises out of two stage symmetry breaking of $SU(2)_R$ allowed by SU(16) grand unification, but only with the replacement of the charged right-handed boson by a heavier one ($> 10^4$ GeV). The SU(16) interpretation of left-right asymmetry and the available charged and neutral current data allows the second neutral boson being observed, together with the two gauge bosons of first generation, but no restoration of parity at ISABELLE energies. However, the parity restoration, if any, may be possible at energies $\gtrsim 10^4$ GeV. Several other observable distinctions of the asymmetric model from the standard one and the symmetric model, with respect to their allowed regions and upper bounds on the allowed values of $\sin^2\theta_w$, the zeros of the neutral current parameters and the variation of the second neutral Z boson mass as functions of $\sin^2\theta_w$, are pointed out. One of the particularly new features observed in this analysis is that for a large but fixed value of the coupling constant ratio, the second neutral Z-boson mass increases with $\sin^2\theta_w$.

I. INTRODUCTION

Very recently, Rizzo and Senjanovic (RS) [1)-3)] have considered the interesting possibility of low mass restoration of parity in the content of a left-right symmetric ($g_L = g_R$) $SU(2)_L \times SU(2)_R \times U(1)$ model of electroweak interactions [4)]. In such models the low masses of the right-handed charged bosons, $W_R^\pm$ and the second neutral vector bosons, Z_2, in conjunction with a larger value of the weak mixing angle ($\sin^2\theta_w \approx 0.25$-$0.31$) are found to fit all the available weak interaction phenomenology [2),3)] within 1.5σ and 2σ limits. In a recent paper the authors have shown that such a model also fits the observed value of the QCD parameter with $\sin^2\theta_w = 0.27$-0.28. The mass of the right-handed charged gauge boson has been predicted [2),3)] between 150-240 GeV and the importance of such left-right symmetric models in the context of SO(10) grand unification has been emphasised [1),3)]. One of the important predictions of the model [3)] requires the proton to be extremely stable ($\tau_p = 10^{38} - 10^{46}$ years) showing that the low-energy restoration of parity and proton decay are mutually exclusive in the context of SO(10) grand unification.

More recently, the interesting possibility of allowing both the physical phenomena has been examined by Pati, Rajpoot and Raychaudhuri [5)] in the context of the grand unified model [6)] based on the one family gauge group SU(16). The authors [5)] are led to consider a two-stage symmetry breaking pattern in the electroweak sector of the type

$$SU(2)_L \times SU(2)_R \times U(1)_{B-L} \xrightarrow{M_R^+} SU(2)_L \times U(1)_R \times U(1)_{B-L}$$
$$\xrightarrow{M_R^0} SU(2)_L \times U(1)_Y \xrightarrow{M_L} U(1)_{EM} \qquad (1)$$

with $M_R^+ \gtrsim 10^4$ GeV and $M_R^0 \approx M_L$. In a situation like the above (especially for large M_R^+, the right-hand coupling constant g_R is less than the left-hand coupling constant g_L (e.g. for $M_R^+ = 10^4$ GeV (10^{10} GeV), $(g_L/g_R)^2 \approx 1.25$ (1.75)). In view of this, it is interesting to investigate how far the charged and neutral current phenomenology allows left-right asymmetric ($g_L \neq g_R$) models. Apart from its connection with SU(16) grand unification [6)], a detailed analysis of the available data on weak interactions is necessary using the asymmetric model, purely from a phenomenological point of view. In this paper we carry out such analyses starting with a phenomenological Lagrangian implied by the gauge group $SU_L(2) \times SU_R(2) \times U_{B-L}(1)$, but with $g_L \neq g_R$ and break the gauge symmetry using the Higgs representation

$$\Delta_L = (3,1,2)\,,\quad \Delta_R = (1,3,2)\,,\quad \phi = (2,2,0) \tag{2}$$

which are contained in 126 of SO(10) and 136 of SU(16).[1)-4),6)] We carry out charged and neutral current tests with all the available data by varying the ratio $(g_L/g_R)^2$ between 1 and 2. Within the phenomenological asymmetric model, available data with enhanced errors of neutral current parameters allow $\sin^2\theta_w = 0.23 - 0.29$ with low mass second generation gauge bosons between 100-450 GeV, but there is violation of parity in the Lagrangian *a priori* to symmetry breaking. We then examine the possibility of relating these phenomenological analyses in the context of SU(16) grand unification and the subsequent two-stage symmetry breaking of the group $SU_R(2)$, as a possible origin of left-right asymmetry [5)]. We find that all our results for the case of non-mixing between the left and right-handed charged gauge bosons can be carried over to this case and can be interpreted as a consequence of two-stage symmetry breaking descending from SU(16) grand unification [6)], but with right-handed charged gauge boson being much heavier than others ($> 10^4$ GeV). In such a case no parity restoration is possible at energies below 10^4 GeV.

We also discuss several other aspects of the asymmetric model, including upper bounds on the allowed values of $\sin^2\theta_w$ and zeros of various neutral current parameters as functions of $\sin^2\theta_w$, in which it can differ from the standard model and the symmetric model. The asymmetric model shows increase of second Z-boson mass with increasing $\sin^2\theta_w$ for a fixed value of the ratio $(g_L/g_R)^2 \gtrsim 1.25$.

The paper is organized in the following manner. In Sec.II we obtain expressions for different charged and neutral current parameters using Higgs representation (1). In Sec.III we compare the formulas with experimental data and state our results of data analysis. Sec.IV is devoted to establishing the connection of our phenomenological analyses with SU(16) grand unification and two-stage symmetry breaking. In Sec.V our conclusions have been stated briefly.

II. LEFT-RIGHT ASYMMETRIC MODEL AND WEAK INTERACTION PHENOMENOLOGY

In this and the next section we consider the asymmetric model, at first, from a phenomenological point of view. Although there have been attempts to examine the consequences of the asymmetric model [7)], the present paper differs from earlier works in many respects. Throughout the paper, wherever necessary, we follow the notions of RS. [2)] Starting with the phenomenological Lagrangian implied by the gauge group $SU_L(2) \times SU_R(2) \times U_{B-L}(1)$ with the general possibility $g_L \neq g_R$, we use the Higgs representation (2) with their vacuum expectation values [1)-4)]

$$\langle\Delta_L\rangle = \begin{pmatrix} 0 & V_L \\ 0 & 0 \end{pmatrix},\quad \langle\Delta_R\rangle = \begin{pmatrix} 0 & V_R \\ 0 & 0 \end{pmatrix},\quad \langle\phi\rangle = \begin{pmatrix} k' & 0 \\ 0 & k \end{pmatrix} \tag{3}$$

Following RS [2)] we introduce the following convenient parameters:

$$\eta_R = \frac{k^2+k'^2}{V_R^2}\,,\quad \eta_L = \frac{V_L^2}{k^2+k'^2}\,,\quad Z = \frac{2k'^2}{k^2+k'^2} \tag{4}$$

and also denote $R = g_R/g_L$.

In line with the current thinking we also assume that the neutrinos are Majorana particles with $M_{\nu_R} \gg M_{\nu_L}$ so that the leptonic currents are purely left-handed. The physical meaning of the parameters η_R, η_L, Z, V_R, V_L, k^2 and k'^2 has been discussed by RS. While η_R measures the amount of breaking of $SU_R(2)$ and smaller η_R implies stronger breaking of parity (in addition to the parity breaking already present in the Lagrangian before spontaneous symmetry breaking, in the present case, because of g_L not being equal to g_R), η_L measures the presence of left-handed Higgs triplet and Z measures the amount of W_L-W_R mixing. The limit $\eta_R \to 0$ corresponds to very heavy right-handed charged and neutral gauge bosons and corresponds to the Glashow-Weinberg-Salam [8)] situation, if in addition η_L is small.

The charged and neutral gauge boson mass matrices assume the following forms:

$$M^2_{W^\pm} = \frac{1}{2} g_L^2 V_R^2 \begin{bmatrix} \eta_R(1+\eta_L) & -R\eta_R[1-(1-Z)^2]^{1/2} \\ -R\eta_R[1-(1-Z)^2]^{1/2} & R^2(1+\eta_R) \end{bmatrix} \tag{5}$$

$$M_Z^2 = \frac{1}{2} g_L^2 V_R^2 \begin{bmatrix} \eta_R(1+\eta_L) & -R\eta_L & -2\varepsilon\eta_R\eta_L \\ -R\eta_R & R^2(2+\eta_R) & -2R\varepsilon \\ -2\varepsilon\eta_R\eta_L & -2R\varepsilon & 2\varepsilon^2(1+\eta_R\eta_L) \end{bmatrix} \tag{6}$$

where we have used

$$\varepsilon = g'/g_L \tag{7}$$

The charged current constraint from μ decay becomes

$$\frac{G_F}{\sqrt{2}} = \frac{g_L^2}{8}\left[\frac{\cos^2\xi}{M_{W_1}^2} + \frac{\sin^2\xi}{M_{W_2}^2}\right] \tag{8}$$

where M_{W_i}, $i = 1,2$ are the masses of the charged W bosons and are equal to the eigenvalues of (6). The mixing angle ξ can be written as

$$\tan 2\xi = \frac{2R\eta_R\left[1-(1-z)^2\right]^{1/2}}{\left[R^2(1+\eta_R) - \eta_R(1+\eta_L)\right]} \tag{9}$$

After suitable transformations onto physical states and diagonalizations, the mass matrices (6) and (8) yield the following eigenvalues:

$$M_W^2 = \frac{g_L^2 V_R^2}{4}\Big[\eta_R(1+\eta_L) + R^2(1+\eta_R) \pm \Big\{\big[\eta_R(1+\eta_L) - R^2(1+\eta_R)\big]^2 + 4R^2\eta_R^2\left[1-(1-z)^2\right]\Big\}^{1/2}\Big] \tag{10}$$

for the charged gauge bosons, $W_L^\pm$ (lighter) and $W_R^\pm$ (heavier), and

$$\begin{aligned} M_Z^2 = \frac{1}{2} g_L^2 V_R^2 \frac{(R^2-x_\omega)(1+\eta_R\eta_L)}{R^2-(R^2+1)x_\omega}\Bigg[1 &+ \frac{\left(R^2-(R^2+1)x_\omega\right)\left(R^2-1+\frac{\eta_R(R^2+1)}{2}\right)}{(R^2-x_\omega)(1+\eta_R\eta_L)} \\ &\pm\Bigg\{1+\frac{R^2-(R^2+1)x_\omega}{(R^2-x_\omega)^2(1+\eta_R\eta_L)^2}\Bigg[\left(R^2-(R^2+1)x_\omega\right)\left(R^2-1+\eta_R\frac{(R^2+1)}{2}\right)^2 \\ &-2x_\omega(1+\eta_R\eta_L)\left(R^2-1+\eta_R\frac{(R^2+1)}{2}\right) - 4R^4\eta_R\eta_L \\ &+2R^2(1+\eta_R\eta_L)\left(R^2-1+\frac{\eta_R(1-R^2)}{2}\right)\Bigg]\Bigg\}^{1/2}\Bigg] \end{aligned} \tag{11}$$

for the neutral gauge bosons, Z_1 (lighter) and Z_2 (heavier). It can easily be checked that for R = 1 all the formulas involving R reduce to the corresponding ones of RS. [2] While obtaining (11) we have used

$$\sin^2\theta_W = x_\omega = e^2/g_L^2 \tag{12}$$

$$1/e^2 = \frac{1}{g_L^2} + \frac{1}{g_R^2} + \frac{1}{g'^2} \tag{13}$$

which yield

$$\varepsilon^2 = \frac{R^2 x_\omega}{R^2-(R^2+1)x_\omega} \tag{14}$$

In Eq.(11) the positivity of M_Z^2 implies the following upper bound on $\sin^2\theta_W$ as a function of R^2:

$$\sin^2\theta_W \leqslant \frac{R^2}{1+R^2} \tag{15}$$

whereas the upper bound is 0.5 in the symmetric model (R = 1), it begins to restrict higher allowed values of $\sin^2\theta_W$ by the experimental data as we approach the bound for $R^2 < 1$. Values of upper bounds for $R^2 = 1 - 0.33$ ($(g_L/g_R)^2 = 1$-3) have been calculated in Table I. Since $g_L^2 = e^2/\sin^2\theta_W$ it may appear at first sight that the neutral boson masses decrease with $\sin^2\theta_W$ as has been shown by RS for $R^2 = 1$. But this is true only if we work away from the upper bound. The denominator $R^2 - (R^2 + 1)x_w$ approaches zero as we approach the upper bound. Whereas this pole behaviour of M_Z^2 is cancelled for $M_{Z_1}^2$ (for the -ive sign before the radical), it gives rise to increase of $M_{Z_2}^2$ (for +ive sign before the radical) with increasing $\sin^2\theta_w$ as we approach the upper bound. Such a behaviour of M_{Z_2} would have been observed in the symmetric model had the tests of charged and neutral current data allowed values of $\sin^2\theta_w$ nearer to 0.5. Although such a possibility does not exist in the context of the symmetric model, we will see in the next section that the experimental data at present are consistent with an increase of M_{Z_2} with $\sin^2\theta_w$ for some fixed value of $R^2 < 1$.

We observe that even with $g_L \neq g_R$, the muon decay constraints and other charged current constraints continue to be the same as in the symmetric model, independent of g_L and g_R

$$\frac{G_F}{\sqrt{2}} = \frac{1}{4(R^2+R'^2)} \frac{1+\eta_R}{1+\eta_L+\eta_R\eta_L+\eta_R(1-Z)^2} \tag{16a}$$

$$\alpha = \frac{-\eta_R}{1+\eta_R}\left[1-(1-Z)^2\right]^{1/2} \tag{16b}$$

$$\beta = \frac{\eta_R(1+\eta_L)}{1+\eta_R} \tag{16c}$$

Note that β is the coefficient of contribution of the right-handed currents and α is the coefficient of the mixing term in the general charged current Hamiltonian [2]. Defining the parameters [2]

$$A = \frac{1+\eta_R(1-Z)^2+\eta_L(1+\eta_R)}{1+\eta_L(2+\eta_R)} \tag{17a}$$

$$B = \frac{1-\eta_R\eta_L}{1+\eta_R} \tag{17b}$$

$$C = \frac{R^2-\eta_R\eta_L}{R^2(1-\eta_R\eta_L)} \tag{18a}$$

$$F = \frac{R^2(2+\eta_R)+\eta_R}{2R^2(1+\eta_R)} \tag{18b}$$

the physical parameters occurring in various neutral current processes can be expressed in terms of R^2, η_R, η_L, Z and $\sin^2\theta_w$ as stated below.

(i) Parity violation in atoms and asymmetry in e-d scattering

$$C_1^u = \frac{AB}{2}\left[-1+\frac{8x_wC}{3}\right] \tag{19a}$$

$$C_1^d = \frac{AB}{2}\left[1-\frac{4x_wC}{3}\right] \tag{19b}$$

$$C_2^u = -C_2^d = \frac{AB}{2}\left[-1+4x_wC\right] \tag{19c}$$

(ii) Neutrino hadron scattering

$$\varepsilon_L(u) = \frac{A}{2}\left[\frac{1}{2}\frac{\eta_R+2}{\eta_R+1}-\frac{4x_wF}{3}\right] \tag{20a}$$

$$\varepsilon_R(u) = \frac{A}{2}\left[\frac{1}{2}\frac{\eta_R}{\eta_R+1}-\frac{4x_wF}{3}\right] \tag{20b}$$

$$\varepsilon_L(d) = \frac{A}{2}\left[-\frac{1}{2}\frac{\eta_R+2}{\eta_R+1}+\frac{2x_wF}{3}\right] \tag{20c}$$

$$\varepsilon_R(d) = \frac{A}{2}\left[-\frac{1}{2}\frac{\eta_R}{\eta_R+1}+\frac{2x_wF}{3}\right] \tag{20d}$$

(iii) Neutrino electron scattering

$$g_V = -\frac{A}{2}\left[-1-4x_wF\right] \tag{21a}$$

$$g_A = -\frac{A}{2(\eta_R+1)} \tag{21b}$$

$$h_{VA} = \frac{AB}{4}\left[1 - 4x_w C\right] \tag{22a}$$

$$h_{AA} = \frac{A}{4}\left[1 + \eta_R\eta_L\right]/(\eta_R + 1) \tag{22b}$$

$$h_{VV} = \frac{A}{(R^2+1)^2(\eta_R+1)}\Big[\frac{R^2-1}{4}\Big\{(R^2-1)(1+\eta_R\eta_L) - 4(R^2-\eta_R\eta_L) + 8x_w\frac{(R^2+1)}{R^2}(R^2-\eta_R\eta_L)\Big\} + \Big\{1 - 2\frac{(R^2+1)}{R^2}x_w\Big\}^2\Big\{R^4 + \eta_R\eta_L + \frac{\eta_R}{2}(R^2+1)^2\Big\}\Big] \tag{22c}$$

For comparison we state the corresponding expressions in the standard model [8]

$$C_1^u = -\frac{1}{2} + \frac{4x_w}{3}$$

$$C_1^d = \frac{1}{2} - \frac{2x_w}{3}$$

$$C_2^u = -C_2^d = -\frac{1}{2} + 2x_w$$

$$\varepsilon_L(u) = \frac{1}{2} - \frac{4}{3}x_w$$

$$\varepsilon_R(u) = -\frac{2}{3}x_w$$

$$\varepsilon_L(d) = -\frac{1}{2} + \frac{1}{3}x_w$$

$$\varepsilon_R(d) = \frac{1}{3}x_w$$

$$g_V = -\frac{1}{2} + 2x_w$$

$$g_A = -\frac{1}{2}$$

$$h_{VA} = \frac{1}{4}(1 - 4x_w)$$

$$h_{AA} = \frac{1}{4}$$

$$h_{VV} = \frac{1}{4}(1 - 4x_w)^2 \tag{23}$$

It may be noted that the introduction of the left and right-handed triplets in Ref.2 modifies the standard model expressions through η_R and η_L when they are different from zero. For $\eta_L = 0$ corresponding to the absence of a left-handed triplet and $\eta_R = 0$, for the case in which right-handed charged boson is infinitely heavier, all the expressions of Ref.2 reduce to those in the standard model.

The standard model describes the available data on neutral current parameters with $\sin^2\theta_w = 0.233$. With their modified forms for the parameters RS [2] have shown the possibility of fitting the data in a broader range $\sin^2\theta_w = 0.23 - 0.31$ since the zeros of some of the neutral current parameters as functions of x_w are likely to fall within the range of Ref.2 and also investigated in this paper, it is useful to examine how they are modified by the symmetric and asymmetric model. Even though the expressions for C_1^u, C_1^d, C_2^u, g_V, g_A, h_{VV} and h_{VA} are modified by RS [2], their zeros remain the same as those in the standard model, whereas the zeros of the parameters $\varepsilon_L(u)$ and $\varepsilon_L(d)$ are shifted to higher values and those of $\varepsilon_R(u)$ and $\varepsilon_R(d)$ are shifted to lower values of $\sin^2\theta_w$, as compared to the standard model [8] for $\eta_R > 0$. In the present case besides the modifications of the type in the symmetric model, the terms proportional to x_w in various parameters in Eqs.(19a)-(22b) get modified by an additional factor C or F. For $\eta_R, \eta_L \neq 0$ and $R^2 < 1$, $C < 1$ and $F > 1$, this causes the zeros of the parameters C_1^u, C_1^d, C_2^u, C_2^d and h_{VA} to be shifted to higher values and those of the parameters $\varepsilon_L(u)$, $\varepsilon_R(u)$, $\varepsilon_L(d)$, $\varepsilon_R(d)$ and g_V to be shifted to lower values of $\sin^2\theta_w$ as compared to the symmetric model [2]. The expression for h_{VV} gets significantly modified for $R^2 \neq 1$ although near $R^2 \simeq 1$ it behaves in the same manner as in the symmetric model [2]. In Table II we present those zeros of various neutral current parameters which fall in the range $0 \leqslant \sin^2\theta_W \leqslant 1$ for the standard model, symmetric model and in the present case for $\eta_R = 0.4$, $\eta_L = 0.1$ and $R^2 = 0.5$. The zero of the function h_{VV} becomes complex, its real part has been reported in Table II. It may be noted that the zeros of the parameters C_2^u, C_2^d, $\epsilon_R(u)$, $\epsilon_R(d)$, g_V, h_{VA} and the real part of the zero of h_{VV} as computed in the present model falls within the range of $\sin^2\theta_W$ of Ref.2 and also of this paper as described in Sec.III. Both the standard [8] and the symmetric model [2] predict the zeros of C_2^u, C_2^d, g_V, h_{VA} and h_{VV} at $x_W = 0.25$ and the contributions of C_2^u and C_2^d to atomic parity violation and e-d asymmetry are small for $\sin^2\theta_W$ in the allowed range. Asymmetric model makes significantly different predictions for the zeros of $\epsilon_R(u)$, $\epsilon_R(d)$, g_V, h_{VA} and h_{VV} as compared to the standard model and the symmetric model. More accurate measurements of the parameters $\epsilon_R(u)$, $\epsilon_R(d)$ and g_V and measurements of the parameters h_{VA} and h_{VV} may be able to discriminate between various models. The above discussions and the formulas imply that, in general, different values of x_W may be allowed in the asymmetric model to yield the same values of the physical parameters in the standard or the asymmetric model.

In Sec.IV the implications of SU(16) grand unification on the left-right asymmetry and weak interaction phenomenology have been investigated using an additional Higgs triplet, and the applicability of the results of analysis of this and the next sections studied. It may be noted that the general results of the model such as the information on zeros, upper bounds and even formulas on neutral current parameters, the possibility of increase of the second neutral Z boson mass with $\sin^2\theta_W$ for $R^2 < 1$ remain unchanged even after the introduction of the additional Higgs triplet. In the next section we carry out tests of the model using the available data on neutral current parameters, while imposing constraints implied by the charged current data.

II. COMPARISON WITH THE EXPERIMENTAL DATA

It has been noted [2] that the charged current constraint imposes $\alpha \leqslant 0.06$. Also $\eta_R \gtrsim 0.1$ in order to make model predictions different from the standard one. As in Ref.2 we also confine our analysis for small values of mixing with $Z \leqslant 0.2$. Imposing charged current constraints RS [2] have varied $\sin^2\theta_W$, Z, η_L and η_R over a wide range such that the predictions of the symmetric model agreed with the reported values of neutral current parameters [9] within 1.5σ or 2σ limits of the experimental data.

In this analysis we impose a somewhat more stringent constraint on the data as compared to Ref.2. Accurate measurements of e-d asymmetry yield [10]

$$C_1^u - \tfrac{1}{2}C_1^d = -.45 \pm .12 \tag{24a}$$

$$C_2^u - \tfrac{1}{2}C_2^d = .23 \pm .38 \tag{24b}$$

while atomic parity violation measurements on heavy atoms yield [11]

$$C_1^u + 1.15\,C_1^d = .24 \pm .068 \tag{24c}$$

$$C_1^u + 1.15\,C_1^d = .49 \pm .41 \tag{24d}$$

In order to analyse these experimental data within 90% confidence level, Kim, Langacker, Levine and Williams [9] have multiplied the errors occurring on the right-hand sides of Eq.(24a), (24c) and (24d) by 1.64. They also also carried out data analysis in the 90% confidence level for some of the other processes [9]. In our analysis while using the errors on the right-hand sides of Eqs.(24a), (24c) and (24d) enhanced by the factor 1.64 we also multiply errors of the other neutral current parameters of Ref.9 by 1.64. In addition we also include the reported experimental value of the asymmetry measurement [12] in $e^+e^- \to \mu^+\mu^-$ on the parameter h_{AA} for our analyses. Imposing the constraint $\alpha \leqslant 0.06$ and fixing R^2, η_R, η_L and Z at certain values we vary $\sin^2\theta_W$ in order to examine the allowed range of $\sin^2\theta_W$ for which there is agreement with the neutral current parameters [9] with enhanced errors. We repeat this for various combinations of R^2, η_R, η_L and Z. Regions allowed by the available data in the η_R vs. $\sin^2\theta_W$ plane have been shown in Figs.1-8 for various values of $(g_L/g_R)^2$. The zigzag nature of the curve occurs because we have chosen the interval in η_R ($\sin^2\theta_W$) variation as 0.1 (0.01). In general $\sin^2\theta_W$ values in the range 0.23-0.29 are allowed depending on the values of the other model parameters. It may be noted that for small mixing ($Z < 0.1$) the allowed region, for a fixed value of η_L and Z, increases with $(g_L/g_R)^2$. For a fixed value of $(g_L/g_R)^2$, the allowed region is more for lower values of η_L and Z. As soon as η_L exceeds 0.1, the values of $\sin^2\theta_W$ below 0.24 are excluded irrespective of other values of model parameters. For values of η_L and $Z \geqslant 0.1$ and large values of $(g_L/g_R)^2$ the allowed values of $\sin^2\theta_w$ are cut off from above and below and those of η_R from above. We find no allowed region for all values of $(g_L/g_R)^2$ between 1 and 2 if Z and/or η_L exceeds 0.2. Also no allowed region exists for the combination $Z = 0.2$ and $\eta_L = 0.1$.

In Tables III-V we present masses of the charged gauge bosons, M_{W_1}, M_{W_2}, M_{Z_1} and M_{Z_2} for different values of R^2, η_R, η_L, Z and $\sin^2\theta_w$. Most of the time it is found that the neutrino-hadron data constrain the lowest allowed value of $\sin^2\theta_w$, whereas neutrino data and/or e-d asymmetry data constrain highest allowed values of $\sin^2\theta_w$ for a given set of fixed values of other model parameters. The increase of allowed range of $\sin^2\theta_w$ with increase of $(g_L/g_R)^2$ (e.g. $\sin^2\theta_w = 0.25$-0.29 for $R^2 = 1$ whereas $\sin^2\theta_w = 0.23$-0.29 for $R^2 = 0.5$ for $\eta_R = 0.2$ $\eta_L = Z = 0$) can be understood in the following manner. The neutral current parameters $\epsilon_L(u)$, $\epsilon_R(u)$, $\epsilon_L(d)$, $\epsilon_R(d)$ are relatively more accurately known than others [9]. With $R^2 < 1$ $((g_L/g_R)^2 > 1)$ and $\eta_R > 0$, $F > 1$ and the asymmetric model allows lower values of $\sin^2\theta_w$ than in the standard [8] or the symmetric model to yield to the same values of these parameters. In Tables III to V we present masses M_{W_1}, M_{W_2}, M_{Z_1} and M_{Z_2} of left-handed charged, right-handed charged, left-handed neutral and right-handed neutral gauge bosons, respectively, as obtained from phenomenological analysis. In the context of SU(16) grand unification and two-stage symmetry breaking, as discussed in the next section, the value of right-handed charged boson mass given in the fourth column of Tables III(a), III(b), IV(a) and IV(b) will be much higher ($> 10^4$ GeV). We have denoted the mass obtained from phenomenological analysis as $M^P_{W_2}$. Analysis of the available data allows the masses in the following range:

$$M_{W_1} = 69\text{-}78 \text{ GeV} \tag{25a}$$

$$M_{Z_1} = 80\text{-}91 \text{ GeV} \tag{25b}$$

$$M^P_{W_2} = 86\text{-}230 \text{ GeV} \tag{25c}$$

$$M_{Z_2} = 190\text{-}455 \text{ GeV} \tag{25d}$$

For a fixed value of R^2, η_L, Z and $\sin^2\theta_w$, although the masses M_{W_1} and M_{Z_1} do not decrease much, the masses $M^P_{W_2}$ and M_{Z_2} decrease drastically. For a fixed value of η_R, η_L, Z and $\sin^2\theta_w$, the mass $M^P_{W_2}$ decreases with decrease of R^2

(increase of $(g_L/g_R)^2$) whereas the mass M_{Z_2} increases with increase of $(g_L/g_R)^2$.

For a fixed value of R^2, η_R, η_L and Z the masses M_{W_1}, M_{Z_1} and $M^P_{W_2}$ decrease with increase of $\sin^2\theta_w$. This observation has also been made for M_{Z_2} in the symmetric model. But the asymmetric model allows increase of M_{Z_2} with $\sin^2\theta_w$ for fixed values of other parameters. As for example for $Z = \eta_L \cong 0$, $\eta_R = 0.2$ and $R^2 = 0.5$, the value of M_{Z_2} is 276 GeV (334.6 GeV) for the value of $\sin^2\theta_w$ at 0.23 (0.28). This behaviour arises if $\sin^2\theta_w$ approaches the pole of the function $(R^2 - x_w)/(R^2 - (R^2+1)x_w)$ occurring in Eq.(11) as explained in the previous section. For $M^2_{Z_1}$ the pole singularity cancels out. This behaviour in the M_{Z_2} mass would have been observed in the symmetric model also, had the available data allowed $\sin^2\theta_w$ value in the range $0.4 \lesssim \sin^2\theta_w \lesssim 0.5$. Note that for $(g_L/g_R)^2 = 2$, $R^2 = 0.5$ and the pole position which happens to be the upper bound falls at $\sin^2\theta_w = 0.33$, in the asymmetric model. As will be discussed in the next section, the masses M_{W_1}, M_{Z_1} and M_{Z_2} reported in this section remain unchanged whereas $M^P_{W_2}$ changes to higher values ($M_{W_2} > 10^4$ GeV) when we correlate left-right asymmetry arising for our SU(16) grand unification [6),13)] and two stage symmetry breaking of $SU_R(2)$. The behaviour of the mass M_{Z_2} for various values of R^2 and $\sin^2\theta_w$ has been shown in Fig.9. The larger rate of increase with $\sin^2\theta_w$ with decreasing value of R^2 has been clearly displayed.

IV. IMPLICATIONS OF GRAND UNIFICATION

The left-right asymmetry with $g_L > g_R$ can be ascribed an origin in the context of SU(16) grand unification [5),6),13)] and the two stage symmetry breaking of $SU(2)_R$ occurring in the descending group $SU_L(2) \times SU_R(2) \times U(1)$. Prior to two stage symmetry breaking $g_L = g_R$, but after it $g_L > g_R$. Just as the Higgs representation <u>126</u> of SO(10) contains [1)-4)] the doublet ϕ and the triplets Δ_L and Δ_R used to break the left-right symmetry [1)-4)], these are also contained in the representation <u>136</u> of SU(16). In addition, the Higgs representation <u>255</u> of SU(16) contains the right-handed triplet [14)]

$$X_R = (1,3,0) \tag{26}$$

Both the representations <u>136</u> and <u>255</u> are needed to break SU(16) as discussed in a recent paper by Pati, Salam and Strathdee [13)]. The right-handed triplet

X_R, in addition to ϕ, Δ_R and Δ_L is essential and plays a crucial role in two-stage symmetry breaking of $SU(2)_R$. This triplet has $T_3 = 0$ and, therefore, does not affect the neutral gauge boson mass matrix. Also in the charged boson sector it contributes only to the mass of the right-handed gauge boson [14]. Writing the vacuum expectation value as

$$\langle X_R \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ \varepsilon_X \\ 0 \end{pmatrix} \tag{27}$$

the charged boson mass matrix is modified as

$$M_W^2 = \frac{1}{2} g_L^2 V_R^2 \begin{bmatrix} \eta_R(1+\eta_L) & -R\eta_R\left(1-(1-Z)^2\right) \\ -R\eta_R\left(1-(1-Z)^2\right) & R^2(1+\eta_R+\eta_R^X) \end{bmatrix} \tag{28}$$

where $\eta_R^X = \varepsilon_X^2/V_R^2$.

The mixing angle ξ can be written as

$$\tan 2\xi = \frac{2R\eta_R\left[1-(1-Z)^2\right]^{1/2}}{\left[R^2(1+\eta_R+\eta_R^X) - \eta_R(1+\eta_L)\right]} \tag{29}$$

The eigenvalues of charged gauge bosons are modified to the form

$$M_W^2 = \frac{1}{4} g_L^2 V_R^2 \Big[\eta_R(1+\eta_L) + R^2(1+\eta_R+\eta_R^X) \pm \left\{\left[\eta_R(1+\eta_L) - R^2(1+\eta_R+\eta_R^X)\right]^2 + 4R^2\eta_R^2\left[1-(1-Z)^2\right]\right\}^{1/2}\Big] \tag{30}$$

where, as before, the lighter (heavier) of these we call M_{W_1} (M_{W_2}), the mass of the charged left-handed (right-handed) gauge boson.

Comparing Eq.(30) with Eq.(10) we find that the masses of the left-handed or the right-handed charged bosons given by the two equations are, in general different, because of the presence of η_R^X. But in the no mixing case, $Z = 0$, and we get

$$M_{W_1} = \left[\frac{1}{2} g_L^2 V_R^2 \eta_R (1+\eta_L)\right]^{1/2} \tag{31}$$

both from Eqs.(10) and (30). Thus the mass of the left-handed charged gauge boson remains unaffected by the introduction of the Higgs triplet X_R in the no mixing limit of the left and right-handed gauge bosons. Since the introduction of Higgs X_R does not affect the neutral mass matrix, the masses of the neutral gauge bosons remain unaffected irrespective of the amount mixing between the charged left and right-handed bosons. In the no mixing case Eq.(30) yields

$$M_{W_2} = \left[\frac{1}{2} g_L^2 V_R^2 R^2 (1+\eta_R+\eta_R^X)\right]^{1/2} \tag{32}$$

as compared to the one coming from Eq.(10)

$$M_{W_2}^P = \left[\frac{1}{2} g_L^2 V_R^2 R^2 (1+\eta_R)\right]^{1/2} \tag{33}$$

Thus M_{W_2} can be made large by making η_R^X large in order to achieve the desired hierarchy (i.e. $SU(2)_R \xrightarrow{M_{W_2} = M_R^+} U(1)_R$). Now we ask the question whether the phenomenological analysis of Secs.II and III still hold in making the right-handed charged boson heavier. In the no mixing case $Z = 0$ and $\xi = 0$ both in Eqs.(8) and (29) and the muon decay constraints coming from Eqs.(8) and the two-stage symmetry breaking case are the same, namely

$$\frac{G_F}{\sqrt{2}} = \frac{1}{8}\frac{g_L^2}{M_{W_1}^2} = \frac{1}{4k^2(1+\eta_L)} \tag{34}$$

Note that the right-hand side of Eq.(34) is also obtained from Eq.(16a) by putting $Z = 0$ ($k'^2 = 0$). Thus, the three masses M_{W_1}, M_{Z_1}, M_{Z_2} presented in Tables III(a)-(IV(b), the values of charged and neutral current parameters, and the allowed regions in the η_R vs. $\sin^2\theta_W$ plane, for the case $Z = 0$ still hold true in this case, except for the fact that the mass M_{W_2} is now heavier. In Ref.5, the values $(g_L/g_R)^2 > 1$ has been used to estimate $M_{W_2} = M_R^{\dagger} > 10^4$ GeV in order to make agreement with QCD parameter also, using renormalization group equations.

Note that upper bounds of $\sin^2\theta_w$ and zeros of the neutral current parameters are presented in Tables I and II remain unaffected provided that the model parameters used there are the same. Thus, in the context of SU(16) grand unification and left-right asymmetry originating from two-stage symmetry breaking of $SU(2)_R$, all our results of phenomenological analysis still hold true only with the modification that the right-handed charged boson is heavy ($M_{W_2} = M_R^{\dagger} > 10^4$ GeV). Masses of $M_{W_2} = M_R^{\dagger}$ can easily be computed for various $\sin^2\theta_w$ values using formulas given in Ref.5, arising out of renormalization group equations.

V. CONCLUSION

From the results of analysis presented in this paper it is clear that the present charged and neutral current data allow a left-right asymmetric model $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ with $g_L \neq g_R$ to pass all the tests with $(g_L/g_R)^2$ value between 1 and 2 and $\sin^2\theta_w$ between 0.23 to 0.29. It has been noted that it is possible to account for the QCD parameter within such ranges. If one takes the phenomenological asymmetric model alone, without asking questions about its origin at present, it allows low mass (86-230 GeV) charged right-handed gauge bosons and low mass (190-455 GeV) neutral bosons of second generation. Obviously, parity violation exists in the asymmetric model. Left-right asymmetry can arise by two-stage symmetry breaking of $SU(2)_R$ contained in the left-right symmetric group $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ descending from SU(16) grand unification [5),13)] and subsequent symmetry breaking using the Higgs doublets and triplets contained in the representations 136 and 255. All our results of phenomenological analysis carried out in this paper for the no-mixing case (Z = 0) can be carried over to this case keeping the masses of $W_L^{\pm}$, Z_1 and Z_2 unchanged but replacing the right-handed charged gauge boson masses with heavier ones $> 10^4$ GeV. Thus, although the possibility of low mass parity restoration and low mass second generation gauge bosons are allowed in the left-right symmetric model [1),2)] which makes the proton extremely stable, in the context of SU(16) grand unification and left-right asymmetry, the present data allows only the observability of a low mass right-handed neutral boson (190-455 GeV) at ISABELLE energies, but with no possibility of parity restoration at such energies. As has been observed elsewhere [5),6),13),15)] SU(16) grand unification allows for the proton decay ($\tau_p \simeq 10^{31}$ years). This analysis also allows the possibility of the grand desert, otherwise admitted by SU(5) grand unification, to bloom with new masses according to SU(16) grand unification scheme.

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TABLE CAPTIONS

Table I Upper bounds on the allowed values of $\sin^2\theta_w$ as a function of the ratio $(g_L/g_R)^2$.

Table II Zeros of several neutral current parameters as functions of $\sin^2\theta_w$ in the standard model and in the symmetric and asymmetric models for various combinations of model parameters.

Table III(a) Variation of the gauge boson masses in the phenomenological model in the allowed region as a function of $\sin^2\theta_w$ and η_R for $(g_L/g_R)^2 = 1.5$.

Table III(b) Same as Table III(a) but with $(g_L/g_R)^2 = 2.0$.

Table IV(a) Same as Table III(a) but with $Z = 0$ and $\eta_L = 0.1$.

Table IV(b) Same as Table IV(a) but with $(g_L/g_R)^2 = 2.0$.

Table V Variation of gauge boson masses in the phenomenological model for $(g_L/g_R)^2$ (R^2) values 1.5 (0.666) and 2(0.5) and for other combinations of the model parameter, e.g. $\eta_L = Z = 0$ in the allowed region. Note that $M^P_{W_2}$ stands for the right-handed charged boson mass in the phenomenological model which becomes $M_{W_2} = M^{\dagger}_R > 10^4$ GeV, when grand unification ideas are used, while others do not change.

FIGURE CAPTIONS

Fig.1 Allowed regions in the η_R vs. $\sin^2\theta_w$ plane implied by the neutral current data with $Z = \eta_L = 0$ (within 1.64 limits of the parameters) for $(g_L/g_R)^2 = 1.0$, 1.25, 1.5 and 1.75.

Fig.2 Same as Fig.1 for $(g_L/g_R)^2 = 2.0$.

Fig.3 Same as Fig.1 but with $\eta_L = 0.1$, $Z = 0$ and $(g_L/g_R)^2 = 1$ and 1.5.

Fig.4 Same as Fig.3 but with $(g_L/g_R)^2 = 2.0$.

Fig.5 Same as Fig.1 but with $\eta_L = 0$, $Z = 0.1$ and $(g_L/g_R)^2 = 1$ and 1.5.

Fig.6 Same as Fig.5 but with $(g_L/g_R)^2 = 2.0$.

Fig.7 Same as Fig.1 but with $\eta_L = Z = 0.1$ and $(g_L/g_R)^2 = 1$ and 1.5.

Fig.8 Same as Fig.7 but with $(g_L/g_R)^2 = 2.0$.

Fig.9 Variation of the mass of the second neutral Z boson as a function of $\sin^2\theta_w$ for several combinations of model parameters.

Table I

$(g_L/g_R)^2$	Upper bound on $\sin^2\theta_W$
1.0	0.500
1.25	0.444
1.5	0.400
1.75	0.363
2.00	0.333
2.25	0.307
2.50	0.285
2.75	0.266
3.0	0.249

Table II

Observable parameters	Positions of zero		
	Standard model	$R^2 = 1$ $\eta_R = 0.4$ $\eta_L = 0.1$	$R^2 = 0.5$ $\eta_R = 0.4$ $\eta_L = 0.1$
C_1^u	0.375	0.375	0.390
C_2^u	0.25	0.25	0.26
C_1^d	0.75	0.75	0.78
C_2^d	0.25	0.25	0.26
$\epsilon_L^{(u)}$	0.75	0.642	0.562
$\epsilon_R(u)$	0	0.142	0.375
$\epsilon_R(d)$	0	0.142	0.375
g_V	0.25	0.25	0.218
h_{VA}	0.25	0.25	0.26
h_{VV}	0.25	0.25	0.138

Table III(a)

η_R	$\sin^2\theta_W$	M_{W_1} (GeV)	$M^P_{W_2}$ (GeV)	M_{Z_1} (GeV)	M_{Z_2} (GeV)
0	0.23	77.6	∞	88.46	∞
0.1	0.24	76.0	205.8	86.5	385.2
0.1	0.25	74.4	201.6	85.4	387.0
0.1	0.26	73.0	197.7	84.3	389.9
0.1	0.27	71.6	194.0	83.42	394.1
0.2	0.24	76.0	152.3	85.8	274.6
0.2	0.25	74.4	148.9	84.8	275.6
0.2	0.26	73.0	146.0	83.8	277.5
0.2	0.27	71.6	143.3	82.9	280.2
0.2	0.28	70.3	140.7	82.1	284.1
0.2	0.29	69.1	138.3	81.3	289.1
0.3	0.25	74.4	126.5	84.1	226.8
0.3	0.26	73.0	124.1	83.2	228.1
0.3	0.27	71.6	121.8	82.4	230.2
0.3	0.28	70.3	119.6	81.7	233.2
0.4	0.27	71.6	109.4	81.9	200.7
0.4	0.28	70.3	107.5	81.2	203.1
0.4	0.29	69.1	105.6	80.6	206.4

Table III(b)

η_R	$\sin^2\theta_W$	M_{W_1} (GeV)	$M^P_{W_2}$ (GeV)	M_{Z_1} (GeV)	M_{Z_2} (GeV)
0	0.23	77.6	∞	88.4	∞
0.1	0.23	77.63	182.0	88.0	388.5
0.1	0.24	75.9	178.2	86.8	397.3
0.1	0.25	74.4	174.6	85.7	409.0
0.1	0.26	73.0	171.2	84.6	424.4
0.2	0.23	77.6	134.4	87.6	276.0
0.2	0.24	75.9	131.6	86.5	282.0
0.2	0.25	74.4	129.0	85.4	300.8
0.2	0.27	71.6	124.1	83.5	315.2
0.2	0.28	70.3	121.9	82.7	334.6
0.2	0.29	79.1	119.7	81.9	361.9
0.3	0.24	75.9	111.9	86.1	231.0
0.3	0.25	74.4	109.6	85.1	237.7
0.3	0.26	73.0	107.5	84.2	246.3
0.3	0.27	71.6	105.5	83.3	257.8
0.3	0.28	70.3	103.6	82.5	273.6
0.3	0.29	69.1	101.8	81.8	295.8
0.4	0.25	74.4	98.5	84.8	206.6
0.4	0.26	73.0	96.5	84.0	213.9
0.4	0.27	71.6	94.7	83.2	223.8
0.4	0.28	70.3	93.6	82.4	237.3
0.4	0.29	69.1	91.4	81.7	256.4
0.5	0.28	70.3	86.1	82.3	212.6

Table IV(a)

η_R	$\sin^2\theta_W$	M_{W_1} (GeV)	$M^P_{W_2}$ (GeV)	M_{Z_1} (GeV)	M_{Z_2} (GeV)
0	0.25	74.4	∞	89.8	∞
0.1	0.26	73.0	188.5	88.3	372.2
0.1	0.27	71.6	185.0	87.3	376.3
0.1	0.28	70.3	181.6	86.4	381.8
0.2	0.26	73.0	139.2	88.1	265.2
0.2	0.27	71.6	136.6	87.1	267.9
0.3	0.27	71.6	116.1	86.8	220.3
0.4	0.27	71.6	104.3	86.6	192.2

Table IV(b)

η_R	$\sin^2\theta_W$	M_{W_1} (GeV)	$M^P_{W_2}$ (GeV)	M_{Z_1} (GeV)	M_{Z_2} (GeV)
0	0.25	74.4	∞	89.8	∞
0.1	0.25	74.4	166.5	89.7	390.8
0.1	0.26	73.0	163.2	88.6	405.6
0.1	0.27	71.6	160.2	87.5	425.3
0.2	0.25	74.4	123.0	89.6	277.7
0.2	0.26	73.0	120.6	88.5	288.2
0.3	0.25	74.4	104.5	89.5	227.9
0.3	0.26	73.0	102.5	88.4	236.4
0.4	0.26	73.0	92.0	88.4	205.7

Table V

R^2	Z	η_L	η_R	$\sin^2\theta_W$	M_{W_1} (GeV)	$M^P_{W_2}$ (GeV)	M_{Z_1} (GeV)	M_{Z_2} (GeV)
0.666	0.1	0	0	0.23	77.6	∞	88.4	∞
0.666	0.1	0	0.1	0.24	75.8	207.9	87.3	388.6
0.666	0.1	0	0.1	0.25	74.3	203.7	86.1	390.4
0.666	0.1	0	0.1	0.26	72.9	199.7	85.1	393.3
0.666	0.1	0	0.1	0.27	71.5	196.0	84.1	397.5
0.5	0.1	0	0	0.23	77.6	∞	88.4	∞
0.5	0.1	0	0.1	0.23	77.4	184.0	88.8	391.9
0.5	0.1	0	0.1	0.24	75.8	180.1	87.6	400.8
0.5	0.1	0	0.1	0.25	74.3	176.5	86.4	412.6
0.5	0.1	0	0.1	0.26	72.8	173.0	85.4	428.1
0.5	0.1	0	0.1	0.27	71.5	169.8	84.4	448.7
0.666	0.1	0.1	0	0.25	74.4	∞	89.8	∞
0.666	0.1	0.1	0.1	0.26	72.9	190.3	89.0	375.2
0.666	0.1	0.1	0.1	0.27	71.5	228.6	87.6	392.1
0.5	0.1	0.1	0	0.25	74.4	∞	89.8	∞
0.5	0.1	0.1	0.1	0.25	74.3	168.1	90.4	393.9
0.666	0.2	0	0	0.23	77.6	∞	88.4	∞
0.666	0.2	0	0.1	0.24	75.8	209.8	87.9	391.7
0.666	0.2	0	0.1	0.25	74.2	205.5	86.8	393.5
0.666	0.2	0	0.1	0.26	72.8	201.5	85.8	396.4
0.666	0.2	0	0.1	0.27	71.4	197.8	84.8	400.7
0.666	0.2	0	0.1	0.28	70.1	194.2	83.9	406.5
0.5	0.2	0	0	0.23	77.6	∞	88.4	∞
0.5	0.2	0	0.1	0.24	75.7	181.8	88.3	404.0
0.5	0.2	0	0.1	0.25	74.1	178.2	87.1	415.8
0.5	0.2	0	0.1	0.26	72.7	174.7	86.1	431.5
0.5	0.2	0	0.1	0.27	71.3	171.4	85.1	452.3

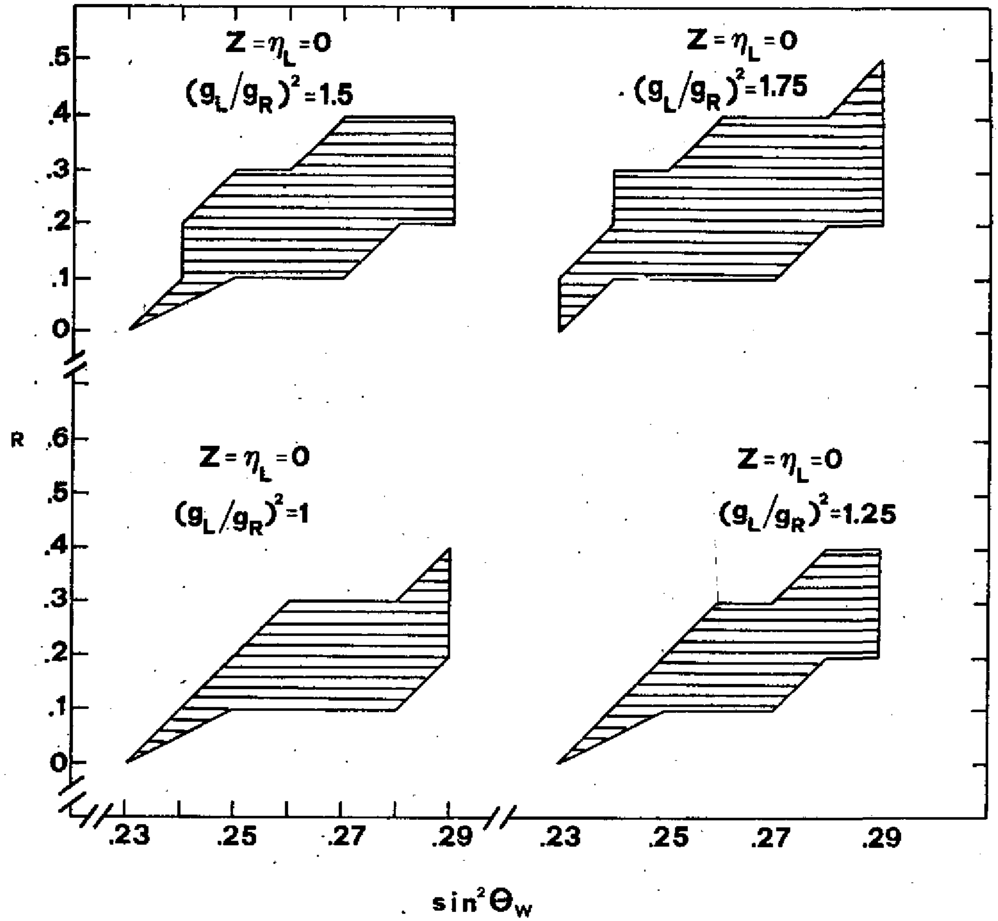
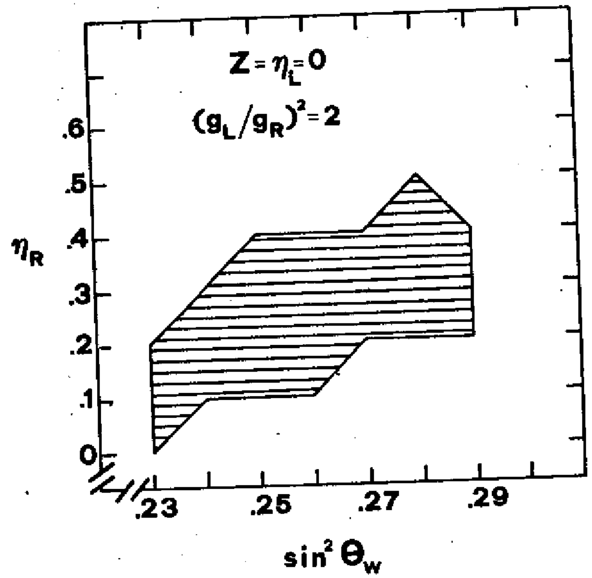
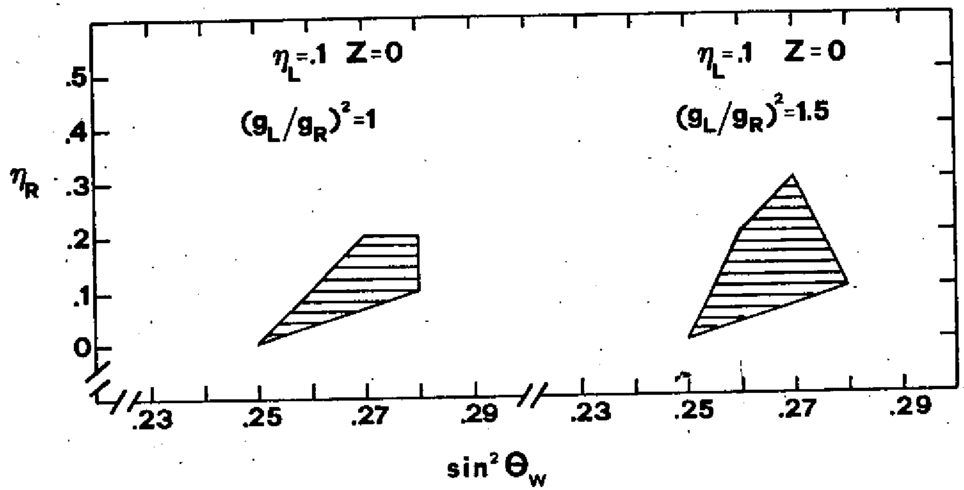


FIG 1



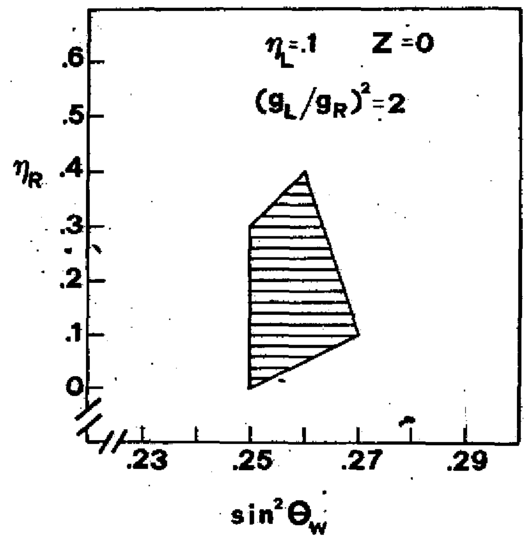
$Z=\eta_L=0$
$(g_L/g_R)^2=2$
η_R
.6
.5
.4
.3
.2
.1
0
.23
.25
.27
.29
$\sin^2\Theta_W$

FIG 2



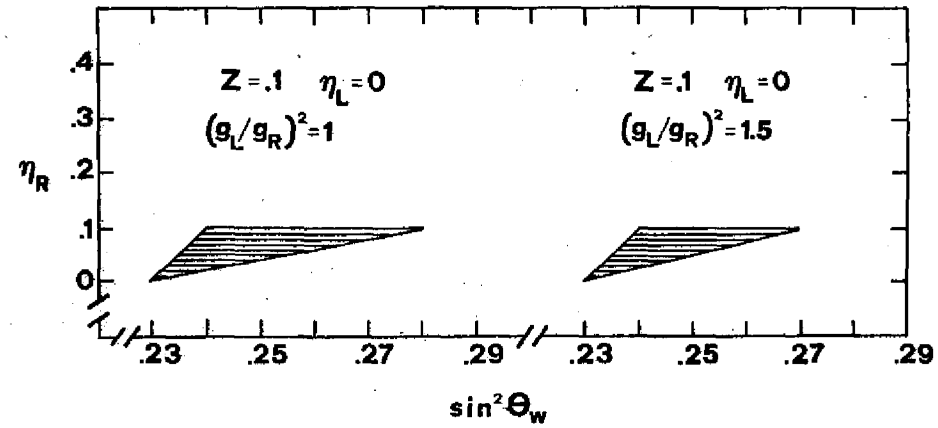
$\eta_L=.1$ $Z=0$
$(g_L/g_R)^2=1$
$\eta_L=.1$ $Z=0$
$(g_L/g_R)^2=1.5$
η_R
.5
.4
.3
.2
.1
0
.23
.25
.27
.29
.23
.25
.27
.29
$\sin^2\Theta_W$

FIG 3



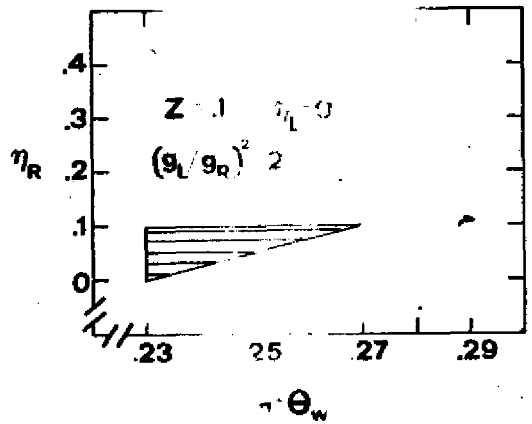
$\eta_L = .1$ $Z = 0$
$(g_L/g_R)^2 = 2$
η_R
.6
.5
.4
.3
.2
.1
0
.23
.25
.27
.29
$\sin^2\Theta_W$

FIG 4



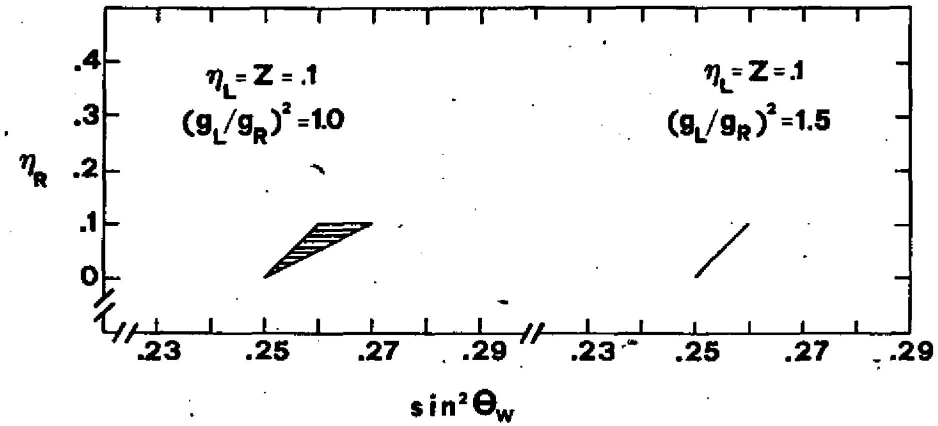
$Z = .1$ $\eta_L = 0$
$(g_L/g_R)^2 = 1$
$Z = .1$ $\eta_L = 0$
$(g_L/g_R)^2 = 1.5$
η_R
.4
.3
.2
.1
0
.23
.25
.27
.29
.23
.25
.27
.29
$\sin^2\Theta_W$

FIG 5



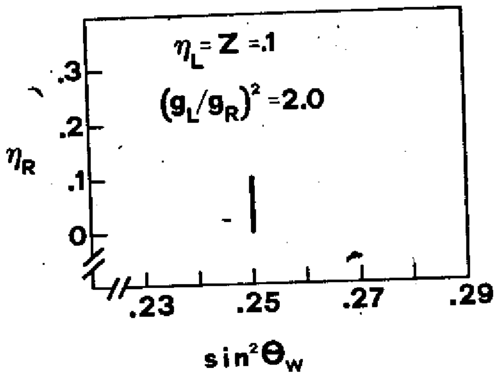
Z = .1 η_L = 0
$(g_L/g_R)^2$ = 2
η_R
.4
.3
.2
.1
0
.23
.25
.27
.29
$\sin^2\Theta_W$

FIG 6



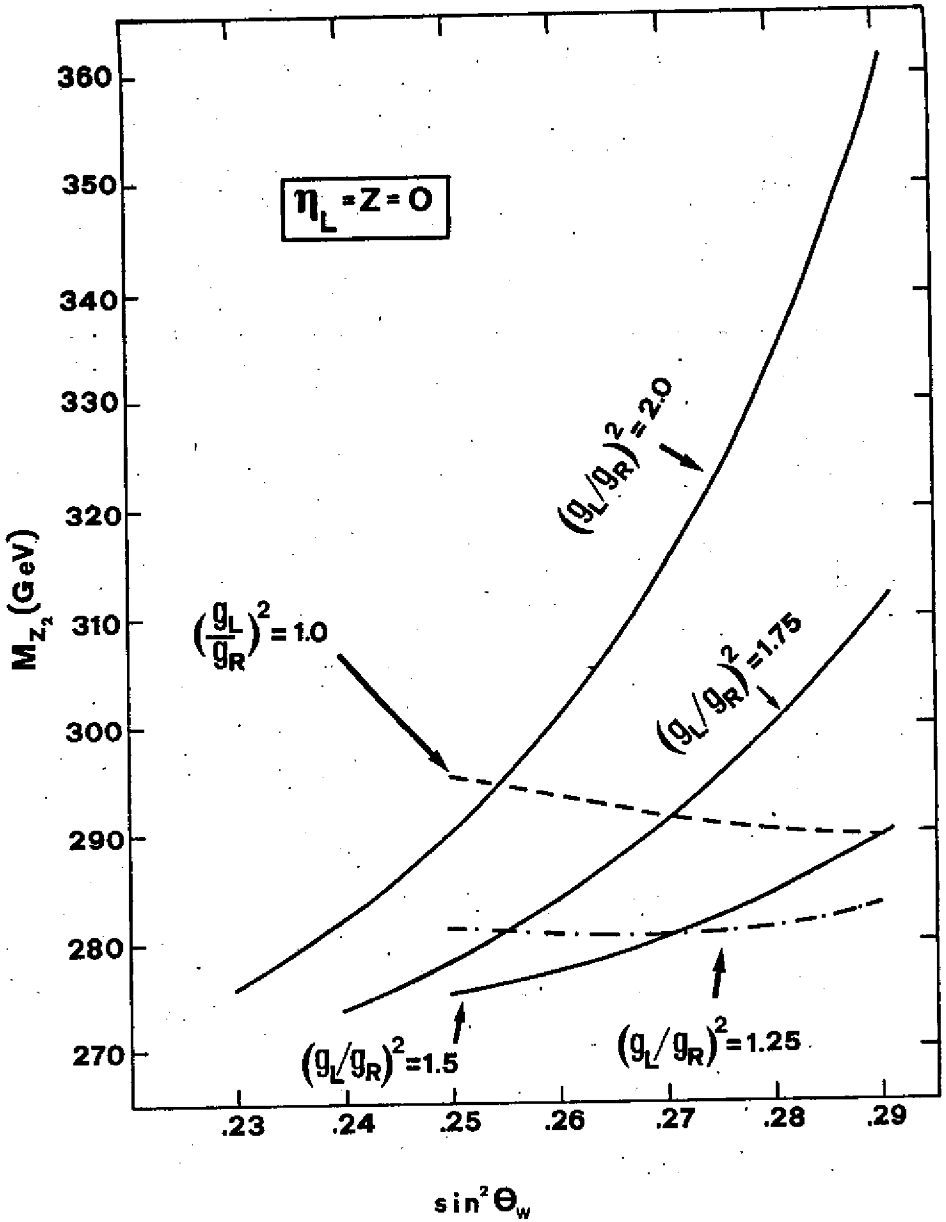
η_L = Z = .1
$(g_L/g_R)^2$ = 1.0
η_L = Z = .1
$(g_L/g_R)^2$ = 1.5
η_R
.4
.3
.2
.1
0
.23
.25
.27
.29
.23
.25
.27
.29
$\sin^2\Theta_W$

FIG 7



$\eta_L = Z = .1$
$(g_L/g_R)^2 = 2.0$
η_R
.3
.2
.1
0
.23
.25
.27
.29
$\sin^2\Theta_w$

FIG 8



$\eta_L = Z = 0$
M_{Z_2} (GeV)
360
350
340
330
320
310
300
290
280
270
$(g_L/g_R)^2 = 2.0$
$(g_L/g_R)^2 = 1.75$
$\left(\frac{g_L}{g_R}\right)^2 = 1.0$
$(g_L/g_R)^2 = 1.5$
$(g_L/g_R)^2 = 1.25$
.23
.24
.25
.26
.27
.28
.29
$\sin^2\Theta_w$

FIG 9

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