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Some low energy restrictions for a flipped left-right symmetric E_6 model

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Abstract
I give a short review of a new left-right symmetric E_6 model containing a right-handed W-boson W_R with odd R-parity. Some restrictions from low-energy data are presented, the most important coming from $D - \overline{D}$ mixing. It is found that W_R is likely to be heavier than 500 to 1500 GeV.

The Standard Model (SM) gives for the moment very good agreement with data. However, elementary particle physicists hardly think that the SM is the final answer, and are eager to see if there are effects due to new physics beyond the SM. Such effects might occur as signals in collisions at very high energy, or as very exotic decay processes. A possible extension of the SM is the left-right symmetric model containing an extra gauge-boson W_R mediating charged right-handed currents[1]. Such interactions have significant impact on low-energy data, in particular $K - \overline{K}$ mixing[2], and it was found that the mass M_R of W_R must be bigger than 1-10 TeV to avoid conflicts with data. Thus the prospects to observe such a particle in a relatively near future is rather poor.

Left-right symmetric models may also be embedded in GUT-models, like $SO(10)$ and E_6. Due to the heterotic string[3], E_6 models have recently been extensively studied. Low energy restrictions for an E_6 model broken down to $SU(3) \times SU(2) \times U(1) \times U(1)$ have been studied[4] previously. But E_6 may also be broken down to $G = SU(3) \times SU(2) \times SU(2) \times U(1)$, containing a left-right symmetric model. A conventional particle assignment for one generation of fermions would then be

$$\begin{aligned}
&\begin{pmatrix} u \\ d \end{pmatrix}_L : (3,2,1,\frac{1}{6}) \,, \qquad (d^c\,,\, u^c)_L : (\overline{3},1,2,-\frac{1}{6}) \,, \\
&h_L : (3,1,1,-\frac{1}{3}) \,, \qquad h_L^c : (\overline{3},1,1,\frac{1}{3}) \,, \\
&\begin{pmatrix} \nu_e \\ e \end{pmatrix}_L : (1,2,1,-\frac{1}{2}) \,, \qquad (e^c\,,\, N^c)_L : (1,1,2,\frac{1}{2}) \,, \\
&\begin{pmatrix} \nu_E & E^c \\ E & N_E^c \end{pmatrix}_L : (1,2,2,0) \,, \qquad n_L : (1,1,1,0) \,,
\end{aligned} \tag{1}$$

where the superscript c denotes charge conjugation. With this particle assignment one obtains the ordinary left-right symmetric model with some extension due to the exotic fermions contained in the $\underline{27}$ representation of E_6. h is an exotic quark with electric charge -1/3, and E, ν_E, N_E, N, n are exotic non-hadronic fermions (-hereafter called "leptons"); E has electric charge -1, while the rest are neutral.

Recently, Ma[5] proposed to flip the particle content of (1) in the following way:

$$\begin{aligned}
&\begin{pmatrix} u \\ d \end{pmatrix}_L : (3,2,1,\frac{1}{6}) \,, \qquad d_L^c : (\overline{3},1,1,\frac{1}{3}) \,, \\
&h_L : (3,1,1,-\frac{1}{3}) \,, \qquad (h_L^c\,, u^c)_L : (\overline{3},1,2,-\frac{1}{6}) \,, \\
&\begin{pmatrix} \nu_e & E^c \\ e & N_E^c \end{pmatrix}_L : (1,2,2,0) \,, \qquad (e^c\,,\, n)_L : (1,1,2,\frac{1}{2}) \,, \\
&\begin{pmatrix} \nu_E \\ E \end{pmatrix}_L : (1,2,1,-\frac{1}{2}) \,, \qquad N_L^c : (1,1,1,0) \,.
\end{aligned} \tag{2}$$

Note that this flipping is not done at the level of unbroken E_6, but at the level of G. In this sense the Ma-model[5] is different from the flipped $SU(5) \times U(1)$ model[6]. The particle assignment (2) means that due to W_R exchange,

$$u \leftrightarrow h, \; \nu_e \leftrightarrow E^c, \; e \leftrightarrow N_E^c, \; e^c \leftrightarrow n, \tag{3}$$

while there is *no* W_R -coupling for $u \leftrightarrow d$ as in ordinary left-right symmetric models. One should note that the exotic "leptons" have lepton numbers equal to zero, while W_R and h have non-zero lepton numbers.

The SM particles have even R-parity, and their SUSY-partners odd R-parity, as usual. The exotic quark h, the exotic "leptons" E, ν_E, N_E, n, N *and* the righthanded W-boson W_R all have odd R-parity, and consequently their SUSY-partners have even R-parity. These R-parity assignments implies that the SUSY-partners of the exotic neutral "leptons" may aquire v.e.v.'s and be used as Higgses. An important consequence of the odd R-parity of W_R is that there is no mixing between W_R and W_L as in ordinary left-right symmetric models. This property combined with the absence of a duW_R (and suW_R) coupling means that there is no significant contribution from W_R-exchange to $K - \overline{K}$ mixing. Thus the previous bound[2] on W_R from $K - \overline{K}$ mixing does not apply any more, and W_R could apriori be as light as 300 GeV, say[5,7,8,9,10].

As in most models beyond the SM, in particular in models including SUSY, rare effects will be generated also in the Ma model[5]. Such effects will depend on the details

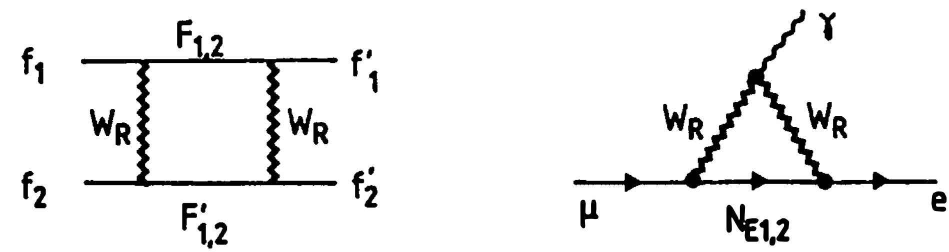

Figure 1: Fig1.a(left)): The box diagram. The exotic fermions F and F', and W_R are running in the loop, while the external fermions $f_i(i = 1, 2, 1', 2'.)$ are SM fermions. Fig.1b(right)): Diagram for $\mu \to e\gamma$ due to W_R-exchange.

of the model[11,12,13], in particular the Yukawa interactions, which may be chosen in slightly different ways. One should note that one may also construct non-SUSY versions of the model[14]. I have therefore concentrated on effects due to exchanges of W_R, which are expected[10] to set the typical scale of rare effects in the model.

Besides the limits on the masses of the exotic particles which might be obtained in high energy collisions[7,8,9], there will also be low energy limits obtained from absence of rare effects. Several rare effects, such as $D - \overline{D}$ mixing, $D^0 \to \mu\overline{\mu}$, $D^0 \to \mu\overline{e}$, $\mu \to 3e$, and $\mu N \to eN$, are obtained [15] from box-diagrams with double W_R-exchange, as shown in Fig.1a. The most important case turns out to be $D - \overline{D}$ mixing[10,15].

For the $D - \overline{D}$ mixing case $f_1 = c, f_{1'} = u, f_2 = \overline{u}, f_{2'} = \overline{c}$, in Fig.1a. The fermions in the loop are the h-quarks of three different generations. The mixing among these are analogous to the mixing of the d, s, b quarks of the SM. Neglecting CP-violating effects, it suffices to consider two generations only, and the diagram is analogous to that for $K - \overline{K}$ mixing with the substitutions $s \to c$; $d \to u$; $u, c \to h_{1,2}$; $W_L \to W_R$. (Note that exchange of one W_L and one W_R is forbidden.) Recall that in the SM, $D - \overline{D}$ mixing is very small, and moreover hard to estimate due to non-perturbative effects. Comparing the box diagram for $D - \overline{D}$ mixing due to W_R-exchange (R) with the short distance (SD) part of the corresponding box diagram for $K - \overline{K}$ mixing in the SM, we obtain

$$\frac{(\Delta m_D)_R}{(\Delta m_K)_{SD}} = \frac{m_D}{m_K}\left(\frac{f_D}{f_K}\right)^2 \frac{B_D}{B_K}\frac{\eta_D}{\eta_K}\left(\frac{\lambda_R}{\lambda_L}\right)^2 \frac{Q_h}{m_c^2}\left(\frac{g_R M_L}{g_L M_R}\right)^4 , \tag{4}$$

where $\Delta m_K = m_{K_L} - m_{K_S}$, and similarly for D^0. $M_{L,R}$ are the masses and $g_{L,R}$ the gauge couplings of $W_{L,R}$. $\lambda_{L,R}$ are the Cabibbo factors for $h_{1,2}$ mixing and d, s mixing, respectively. (One may for instance assume $\lambda_R \simeq \lambda_L$ [10], or use the Fritzsch ansatz[16]). B_K is the socalled B-parameter due to the hadronic matrix element, and η_K contains the perturbative QCD corrections in $K - \overline{K}$ mixing[17]. B_D and η_D are the corresponding parameters for $D - \overline{D}$ mixing in our case. Q_h is a factor determined by the box loop integration:

$$Q_h \simeq M_2^2 ; \qquad Q_h \simeq \frac{1}{3} M_R^2 ; \qquad Q_h \simeq M_R^2 , \tag{5}$$

for the cases $M_1^2 \ll M_2^2 \ll M_R^2$, $M_1^2 \ll M_2^2 \sim M_R^2$, and $M_2^2 \gg M_{1,R}^2$ respectively. ($M_{1,2}$ are the masses of $h_{1,2}$.) It is known[17] that the SD amplitude for $K^0 \to \overline{K^0}$ can account for $\simeq 1/2$ of the observed Δm_K. Thus, $\Delta m_K = \beta(\Delta m_K)_{SD}$ with $\beta \simeq 2$.

Using[18] $\Delta m_D/\Delta m_K < 37$, we obtain a bound on the combination of parameters of the right hand side of (4). Taking explicite values for $M_{1,2}$, we will obtain a corresponding bound for the W_R mass. In [7,8,9] $M_1 \sim 100$ and 300 GeV are taken as examples. One would then obtain $M_R > 0.5$ to 1.5 TeV. (For numerical estimates, $g_R = g_L$ is assumed. The ratios of the f's, B's and η's in (4) are of order one[10,15]). Thus, unless the masses M_1 and M_2 are rather close, W_R has to be heavier than the bound 2-300GeV mentioned in [5,7,8,9,10]. (If $M_1/M_2 \simeq 0.7$, the W_R-mass may still be 2-300 GeV [10], but it might be argued that $M_2^2 \gg M_1^2$ is more likely, and more spesific that $M_1 : M_2 : M_3 = m_d : m_s : m_b$ at some scale[14])

W_R-exchange will also contribute to $\mu \to e\gamma$, as shown in Fig.1b, but this process gives a slightly milder bound on M_R (350 to 650 GeV, say) compared to (4)[15]. (Note that in this case there is a complication due to mixing between N_E^c, ν_E and n of the same generation.) The process $\mu \to 3e$ gives a bound comparable to $\mu \to e\gamma$, while $\mu N \to eN$ gives an uninteresting bound ~ 200 GeV for M_R ($M_2^2 \gg M_1^2$ is assumed). The process $D^0 \to \mu\bar{\mu}$ will not give an interesting bound on M_R. One finds that for $M_R \sim 0.5$ to 1 TeV, $Br(D^0 \to \mu\bar{\mu})$ will hardly exceed 10^{-10} (-but will still be bigger than in the SM), while $Br(D^0 \to \mu\bar{e})$ is one or two orders of magnitude smaller. W_R-exchange will also generate magnetic (transition) moments of the neutrinos of the SM. But as in the SM, the moments are proportional to the neutrino mass, and will be too small to be interesting for the proposed VVO-solution of the solar neutrino problem[19].

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