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New approach to test the hypothesis of compositeness

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We explore the possibility that composite weak vector bosons could behave accordingly to an $SU_L^*(2)\otimes U(1)$ group. New neutral-current effects are predicted in the 100–200-GeV region. We discuss the experimental consequences of this model for e^+e^- colliders and compare possible excited-lepton decays with a fourth-generation lepton.

I. INTRODUCTION

We find today a great interest in a new neutral gauge boson. This is mainly motivated by the $E_8\times E_8'$ superstring model, which can lead to a low-energy gauge group larger than $SU(3)_C\otimes SU(2)_L\otimes U(1)_Y$. As new hadronic facilities and highly precise experiments in e^+e^- [CERN, SLAC Linear Collider (SLC)] are reached we expect to verify if these models are correct or not.[1] In this paper we point out that a similar neutral gauge boson could have a different origin.

The repetition of fermionic families with similar properties seems to be an indication for a possible structure of the presently known elementary fermions. This possibility has been considered by many authors. But the effort in this direction has failed (so far) in answering two fundamental points.

The first is to reproduce the mass spectrum and observable properties of the known families. The only insight we have is by symmetry breaking but we must then introduce arbitrary couplings to be adjusted to the fermionic masses.

The second point is the identification of an excited fermion without ambiguity. In other words, a composite model must answer if the muon (and/or the τ) is an excited electron or not. Of course, different lepton numbers may be an answer but we could have alternatives such as the old Konopinski-Mahmoud scheme[2] where this is not quite true. In any case the hypothesis of compositeness must clarify this point.

This paper is an attempt to identify excited states if quarks and leptons are composite objects. As the mechanism for this structure is unknown and we have no direct experimental evidence we take as a starting point the global properties of compositeness. An example is the possibility of spin-$\frac{3}{2}$ states.[3] If the known fermions are composite states of three spin-$\frac{1}{2}$ fundamental fields we expect spin $\frac{3}{2}$ as in the barionic multiplets. In the same way, if the known vector bosons are considered as bound states of two spin-$\frac{1}{2}$ fundamental fields we expect spin-0 bound states to exist.[4]

The hypothesis of more fundamental fermionic degrees of freedom is very appealing since we can have quarks and leptons as bound states of three fermions of spin $\frac{1}{2}$ and gauge bosons as two-fermion states. We consider only the weak gauge vector bosons as composite. An argument in this direction is given by the fact that other short-range forces known in nature, such as the van der Waals interaction and the "old" hadron-hadron strong interaction, are resulting interactions of more fundamental phenomena.

II. THE MODEL

If the hypothesis of compositeness is true we expect to find excited states with a higher mass than the presently known fermions and vector bosons, as well as scalars. Our first step is then to find out what kind of interactions will appear among these excited states. We call "excited states" the high mass levels of the presently known matter which maintain similar quantum numbers as charge, spin, lepton number, isospin, etc. Following the success of the standard electroweak model we postulate that excited matter must interact according to the gauge group $SU_L^*(2)\otimes U(1)$.

This hypothesis implies that we have the following assignment for excited fermions:

$$\begin{bmatrix}\nu_e\\ e\end{bmatrix}_L,\quad e_R\to\begin{bmatrix}N\\ E\end{bmatrix}_{L^*},\quad E_{R^*} \tag{2.1}$$

for the electronic sector and similar terms for the other lepton and quark families (the star refers to the excited states).

If the gauge bosons of the standard model are composite objects we expect new excited vector bosons according to

$$(W^{(\pm)},Z^{(0)})\to(W^{(\pm)*},Z^{(0)*})\ . \tag{2.2}$$

We are taking a conservative point of view and considering massless gauge bosons as elementary.

For a symmetry-breaking pattern similar to the standard model, we need only a new scalar doublet ϕ^* [relative to SU*(2)]. As the scalar sector in the standard model is not completely settled we may have other representations involved but here we do not consider this possibility.

This is the minimal set of fundamental hypothesis that we need to specify the dynamics of excited states. We emphasize that this is the more conservative extension of the standard model from low-lying matter to excited states. This is not to be misunderstood with the unknown dynamics that should be responsible for the reproduction of the family generations. This approach has been developed by one of the authors (J.A.M.S.) in Ref. 5. Here we are considering a more general treatment and discussing in more detail their phenomenological consequences.

III. FUNDAMENTAL PARAMETERS

If we call g, g', g'' the constants associated with SU(2), U(1), SU*(2), respectively, and v and v' the vacuum expectation values of ϕ and ϕ^* we have five unknown parameters in the model. We can consider as independents inputs α, M_W, M_Z, G_F. In the next section we show that $\sin\theta_W$ is not an independent parameter. In our approach ϕ^* is an excited state of ϕ and it is reasonable to suppose that their ground state is characterized by the same parameter $v'=v''$. The new-vector-boson masses and couplings are then uniquely determined, and the new mass scale is in the 100–200-GeV range.

The vector-boson masses are generated from the Lagrangian

$$L_{\text{masses}}=\tfrac{1}{4}\langle\phi\,|\,(g\mathbf{W}\cdot\tau-g'B)^2\,|\,\phi\rangle+\tfrac{1}{4}\langle\phi^*\,|\,(g''\mathbf{W}\cdot\tau-g'B)^2\,|\,\phi^*\rangle\ . \tag{3.1}$$

The charged-vector-boson masses are then

$$m_{W_1}^2=\tfrac{1}{4}g^2v'^2,\quad m_{W_2}^2=\tfrac{1}{4}g''^2v''^2\ . \tag{3.2}$$

For the neutral vector fields, after rotation, we have one massless field A^μ and two massive fields Z_1^μ, Z_2^μ. We identify $W_1^\mp$ and Z_1 as the observed vector bosons which have the same properties predicted by the standard electroweak model. For these neutral fields we have the relations

$$m_{Z_1}^2+m_{Z_2}^2=\left[\frac{g'^2}{g^2}+1\right]m_{W_1}^2+\left[\frac{g'^2}{g''^2}+1\right]m_{W_2}^2 \tag{3.3a}$$

and

$$m_{Z_1}^2m_{Z_2}^2=\frac{g'^2}{e^2}m_{W_1}^2m_{W_2}^2\ . \tag{3.3b}$$

The general rotation from the primaries $(B_1W_3W_3^*)$ fields to the physical (AZ_1Z_2) is given by the matrix

$$U=\begin{bmatrix} x_0 & x_1 & x_2\\ -\dfrac{g'}{g}x_0 & \dfrac{g'}{g}\dfrac{x_1}{t_1^2} & \dfrac{g'}{g}\dfrac{x_2}{t_2^2}\\ -\dfrac{g'}{g''}x_0 & \dfrac{g'}{g''}\dfrac{x_1}{t_1^{*2}} & \dfrac{g'}{g''}\dfrac{x_2}{t_2^{*2}}\end{bmatrix}, \tag{3.4}$$

where we adopt the useful mass relations

$$t_a^2=\frac{m_{Z_a}^2-m_{W_1}^2}{m_{W_1}^2},\quad t_a^{*2}=\frac{m_{Z_a}^2-m_{W_2}^2}{m_{W_2}^2}\quad(a=1,2)\ . \tag{3.5}$$

The normalization conditions $(U^+U=UU^+=1)$ results in

$$x_a^2=\frac{1}{g'^2}\left[\frac{1}{1/g'^2+1/g^2t_a^4+1/g''^2t_a^{*4}}\right]\quad(a=0,1,2,\ t_0^2=1)\ . \tag{3.6}$$

With Fermi's constant given by

$$G_F=\frac{1}{4\sqrt{2}}\frac{g^2}{m_{W_1}^2} \tag{3.7}$$

and the electric charge identified with (see next section)

$$\frac{1}{e^2}=\frac{1}{g^2}+\frac{1}{g'^2}+\frac{1}{g''^2} \tag{3.8}$$

we can fix the new parameters in the model.

We show in Table I our predictions for the coupling constants g, g', g'' and the new vector-boson masses. In order to give an estimate of the effects of our hypothesis on the ratio $R=v'/v''$ we indicate also the mass values corresponding to different values of R. We have taken values of m_{W_1} and m_{Z_1} a little below their experimental values since we are not taking into account the radiative corrections.

IV. THE NEW INTERACTIONS

The structure of the charged-current interactions is the same as in the standard model. As the new charged vector bosons are not coupled to ordinary matter, their production and decays will be difficult to be experimentally detected. This is due to our choice for the scalar sector. If we enlarge the usual Yukawa's couplings we can have mixing in the charged sector. This case will be considered in Sec. VI.

For the neutral sector we have

$$L_{\text{neutral}}=\sum_{a=1,2}\left[\frac{-g'x_a}{s_a^2}\{j_0^\mu(\nu)+[j_0^\mu(e)+s_a^2j_{\text{EM}}^\mu(e)]\}Z_{a_\mu}-\frac{g'x_a}{s_a^{*2}}\{j_0^\mu(N)+[j_0^\mu(E)+s_a^{*2}j_{\text{EM}}^\mu(E)]\}Z_{a_\mu}\right]+ej_{\text{EM}}^\mu(e)A_\mu+ej_{\text{EM}}^\mu(E)A_\mu\ , \tag{4.1}$$

TABLE I. The square of the coupling constants of the model, and the known-vector-boson masses.

M_{W_1} (GeV)	M_{Z_1} (GeV)	R	g^2	g'^2	g''^2	M_{W_2} (GeV)	M_{Z_2} (GeV)
80	90	0.1	0.422	0.119	7.283	105.1	106.4
80	90	0.5	0.422	0.123	2.298	131.9	136.1
80	90	1.0	0.422	0.127	1.485	150.0	157.0
81	90.5	1.0	0.433	0.129	1.185	134.0	142.3
81.5	91.5	1.0	0.438	0.122	2.299	186.7	191.9

where

$$s_a^2=\frac{m_{Z_a}^2-m_{W_1}^2}{m_{Z_a}^2},\quad s_a^{*2}=\frac{m_{Z_a}^2-m_{W_2}^2}{m_{Z_a}^2}\quad (a=1,2)$$

with the usual definitions

$$j_0^\mu(\nu)=\tfrac{1}{4}\bar{\nu}\gamma^\mu(1-\gamma^5)\nu\ ,$$
$$j_0^\mu(e)=-\tfrac{1}{4}\bar{e}\gamma^\mu(1-\gamma^5)e,\quad j_{\mathrm{EM}}^\mu(e)=\bar{e}\gamma^\mu e\ , \tag{4.2}$$

and similar terms for the excited leptons.

In the neutral interaction Lagrangian we have identified the coefficient of the electromagnetic interaction with the electric charge as shown in Eq. (3.8). It is clear from our Eq. (4.1) that the neutral-current term for the known leptons is the same as in the standard model if we identify $s_1^2=\sin^2\theta_W=1-m_{W_1}^2/m_{Z_1}^2$.

The low-energy limit of the interaction Lagrangian is the same as in the standard model except for a term $Cj_{\mathrm{EM}}^\mu j_\mu^{\mathrm{EM}}$ where

$$C=\frac{e^4}{g''^2g^2}\frac{m_{W_1}^2}{m_{W_2}^2}\ . \tag{4.3}$$

However from the values of the coupling constants and bosons masses we have $C<0.005$, far below the experimental[6] upper bound $C_{\mathrm{expt}}<0.035$.

Before discussing the phenomenological consequences of our model we rewrite the neutral interaction in a form which is more suitable for numerical estimates. The weak neutral-current interaction of Eq. (4.1) is

$$\begin{aligned}L_{\mathrm{NC}}=&\tfrac{1}{4}[\bar{\nu}\gamma^\mu(1-\gamma^5)\nu](g_{N_1}Z_{1_\mu}+g_{N_2}Z_{2_\mu})+\tfrac{1}{4}(\bar{e}\gamma^\mu e)(g_{V_1}Z_{1_\mu}+g_{V_2}Z_{2_\mu})+\tfrac{1}{4}(\bar{e}\gamma^\mu\gamma^5 e)(g_{A_1}Z_{1_\mu}+g_{A_2}Z_{2_\mu})\\&+\tfrac{1}{4}[\bar{N}\gamma^\mu(1-\gamma^5)N](g_{N_1}^*Z_{1_\mu}+g_{N_2}^*Z_{2_\mu})+\tfrac{1}{4}(\bar{E}\gamma^\mu E)(g_{V_1}^*Z_{1_\mu}+g_{V_2}^*Z_{2\mu})+\tfrac{1}{4}(\bar{E}\gamma^\mu\gamma^5 E)(g_{A_1}^*Z_{1\mu}+g_{A_2}^*Z_{2\mu})\ ,\end{aligned} \tag{4.4}$$

where

$$g_{A_a}=g_{N_a}=-\frac{g'x_a}{s_a^2},\quad g_{A_a}^*=g_{N_a}^*=-\frac{g'x_a}{s_a^{*2}}\quad (a=1,2)$$
$$g_{V_a}=\left[\frac{1}{s_a^2}-4\right]g'x_a,\quad g_{V_a}^*=\left[\frac{1}{s_a^{*2}}-4\right]g'x_a\ . \tag{4.5}$$

In Table II we give values for these parameters. We call attention to the small difference between $g/\cos\theta_W$ from the standard model and our value g_{N_1}. These differences, however, can produce experimental consequences that are to be detected in the new e^+e^- machines.

V. PHENOMENOLOGICAL CONSEQUENCES

We show here some predictions of the model such as decay width, asymmetries, and cross sections, that could be verified in the new e^+e^- machines. Table III gives the results for the decay widths of the neutral boson Z_1 and its difference from the standard-model prediction. In this calculation we did not take into account the effect of the top-quark mass which is not relevant for the difference in the decay widths. Since both the SLC and the LEP at CERN will measure this quantity with a precision better than 50 MeV, we see that for various choices of parameters it will be possible to test the results. There is the alternative that the lighter of the neutral excited

TABLE II. Some parameters from Eq. (4.5).

M_{W_1} (GeV)	M_{Z_1} (GeV)	R	$g/\cos\theta_W$	g_{N_1}	g_{N_2}	$g_{N_1}^*$	$g_{N_2}^*$
80	90	0.1	0.731	0.719	−0.156	−0.416	−2.689
80	90	0.5	0.731	0.725	−0.142	−0.132	−1.550
80	90	1.0	0.731	0.726	−0.149	−0.086	−1.267
81	90.5	1.0	0.735	0.725	−0.190	−0.121	−1.140
81.5	91.5	1.0	0.743	0.742	−0.102	0.048	−1.555

TABLE III. The decay width Γ of the Z_1 (in GeV) and, in parentheses, the difference $\Delta\Gamma=\Gamma-\Gamma_{\text{standard}}$ (in MeV).

M_{W_1}, M_{Z_1} (GeV)	$R=0.1$	$R=0.5$	$R=1.0$
80,90	2.58 (90)	2.63 (40)	2.63 (40)
80.5,90.5	2.66 (60)	2.69 (30)	2.69 (30)
81,90.5	2.54 (220)	2.66 (90)	2.68 (70)
81,91	2.73 (40)	2.74 (20)	2.75 (20)
81.5,91	2.62 (180)	2.72 (80)	2.74 (60)
81.5,91.5	2.80 (20)	2.80 (10)	2.81 (10)
82,91.5	2.70 (150)	2.78 (70)	2.80 (60)

fermions N also contributes to the decay widths. However this will not change very much the Z_1 decay widths since the coupling $g^*_{N_1}$ is smaller than g_{N_1} (see Table II). This is not the case with the heavier neutral boson Z_2. If we calculate its decay width without the $N\bar{N}$ channel we get values around 100–300 MeV but if we include this channel they increase to about 3–7 GeV. The reason is that here the coupling with the conventional fermions, which form the majority of allowed channels is weak.

Let us now consider the e^+e^- scattering. For the forward-backward and left-right asymmetries we get

$$A_{FB}=\frac{\int_0^1 \frac{d\sigma}{d\cos\theta}d\cos\theta-\int_{-1}^0 \frac{d\sigma}{d\cos\theta}d\cos\theta}{\int_{-1}^1 \frac{d\sigma}{d\cos\theta}d\cos\theta}$$

$$=\frac{3}{4r}\left[\sum_{a=1,2}[2(g_{L_a}-g_{R_a})^2\rho_a\chi_a+(g_{L_a}^2-g_{R_a}^2)^2\rho_a^2\chi_a]+2(g_{L_1}g_{L_2}-g_{R_1}g_{R_2})^2\rho_1\chi_1\rho_2\chi_2\right]$$

and

$$A_{LR}=\frac{\sigma_L-\sigma_R}{\sigma_L+\sigma_R}=\frac{1}{r}\left[\sum_{a=1,2}[2(g_{L_a}^2-g_{R_a}^2)\rho_a\chi_a+(g_{L_a}^4-g_{R_a}^4)\rho_a^2\chi_a]+2(g_{L_1}^2g_{L_2}^2-g_{R_1}^2g_{R_2}^2)\rho_1\chi_1\rho_2\chi_2\right],$$

where

$$\rho_a=\frac{1}{128\pi\alpha}\frac{s}{s-m_{Z_a}^2},\quad \chi_a=\frac{s-m_{Z_a}^2}{(s-m_{Z_a}^2)^2+m_{Z_a}^2\Gamma_{Z_a}^2},$$

using the notation introduced by Ellis, Gaillard, Girardi, and Sorba (Ref. 7), and

$$g_{L(R)}^a=g_V^a\mp g_A^a,\quad a=1,2\ .$$

Here $\sigma_{L(R)}$ is the cross section for a left-handed (right-handed) polarized electron colliding with an unpolarized positron. The quantity r above is the ratio of the total to the pure QED cross section for the process $e^+e^-\to\mu^+\mu^-$:

$$\sigma_{\text{total}}=\frac{4\pi\alpha^2}{3s}r\ ,$$

where

$$r=1+\sum_{a=1,2}[2(g_{L_a}+g_{R_a})^2\rho_a\chi_a+(g_{L_a}^2+g_{R_a}^2)^2\rho_a^2\chi_a]$$
$$+2(g_{L_1}g_{L_2}+g_{R_1}g_{R_2})^2\rho_1\chi_1\rho_2\chi_2\ .$$

The results for the standard model are recovered if we put $g_{L_2}=g_{R_2}=0$ and use for g_{L_1} and g_{R_1} the appropriate values.

For the energy range below m_{Z_1} mass we get a remarkable coincidence between the predictions of our model and that of the standard model. But for energies above this value, that will be reached at LEP at CERN, the differences get larger and would be easily detected. In Figs. 1 and 2 we show the results for the forward-backward and left-right asymmetries, respectively, with the same values of m_{W_1} and m_{Z_1}, but with $R=0.1$, 0.5, and 1.0. In Figs. 3 and 4 we show the same for $R=1.0$, but different values of m_{W_1} and m_{Z_1}.

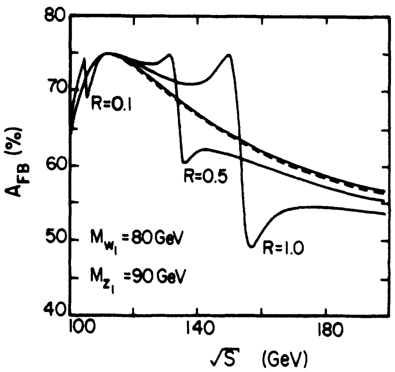

FIG. 1. Forward-backward asymmetry for $M_{W_1}=80$ GeV, $M_{Z_1}=90$ GeV, and $R=0.1$, 0.5, 1.0. Dashed curve is the standard-model prediction.

We also present in Table IV the total cross section for $e^+e^- \to \mu^+\mu^-$ at the Z_2 peak. These values are 3 orders of magnitude greater than the standard-model prediction at this energy.

We have considered the predictions of the present model to the anomalous magnetic moment and the charge radius of both the electron and muon due to the presence of an extra neutral weak boson. Even if one can expect an almost negligible variation with respect to the standard-model values, it is interesting to present these results in order to explicitly show the consistency of the model with the present experimental values[8,9] and theoretical estimates.[10]

The Z_2 contribution to the anomalous magnetic moment comes from the standard triangular diagram shown in Fig. 5. Here the new contribution comes from the vertex (lZ_2l) present in the Lagrangian (4.1) that reads

$$(lZ_2l):\quad -ie\gamma^\mu(\alpha_1+\alpha_2\gamma^5),\quad l=e,\mu\ ,$$

where

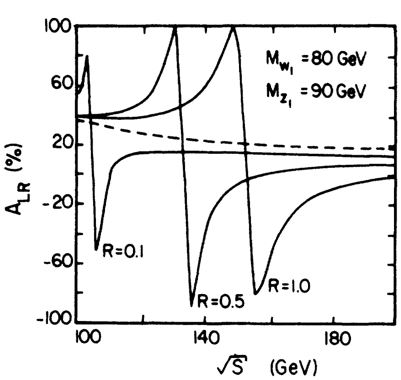

FIG. 2. Left-right asymmetry for $M_{W_1}=80$ GeV, $M_{Z_1}=90$ GeV, and $R=0.1$, 0.5, 1.0. Dashed curve is the standard-model prediction.

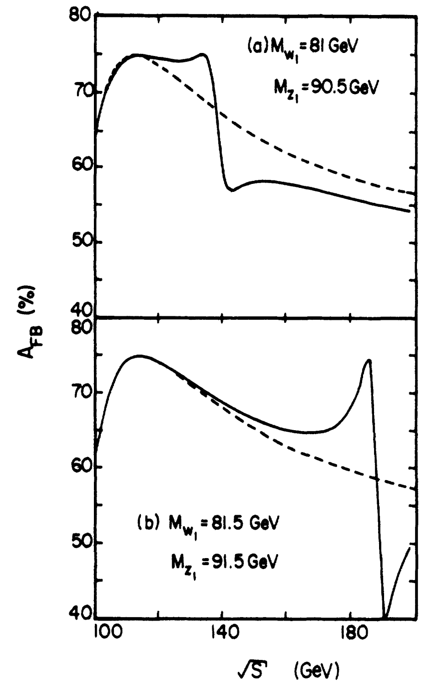

FIG. 3. Forward-backward asymmetry for $R=1.0$ and (a) $M_{W_1}=81$ GeV, $M_{Z_1}=90.5$ GeV, and (b) $M_{W_1}=81.5$ GeV, $M_{Z_1}=91.5$ GeV. Dashed curve is the standard-model prediction.

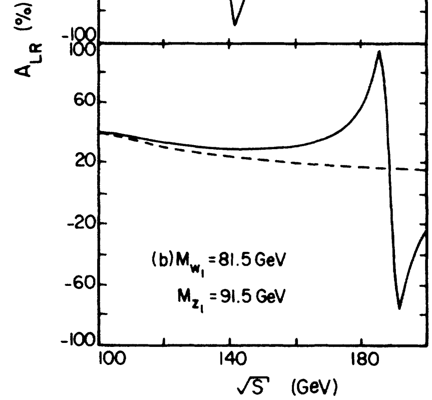

FIG. 4. Left-right asymmetry for $R=1.0$ and (a) $M_{W_1}=81$ GeV, $M_{Z_1}=90.5$ GeV, and (b) $M_{W_1}=81.5$ GeV, $M_{Z_1}=91.5$ GeV. Dashed curve is the standard-model prediction.

TABLE IV. The cross section $\sigma(e^+e^- \Rightarrow \mu^+\mu^-)$ at Z_2 pole.

M_{W_1} (GeV)	M_{Z_1} (GeV)	R	$\sigma(e^+e^- \Rightarrow \mu^+\mu^-)$ (nb)
80	90	0.1	3.39
80	90	0.5	6.57
80	90	1.0	6.28
81	90.5	1.0	6.41
81.5	91.5	1.0	5.03

$$\alpha_1 = -\frac{g_{N_2}}{4}(4s_2^2 - 1)$$

and

$$\alpha_2 = -\frac{g_{N_2}}{4} ;$$

then it is easy to obtain

$$\left[\frac{g-2}{2}\right]_l = \frac{1}{12\pi^2}(\alpha_1^2 - 5\alpha_2^2)\left[\frac{m_l}{m_{Z_2}}\right]^2$$

and

$$\langle r^2 \rangle_l = \frac{1}{4\pi^2}(\alpha_1^2 + \alpha_2^2)\left[\frac{\ln\left[\frac{m_{Z_2}}{m_l}\right]^2 - \frac{7}{9}}{m_{Z_2}^2}\right] ,$$

where $l = e, \mu$.

As was already mentioned, the values for the contributions to $[(g-2)/2]_l$ and to $\langle r^2 \rangle_l$ coming from the new Z_2 boson are safely below the experimental bounds.

VI. NEW-FERMION DECAYS

The most general Yukawa coupling which generates fermion masses is

$$L_Y = -\sum_{A,B} f_{AB}^{(e)} \bar{l}_{AL} \phi_A e_{BR} + f_{AB}^{(\nu)} \bar{l}_{AL} \tilde{\phi}_A \nu_{BR} , \quad (6.1)$$

where $A, B = 1, 2$ with the index 1 for the usual states and

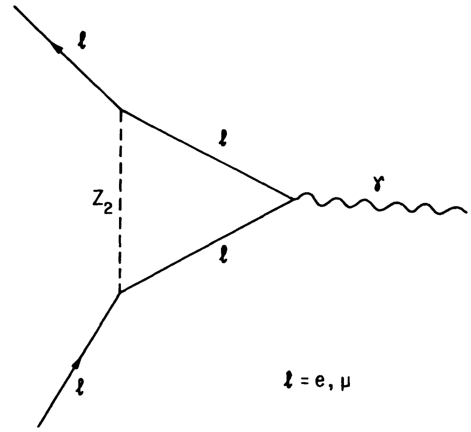

FIG. 5. The triangular diagram which gives the Z_2-boson contribution to the anomalous magnetic moment and the charge radius of both the electron and muon.

2 for the excited states. We have the following current eigenstates:

$$l_{1L} = \begin{bmatrix} \nu_c \\ e_c \end{bmatrix}_L , \quad l_{2L} = \begin{bmatrix} N_c \\ E_c \end{bmatrix}_L ,$$
$$e_{1R} = e_{cR} , \quad e_{2R} = E_{cR} , \quad (6.2)$$
$$\nu_{1R} = \nu_{cR} , \quad \nu_{2R} = N_{cR} .$$

The mass matrices are

$$M_{AB}^e = \frac{v_A}{\sqrt{2}} f_{AB}^{(e)} , \quad M_{AB}^\nu = \frac{v_A}{\sqrt{2}} f_{AB}^{(\nu)} . \quad (6.3)$$

After diagonalization, if we impose CP conservation we have only two independent mixing parameters. We call α and β the mixing angles for the neutral and charged leptons, respectively.

This mixing will change the interactions developed in Sec. IV. For the charged sector we have

$$L_{\text{charged}}^{(M)} = -\frac{g}{2\sqrt{2}}[\bar{\nu}\gamma_\mu(1-\gamma_5)e \cos\alpha \cos\beta + \bar{\nu}\gamma_\mu(1-\gamma_5)E \cos\alpha \sin\beta + \bar{N}\gamma_\mu(1-\gamma_5)e \sin\alpha \cos\beta + \bar{N}\gamma_\mu(1-\gamma_5)E \sin\alpha \sin\beta] W_1^\mu$$
$$- \frac{g''}{2\sqrt{2}}[\bar{\nu}\gamma_\mu(1-\gamma_5)e \sin\alpha \sin\beta - \bar{\nu}\gamma_\mu(1-\gamma_5)E \sin\alpha \cos\beta - \bar{N}\gamma_\mu(1-\gamma_5)e \cos\alpha \sin\beta + \bar{N}\gamma_\mu(1-\gamma_5)E \cos\alpha \cos\beta] W_2^\mu + \text{H.c.} \quad (6.4)$$

and for the neutral interactions

$$L_{\text{neutral}}^{(M)} = L_{NC} + [\tfrac{1}{4}\bar{\nu}\gamma_\mu(1-\gamma^5)N \sin\alpha \cos\alpha - \tfrac{1}{4}\bar{e}\gamma_\mu(1-\gamma_5)E \sin\beta \cos\beta][(g_{N_1} - g_{N_1}^*)Z_1^\mu + (g_{N_2} - g_{N_2}^*)Z_2^\mu] + O(\sin^2\alpha, \beta) , \quad (6.5)$$

TABLE V. A comparison between branching ratios for excited leptons and a possible fourth-generation doublet. We consider the case $M_E \gg M_N$ and $M_E, M_N \gg m_q, m_l$, except for the top quark.

E decay	Excited lepton	Fourth generation	N decay	
$e\nu_l\bar{\nu}_l$	0.11	0.11	$\nu_e ee$	0.043
$\nu_e\mu\bar{\nu}_\mu$	0.03	0.11	$e\mu\nu_\mu$	0.004
$\nu_e\tau\bar{\nu}_\tau$	0.03	0.11	$e\tau\nu_\tau$	0.004
ν_e hadrons	0.15	0.67	$\nu_e\mu\mu$	0.041
e hadrons	0.50	0	$\nu_e\tau\tau$	0.041
$e\,ee$	0.03	0	e hadrons	0.024
$e\,\mu\mu$	0.03	0	ν hadrons	0.612
$e\,\tau\tau$	0.03	0	$3\nu_l$	0.231
$e\nu_e N$	0.05	0	$\nu\gamma$	1.2×10^{-4}
eNN	0.04	0		
$e\gamma$	1.2×10^{-4}			

where $L_{\rm NC}$ is given by Eq. (4.4).

There are important remarks concerning these new interactions. From Eq. (6.4) we have the following expression for the Fermi constant:

$$G_F=\frac{1}{4\sqrt{2}}\left[\frac{g^2}{m_{W_1}^2}\cos^2\alpha\cos^2\beta+\frac{g''^2}{m_{W_2}^2}\sin^2\alpha\sin^2\beta\right], \tag{6.6}$$

which is to be compared with the standard-model result $G_F=\pi\alpha/\sqrt{2}\sin^2\theta_W m_{W_1}^2$. Since we have independent measurements for the parameters G_F, α, $\sin^2\theta_W$, $m_{W_1}^2$ we can deduce a bound for the mixing angles in Eq. (6.6). If we consider the case $\sin\alpha \simeq \sin\beta$ this upper bound is 10^{-1}. This justifies the fact that we have neglected some terms in Eq. (6.5).

The other important point is that our excited fermions have the same flavor as the low-lying fermions. This means that we have no lepton-number violation and no flavor-changing neutral currents. The mixing we introduce in this section is applied between normal and excited fermions, not between different families.

The extension to other families is trivial. We consider in Table V an example of a possible scenario for the first new excited fermionic doublet. We have taken the electronic family as the possible low-mass excited case.

In conclusion, excited-lepton decays are suppressed relative to a possible fourth-generation lepton from charged-current channels. But there is an important enhancement from new neutral-current channels. We have a very clear difference between both cases via multilepton decays and a relatively high branching ratio for radiative decays.

VII. CONCLUSIONS

A second neutral boson could indicate a structure for the presently known matter. The model presented here shows that there is an experimental possibility for these effects to be detected at SLAC and CERN. If this new neutral current is accompanied with new fermionic decays of the type described in our model then we could suggest that a new level of structure is attained.

There is some similarity between our Z_2 and the predictions of superstring theories,[1] which will be discussed elsewhere.

[1]D. London, G. Belanger, and J. N. Ng, Phys. Rev. Lett. **58**, 6 (1987).
[2]J. Konopinski and H. Mahmoud, Phys. Rev. **99**, 1065 (1953).
[3]J. Leite Lopes, D. Spehler, and J. A. Martins Simões, Phys. Lett. **94B**, 367 (1980); Phys. Rev. D **23**, 797 (1981); **25**, 1854 (1982).
[4]M. Barroso, M. E. Magalhães, J. A. Martins Simões, N. Fleury, and J. Leite Lopes, Phys. Rev. D **34**, 1451 (1986); J. H. Lopes and J. A. Martins Simões, *ibid.* **35** 3428 (1987).
[5]J. A. Martins Simões, Nuovo Cimento **A89**, 235 (1985).
[6]B. Adeva *et al.*, Phys. Rev. Lett. **35**, 665 (1985).
[7]J. Ellis, M. K. Gaillard, G. Girardi, and E. P. Sorba, Annu. Rev. Nucl. Part. Sci. **32**, 443 (1982).
[8]D. P. Barber *et al.*, Phys. Rev. Lett. **43**, 1915 (1979).
[9]T. Kinoshita, *High Energy Spin Physics,* proceedings of the Fifth High Energy Spin Symposium, edited by G. M. Bunce (AIP Conf. Proc. No. 95) (AIP, New York, 1982).
[10]F. M. Renard, Phys. Lett. **116B**, 264 (1982).