Current Mixing and Properties of Vector Bosons in Preon Model with Preonic Charge

Hirofumi SENJU
Nagoya Municipal Women's College, Nagoya 464

(Received April 11, 1994)

In the preon model with preonic charge, new vector boson which can mix with the photon exists. On the basis of the current mixing model, its properties are studied. Cross sections of $e^+e^-$ to $U$ boson pair and of $e$-nucleus scattering are given. It will be also shown that, if the new vector boson is sufficiently heavy (say $\sim 500$ GeV), the success of the standard model at the LEP level is naturally reproduced. Small deviations from the standard model are predicted in a definite way, which seems to be rather supported by the data. Our model leads to lighter $W$ boson than the standard model does and to positive $e_\beta$ parameter in contrast to the standard model.

§ 1. Introduction

It is a common belief that the standard model (SM) despite all its success cannot be the ultimate theory since it involves a large number of arbitrary parameters which are not theoretically determined. More important and closely related to this problem is that, in the SM, matter and interactions are not fully unified and there is no fundamental understanding of origins of $CP$ violations and of the family structure and family mixings. In addition, if cold dark matter exists as strongly suggested by the COBE experiment and it is a stable weakly-interacting-massive particle (WIMP), it implies the existence of new particles which do not exist in the SM.

Several new models beyond the SM have been proposed. One of them is the supersymmetric extension of the SM, in which the fundamental concepts of the SM are not altered, such as point-like nature of leptons and quarks, weak bosons as fundamental gauge bosons and the spontaneous breakdown of gauge theories through the Higgs mechanism. This idea has a virtue that the success of the SM is easily maintained. In addition, a stable WIMP is predicted, if new conservation law is imposed (although rather ad-hoc). However, in this way, it seems hard to make an essential progress in understanding an origin of $CP$ violations and of the family structure and family mixings. Another way is, along the line of the atomic view, to consider that leptons, quarks and weak bosons are composites of more fundamental matter. We call such a model full preon model. Although it is possible to take that only leptons and quarks are composites and $W$-bosons are elementary (partial preon model), we believe that, without a compositeness of $W$, it will be impossible to understand essentially $CP$ violations because the invariance under gauge transformation is intimately related to the $CP$ invariance in an ordinary (i.e., non-dual) gauge theory.

Recently the author has developed a full preon model by introducing preons with charge $e/2$ as well as the preonic charge which is identified with the magnetic charge. The model has some interesting features, such as the explanation of...
H. Senju

charge quantisation and the color-charge relation\textsuperscript{2) and understanding of quark masses and CKM matrices\textsuperscript{5-6} and of CP violations\textsuperscript{5} in weak interactions. In the model a stable WIMP exists automatically and the proton becomes stable in spite of the existence of baryon number non-conserving interactions.\textsuperscript{4) This model predicts new vector bosons,\textsuperscript{2,3} some of which are neutral and mix with the photon. Properties of neutral vector bosons have been left undetermined. An improvement in this point is essential to the development of our model, since they play one of the main roles in many important processes such as \(U\) boson productions in \(e^+e^-\) collisions and \(l_s\)-nucleus scattering (\(l_s\) is the cold dark matter particle in our model). In this paper we study their properties based on the so-called current mixing model. To a model in which neutral vector bosons exist besides the \(Z\) boson, one of the severest problems is to show how the success of the SM at low energy is not affected. In this paper we also deal with this problem. It will be shown that, although our model predicts some deviations from the SM, these deviations become very small at low energy in a natural way so that the precise data\textsuperscript{7} on the \(Z\) boson physics at LEP are naturally explained and also shown that predicted deviations seem to be rather supported by the data. In the next section, our model is briefly reviewed to the extent of the purpose of this paper. In § 3, properties of new neutral vector bosons are studied based on the current mixing model. In § 4, cross sections of \(U\) boson pair production in \(e^+e^-\) collisions and of \(l_s\)-nucleus scattering are given. In § 5, effects on the \(Z\) boson decays are discussed. The final section is devoted to some remarks.

\section*{§ 2. Brief review of our model\textsuperscript{2-6}}}

The model consists of colorless preons \(w_1, w_2, c_0, h\) and colored preon \(c_i (i=1 \sim 3)\). The first three carry charge \(e/2, -e/2\) and \(-e/2\), respectively, and \(h\) is neutral. The charge of \(c_i\) is \(e/6\). All preons carry preonic charges, which are identified with a magnetic charge, and a color magnetic charge which is a source of the color magnetic field. The Dirac quantisation condition is satisfied by the compensation of the phase acquired by the wave function due to the color vector potential for the phase due to the electromagnetic potential. The interactions among preons are super-strong even at a short distance. Hence, a formation of bound states with a mass much less than the inverse of its radius is expected, which implies that the typical scale to preon dynamics (\(\equiv \Lambda_p\)) \~ the inverse of the radius \(\gg\) the weak boson mass. \(\Lambda_p\) is assumed to be about 1000 \text{TeV}, which is required by the success of QED (e.g., the experiment on anomalous magnetic moment of electron) and the rare \(K\) decays (e.g., the non-observation of the decay \(K_L \to \mu e\)) and suggested by quark masses (the charm quark mass \(~10^{-6}\Lambda_p\) in the ortho-para mixing model\textsuperscript{5-6}). The dominant interaction among preons is that due to a preonic charge. Since preons \(w\) and \(c\) carry the same preonic charge, an approximate symmetry, \(SU(6)_{\text{we}} (=G_0)\), holds, where preons \(w\) and \(c\) belong to 6 under \(G_0\). Bound states of preons (BSP) containing preons \(w\) and/or \(c\) are \([p, p_i]h\) (15 under \(G_0\)), \((p, p_i)h\) (21 under \(G_0\)) and \((p, p_i)\) (35 and 1 under \(G_0\)), where \(p_i\) stands for preons \(w\) and \(c\). The first two are fermions and the last bosons. The particles in the 15 (21) are called orthofermions (parafermions). Parafermions are assumed to be heavier than orthofermions by an amount of the order of the mass scale
Current Mixing and Properties of Vector Bosons

This is supported by quark masses.\textsuperscript{5,6} Leptons (quarks) are \([w_0]^h ([w^c]^h)\). Since preons \(w\) and \(c\) are assumed to have different electric charges and colors, \(G_0\) is broken. BSP's are classified into two classes, i.e., those having no decay mode into leptons and quarks alone (first class: new fermions \([ww]^h\) and \([cc]^h\)) and the others (second class: leptons, quarks and bosons \(W(=\{ww\}), S(=\{cc\}), G_0(=\text{color octet } (c\bar{c}))\) and two colorless neutral bosons \(D_1\) and \(D_2\). At the tree level, second class bosons alone contribute to processes involving only leptons and quarks.

Among preons, \(w_2\) and \(c_0\) have special properties. They have the same electric charge and color in addition to the same preonic charge. This implies that \(SU(2)_{w_2c_0}\) symmetry\textsuperscript{5} (we call this \(K\) symmetry) holds more strictly in the preon dynamics than \(G_0\) which relies on the equality of the preonic charge alone. \(K\) symmetry is expected to be broken due to a mass difference between \(w_2\) and \(c_0\). It can be shown that the breaking scale of the \(K\) symmetry is \(O(100\text{ GeV})\).\textsuperscript{9} Since, compared with \(G_0\), the \(K\) symmetry and weak isospin are good symmetries, a breaking series \(SU(6)_{w^c}(=G_0) \supset SU(3)_{w_1w_2c_0} \times SU(3)_{c_0}(=G) \supset SU(2)_{w} \times U(1)_{c_0} \times SU(3)_{c_0}\) is expected to reflect some aspects of the real world, where the weak isospin is assumed to be a better symmetry than the \(K\) symmetry. In this case, the boson multiplet is decomposed as follows:

\[
35 = (8, 1) + (3, 3^*) + (3^*, 3) + (1, 8) + (1, 1),
\]

where the former (latter) in the parentheses is the representation under \(SU(3)_{w_1w_2c_0}(SU(3)_{c_0})\). \((8, 1)\) contains \(W\)-bosons, \(U^+ (=w_1\bar{c}_0), U^- (=\bar{w}_1c_0), U^0 (=w_2\bar{c}_0)\), and \(D_1 = (w_1\bar{w}_1 + w_2\bar{w}_2 - 2c_0\bar{c}_0)/\sqrt{6}\), \((3, 3^*) + (3^*, 3)\) does \(Y\) and \(S\), \((1, 8)\) does \(G_8\) and \((1, 1)\) does \(D_2 = (w_1\bar{w}_1 + w_2\bar{w}_2 + c_0\bar{c}_0 - \Sigma c_i\bar{c}_i)/\sqrt{6}\). Considering the data on rare \(K_L\) decays, we assume that only members of \((8, 1)\) are relatively light and other bosons have masses of \(O(A_F)\).

Bound states of preons are constructed by a magnetic force. When bound states are formed by gauge interactions, it seems to occur rather naturally that they behave as if they are a string-like object as suggested by the structure of hadrons. We make the conjecture that BSP's behave as a string at a long distance due to the formation of a magnetic flux tube through the Meissner effect. BSP's lie on a linear Regge trajectory with Regge slope \(a'\sim A_F^{-2}\) and the scattering of BSP's via vector boson exchange is described by a Veneziano type amplitude. In this case, through the well-known mechanism,\textsuperscript{8} a vector boson with a mass much less than \(A_F\) behaves as a gauge boson at low energy. It is speculated that \(W\)-bosons and also other members of \((8, 1)\) are such effective gauge bosons working only at energy sufficiently less than \(A_F\). At energy of \(O(M_Z)\), corrections to the gauge theory of \(W(Z)\) are expected to be of the order of \((M_Z/A_F)^2 \sim 10^{-8}\), because a string amplitude \((F)\) can be expanded at low energy in powers of \(a'\), \(F = F_0 + a'F_1 + \cdots\) and the second term represents a dominant non-gauge-theory effect. The universality of coupling constants is expected to hold with excellent accuracy at low energy.

At the preon level, the electromagnetic current due to the electric charge is

\[
\sim \bar{w}_1w_1/2 - \bar{w}_2w_2/2 - \bar{c}_0c_0/2 + (\bar{c}_1c_1 + \bar{c}_2c_2 + \bar{c}_3c_3)/2 + \bar{c}_0c_0/2 + (\bar{c}_1c_1 + \bar{c}_2c_2 + \bar{c}_3c_3)/6 \sim W_2/\sqrt{2} + D_1/\sqrt{6} - D_2/\sqrt{6},
\]

where \(W_2 = (\bar{w}_1w_1 - \bar{w}_2w_2)/\sqrt{2}\). Consequently, the \(\gamma - W_2\) and \(\gamma - D_1\) transitions occur (we
neglect $\gamma - D_2$ transition because $D_2$ does not belong to $(8, 1)$ and is assumed to have a mass of $O(A_p)$. Thus the weak isospin is broken electromagnetically. Since $\omega_1$ and $\omega_2$ are different particles, there may exist non-electromagnetic breaking of the weak isospin which gives rise to a direct $W_3 - D_1$ mixing. However, the mass differences between members of the weak isospin multiplets are rather small, 100 GeV or smaller. This implies the weak isospin symmetry holds up to the extent of $\sim 100$ GeV/$A_p \sim 10^{-4}$. Hence we neglect a direct $W_3 - D_1$ mixing in this paper. Since the photon and, at low energy $W$ and $D_1$ bosons are the gauge bosons, it is adequate to deal with mixings based on the current mixing.\(^9\) The current mixing in the case of many vector bosons was studied by de Groot and Schildknecht\(^10\) from a different motivation. In this paper, we study $\gamma$, $W$ and $D_1$ bosons following their formulation.\(^10\)

§ 3. Current mixing and properties of $D_1$

Mixing with the photon is introduced as follows:

$$L_{\text{mix}} = -1/2(\lambda_1 \tilde{F}_{\mu\nu} W_{(0)3}^{\mu\nu} + \lambda_2 \tilde{F}_{\mu\nu} D_{(0)1}^{\mu\nu}) \; ,$$

(1)

where $\tilde{F}$, $W_{(0)3}$ and $D_{(0)1}$ are the unmixed photon, unmixed $W_3$ and unmixed $D_1$, respectively and are expressed as

$$\tilde{F}_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu \; ,$$

$$W_{(0)3}^{\mu\nu} = \partial^\mu W_{(0)3}^{\nu} - \partial^\nu W_{(0)3}^{\mu}$$

and

$$D_{(0)1}^{\mu\nu} = \partial^\mu D_{(0)1}^{\nu} - \partial^\nu D_{(0)1}^{\mu} \; .$$

(2)

The real parameters $\lambda_i$ are mixing parameters and we have from the structure of the electromagnetic current at the preon level,

$$\lambda_3 = \lambda_1 / \sqrt{3} \; .$$

(3)

The unmixed photon is assumed to be massless and to couple to the electromagnetic current $j^{\text{em}}$ with a strength determined by the electric charge $e$. $W_{(0)3}$ and $D_{(0)1}$ are assumed to couple to the third and the eigth current of $SU(3)$ octet currents, respectively. The neutral current four fermion interaction then takes the form,

$$2H_{\text{NC}} = \sum_{i,j=0}^{2} f_{ij}^{\nu\nu}(m^2 - \Lambda q^2)^{-1} j_i j_{\nu} \; ,$$

(4)

where the currents are given for fermions by

$$j_0 = j_0^{\text{em}} = \bar{\psi} \gamma_\nu Q \psi \; ,$$

$$j_1 = j_1^{(3)} = \bar{\psi} \gamma_\mu (\lambda_3 / 2) \psi_L$$

and

$$j_2 = j_2^{(8)} = \bar{\psi} \gamma_\mu (\sqrt{3} \lambda_3 / 2) \psi_L \; ,$$

(5)

$$j_\nu = j_\nu^{(8)} = \bar{\psi} \gamma_\nu (\lambda_3 / 2) \psi_L \; ,$$

$$j_\mu = j_\mu^{(8)} = \bar{\psi} \gamma_\mu (\lambda_3 / 2) \psi_L \; .$$

(6)
where \( Q \) is the electric charge operator \( (f_0 = e) \), \( \lambda_s \) and \( \lambda_8 \) are the usual Gell-Mann matrices and \( \phi_L \) is the left-handed field \( (\phi = [(1 - \gamma_5) / 2] \phi) \). (A model with \( j^\alpha \) and \( j^8 \) was discussed previously in some detail.\(^{11}\)) With mass zero for the unmixed photon, the mass matrix in Eq. (4) is given by

\[
(m_u^2)_{ij} = m_i^2 \delta_{ij},
\]

where \( m_0 = 0, m_1 = \) the charged weak boson mass \( (= M_w) \) and \( m_2 \) is the mass of unmixed \( D_i \). The current mixing matrix \( A \) reads

\[
A_{ij} = \delta_{ij} + \lambda_{ie} \delta_{io} + \lambda_{ij} \delta_{oJ}
\]

with \( \delta_{ij} = 0 \). The mixing parameters are restricted by

\[
\text{Det}(A) = 1 - \lambda_i^2 - \lambda_e^2 > 0 \quad \text{and so } \lambda_i^2 < 3/4.
\]

Defining \( J_\mu = (j_{\mu}^{em}, j_{\nu}^{(3)}, j_{\nu}^{(8)}) \), \( (V^2)_{ij} = m_i^2 f_i^2 \delta_{ij} \) and \( R_{ij} = f_i f_i^{-1} \delta_{ij} + \lambda_{ij} f_0^{-1} f_j^{-1} \delta_{io} \), we obtain

\[
2H_{ij} = J_\mu (V^2 - q^2 R)^{-1} J_\mu.
\]

In terms of the physical masses of neutral vector bosons \( M_k (k = 0, 1, 2) \), \((V^2 - q^2 R)^{-1}\) may be written as

\[
(V^2 - q^2 R)^{-1} = \sum_k h_i^k h_j^k / (M_k^2 - q^2),
\]

where \( M_0, M_1 \) and \( M_2 \) are the masses of photon, of the \( Z \) boson and of physical (mixed) \( D_i \), respectively (hereafter we denote \( M_1(M_2) \) as \( M_L(M_D) \)) and \( h_i^k \) denotes the coupling of the \( k \)th boson to the \( i \)th current. Hence we obtain the following relation.

\[
\delta_{ij} = \sum_k h_i^k m_i^2 f_i^{-2} h_i^k - q^2 f_0 f_i^{-1} m_i^2 \delta_{io} \sum_k \lambda_{ik} f_0^{-1} h_i^k + \lambda_{ij} f_0^{-1} f_i^{-1} h_i^k] / (M_k^2 - q^2).
\]

Equation (11) implies that \( M_0 = 0 \) and \( h_0^k = e \delta_{oJ} \). Assuming \( D_1 \) is heavy, we solve Eq. (11) for other quantities to the extent of \( O(m_1^2 / m_2^2) \) (and so \( O(M_L^2 / M_D^2) \)). We have for masses,

\[
(m_2^2 + \lambda_8^2 M_2^2) (m_1^2 - M_Z^2) = - m_2^2 M_2^2 \lambda_1^2
\]

and

\[
[M_D^2 (1 - \lambda_1^2) - m_1^2 \lambda_1^2] (M_D^2 - m_2^2) = M_D^4 \lambda_8^2.
\]

We obtain for \( h_1 \),

\[
h_1 = \frac{f_i}{\sqrt{1 - \lambda_1^2}} \left[ 1 - a \frac{\lambda_1^2 \lambda_8^2}{(1 - \lambda_1^2)} \right],
\]

\[
h_0 = - \frac{e \lambda_1}{\sqrt{1 - \lambda_1^2}} \left[ 1 - a \frac{\lambda_8^2}{(1 - \lambda_1^2)} \right],
\]

and
where \( f_2 = f_1 / \sqrt{3} \) due to the properties of \( W_5 \) and \( D_1 \) under \( SU(3)_{W_1 W_2 c_0} \) and \( a = M_2^2 / m_2^2 \)

\[
= (M_2^2 / M_0^2) [(1 - \lambda_1^2) / (1 - \lambda_1^2 - \lambda_2^2)].
\]

\( h_i^2 \) are as follows:

\[
h_i^2 = \frac{f_i \sqrt{1 - \lambda_i^2}}{\sqrt{1 - \lambda_i^2 - \lambda_2^2}},
\]

\[
h_0^2 = \frac{-e \lambda_2}{\sqrt{(1 - \lambda_1^2)(1 - \lambda_1^2 - \lambda_2^2)}} \left[ 1 + b \left( \frac{\lambda_1^2}{(1 - \lambda_1^2)} \right) \right]
\]

and

\[
h_1^2 = \frac{f_1 \lambda_1 \lambda_2}{\sqrt{(1 - \lambda_1^2)(1 - \lambda_1^2 - \lambda_2^2)}} \left[ 1 + b + b \left( \frac{\lambda_1^2}{1 - \lambda_1^2} \right) \right],
\]

where \( b = m_1^2 / M_2^2 = M_2^2 (1 - \lambda_1^2) / M_0^2 \).

Here we assume the \( W \) dominance of the weak isovector photon\(^{12} \) as the \( \rho^0 \) dominance in QCD, which implies

\[
\lambda_1 f_1 = e.
\]

Since \( \lambda_1^2 < 1 \), we can express \( \lambda_1 \) as \( \sin \theta_w \). Thus \( f_1 = e / \sin \theta_w \), the \( h_i^2 \)'s are expressed in terms of \( e \) and \( \theta_w \) as follows:

\[
h_0^0 = e \delta \omega,
\]

\[
h_1^1 = -\frac{e}{s_w c_w} (1 - a t_w^2 s_w^2 / 3),
\]

\[
h_0^1 = -e t_w (1 - a t_w^2 / 3),
\]

\[
h_2^1 = -e a t_w / 3,
\]

\[
h_2^2 = \frac{e c_w}{s_w \sqrt{3 - 4 s_w^2}},
\]

\[
h_3^2 = -\frac{e t_w}{\sqrt{3 - 4 s_w^2}} (1 + b t_w^2)
\]

and

\[
h_1^2 = \frac{e t_w}{\sqrt{3 - 4 s_w^2}} (1 + b + b t_w^2),
\]

where \( a = (M_2^2 / M_0^2) [3 c_w^2 / (3 - 4 s_w^2)] \), \( b = c_w^2 (M_2^2 / M_0^2) \) and \( s_w, c_w \) and \( t_w = \sin \theta_w, \cos \theta_w \) and \( \tan \theta_w \), respectively.

Equations (12) and (16) show that, for sufficiently large \( M_0 \), \( W(Z) \) physics is the same as that in the SM, namely the existence of \( D_1 \) does not bring about a trouble, because, in the approximation of \( a = 0 \), we obtain
Current Mixing and Properties of Vector Bosons

\[ h_1^1 = e/(s_w c_w), \]
\[ h_0^1 = -e s_w/c_w, \]
\[ h_2^1 = 0 \]

and

\[ M_w = M_{Zc}, \] (17)

where \( s_w = \sin \theta_w \) and \( c_w = \cos \theta_w \). For \( b = 0 \), we have that \( m_2^2 = M_b^2 (1 - t_w^2/3) \), where \( t_w = s_w/c_w \).

Equation (16) tells us that the fermion-fermion-\( Z \) vertices are as follows:

\[ llZ: \left[ -e/(4s_wc_w) \right] \left[ 1 - atw^2/3 \right] \left[ -\gamma_\mu \gamma_5 + (1 - 4s_w^2) \gamma_\mu \right], \]
\[ \nu \nu Z: \left[ e/(4s_wc_w) \right] [1 + atw^2 (c_w^2 - s_w^2)/3] \gamma_\mu (1 - \gamma_5), \]
\[ ddZ: \left[ -e/(4s_wc_w) \right] \left[ -\gamma_\mu \gamma_5 [1 + atw^2 (c_w^2 - s_w^2)/3] 
+ \gamma_\mu [1 - 4s_w^2/3 + a(7t_w^2/9 - 13t_w^2 s_w^2/18) - btw^2 s_w^2/6] \right], \] (18)

and

\[ uuZ: \left[ e/(4s_wc_w) \right] [1 - atw^2/3] \left[ -\gamma_\mu \gamma_5 + \gamma_\mu (1 - 8s_w^2/3) \right], \] (18)

where \( l \) denotes a charged lepton, \( \nu \) does a neutrino, \( d \) does a down-type quark and \( u \) does an up-type quark.

For vector boson \( B \), the amplitude of \( B_a - \bar{B}_b - V_\mu \) \( (M_{BBV}) \) is expressed as

\[ M_{BBV} = g_{BBV} \{ g_{aB} (p_1 - p_2) + p_2 g_{B\mu} - p_1 g_{a\mu} + g_{aB} (p_1 + p_2) - g_{B\mu} (p_1 + p_2) \}, \] (19)

where \( p_a \) is a four momentum of \( B \), \( p_1 \) that of \( \bar{B} \) and \( (p_1 + p_2) \) that of \( V \). For \( U^+ - U^- - V \) and \( U^0 - \bar{U}^0 - V \), we obtain, since \( <U^+|Q|U^+> = 1, <U^0|Q|U^0> = 0, <U^+|\lambda_3/2|U^+> = 1/2, <U^0|\lambda_3/2|U^0> = -1/2, <W^+|\lambda_3/2|W^+> = 1, <U^+|\sqrt{3}\lambda_3/2|U^+> = <U^0|\sqrt{3}\lambda_3/2|U^0> = 3/2 \) and \( <W^+|\sqrt{3}\lambda_3/2|W^+> = <Z|\sqrt{3}\lambda_3/2|Z> = 0, \)

\[ g_{U^+U^-} = e(c_w^2 - s_w^2)/(2s_w c_w), \]
\[ g_{U^0U^0} = -e/(2s_w c_w), \]
\[ g_{U^+U^-} = e\sqrt{3 - 4s_w^2}/(2s_w c_w), \]
\[ g_{W^+W^-} = e c_w/s_w, \]
\[ g_{W^+W^-} = g_{Z\gamma} = 0 \]

and

\[ g_{U^+U^-} = g_{W^+W^-} = e, \] (20)

where the approximation of \( a = b = 0 \) is taken.
§ 4. Physics related to $D_1$

The couplings of $eeD_1$ and $qqD_1$ are in the approximation of $a = b = 0$,

$eeD_1: \frac{e}{4swc_w\sqrt{3 - 4sw^2}} \{\gamma_\mu \gamma_5 - (1 - 4sw^2)\gamma_\mu\},$

$ddD_1: \frac{e}{4swc_w\sqrt{3 - 4sw^2}} \{-(cw^2 - sw^2)\gamma_\mu \gamma_5 + (cw^2 + sw^2/3)\gamma_\mu\}$

and

$uuD_1: \frac{e}{4swc_w\sqrt{3 - 4sw^2}} \{-\gamma_\mu\gamma_5 + (1 - 8sw^2/3)\gamma_\mu\}. \quad (21)$

1. $e^+e^- \to U^0\bar{U}^0$

The process $e^+e^- \to U^0\bar{U}^0$ occurs via $s$ channel $Z$ and $D_1$ exchanges as shown in Fig. 1. Hence, the cross section is for $s = M_D^2$, $M_Z^2$,

$$
\sigma(e^+e^- \to U^0\bar{U}^0) = \frac{\pi \alpha^2(sw^4 - sw^2/2 + 1/8)/(32sw^4cw^4)}{\{\beta^3(s - M_0^2 - M_Z^2)^2/[s - M_0^2(s - M_Z^2)^2]\}} \times \frac{16(s/M_0^2) + 2/3[(s/M_0^2)^2 - 4(s/M_0^2) + 12]}{. \quad (22)
$$

Fig. 1. Diagrams for (a) $e^+e^- \to U^0\bar{U}^0$ and (b) $e^-e^- \to U^+U^-$.  

where $M_0$ is the mass of $U^0$ and $\beta=\sqrt{1-4M_0^2/s}$. Equation (22) has a good asymptotic behavior required by the unitarity. The good asymptotic behavior is not affected even if effects of non-zero $a$ and $b$ are taken into account. The unitarity bound is satisfied if $M_0$ is less than about 40$M_0$, which is expected to be about 4 TeV. 

$(2) \ e^+ e^- \rightarrow U^+ U^-$

The process $e^+ e^- \rightarrow U^+ U^-$ occurs through the exchanges of photon, $Z$-boson and $D_1$-boson in the s-channel and of $\ell_s$ in the t-channel (see Fig. 1). The coupling constant of the vertex $U^+ - \ell_s - e^-$ is that of $W^+ - \nu - e^-$ multiplied by $-1$. Hence, the cross section is for $s=M_0^2$, $M_2^2$, neglecting the mass of $\ell_s$,

$$\sigma(e^+ e^- \rightarrow U^+ U^-) = \frac{\pi a^2}{8s w^4} \left( \frac{\beta}{s} \right) \left( \sigma_1 + s w^4 \sigma_2 + y^2 (s w^4 - s w^2/2 + 1/8) \right) \times \left[ \frac{1}{s} - \frac{1}{M_0^2} \right] \sigma_3 + 2s w^2 \left( 1 - y \right)^2 (s w^4 - s w^2/2 + 1/8) \times \left[ \frac{1}{s} - \frac{1}{M_0^2} \right] \sigma_4 + 4 \left( 1 - 2M_0^2/s \right) L/\beta - 1,$$

where $y = (c w^2 - s w^2)/(2 c w^2)$, $M_2(M_0)$ is the mass of $Z(D_1)$ and $\sigma, \sigma_2$ and $\sigma_3$ are

$$\sigma_1 = 2(s/M_2^2) + (s/M_2^2)^2 \beta^2/12 + 4[1 - 2M_0^2/s] L/\beta - 1,$$
$$\sigma_2 = 16(s/M_2^2) \beta^2 + 2 \beta^2 [(s/M_2^2)^2 - 4(s/M_2^2) + 12]/3,$$

and

$$\sigma_3 = 16 - 32(M_0^2/s) L/\beta + 8 \beta^2 (s/M_2^2) + \beta^2 (s/M_2^2)^2 (1 - 2M_0^2/s) / 3 + 4(1 - 2M_0^2/s)$$
$$- 16(M_0^2/s)^2 L/\beta,$$

where $M$ is the mass of $U^+$, $s$ the square of the center-of-mass energy, $\beta=\sqrt{1-4M^2/s}$ and $L=\ln((1+\beta)/(1-\beta))$. In Eq. (24) we use the same notation as Alles, et al.\textsuperscript{13} Due to the cancellation, Eq. (23) has the same asymptotic behavior as $\sigma(e^+ e^- \rightarrow W^+ W^-)$ as required by the $K$ symmetry, namely $[\pi a^2/(2s w^4)] \ln(s/M_0^2)/s$. If $U^+$ is lighter than 100 GeV, it can be produced at LEP 200. If this is the case, Eq. (23) will be tested. Equation (23) is plotted for $M_0=500$ GeV in Fig. 2.

![Fig. 2. Plot of $\sigma(e^+ e^- \rightarrow U^+ U^-)$ versus $\sqrt{s}$ for $M_0=500$ GeV. $s w^2=0.23$ is assumed.](https://academic.oup.com/jphysb/article-abstract/82/361/167917/167917)
In our model, \( I_s = \sum w_i w_5 \) is a stable weakly-interacting-massive-particle and behaves as cold dark matter in the Universe. In principle, it can be detected on the earth through \( I_s \)-nucleus scattering. This scattering occurs via exchanges of bosons \( Y = (w_c) \) and \( D_1 \). Since the \( Y \)'s are super-heavy, only \( t \)-channel \( D_1 \) exchange governs the cross section. Because \( I_s \) is electrically neutral, weak isospin singlet and \( \langle I_s | \sqrt{3} A_4/2 | I_s \rangle = 1 \), the \( I_sI_sD_1 \) coupling is \( h^2 \gamma_8 (1 - \gamma_8)/2 \), namely,

\[
I_sI_sD_1: \frac{e c_w}{2 s_w \sqrt{3 - 4 s_w^2}} \gamma_8 (1 - \gamma_8).
\]

The cross section of coherent \( I_s \)-nucleus\((=A) \) elastic scattering at a low momentum limit is as follows, assuming that the mass number of the nucleus is large and its spin is not high:

\[
\sigma(I_sA \rightarrow I_sA) = \left( G^2/\pi \right) [M_A m/(M_A + m)]^2,
\]

where \( G = \{ \pi a/[2 s_w^2 (3 - 4 s_w^2) M_B^2] \} \left( 1 - 8 s_w^2/3 \right) (2Z + N) + (c_w^2 + s_w^2/3)(Z + 2 N) \), where \( Z(N) \) is the number of proton (neutron) in the nucleus, \( M_A \) the mass of the nucleus and \( m \) the mass of \( I_s \). If \( M_B \) is 500 GeV and \( m \) is 5 GeV, the cross section is \( \sim 4 \times 10^{-37} \) cm\(^2\) for \( \text{Ge} \) nucleus. A detection of \( I_s \) as the CDM particle may be possible through \( I_s \)-nucleus scattering. According to the experiments up to now, the upper limit of \( \sigma(I_s \text{Ge} \rightarrow I_s \text{Ge}) \sim 10^{-34} \) cm\(^2\).

§ 5. Qualitative features of effects on \( Z \) decays

The LEP data on \( Z \) decays can be described well by the SM. However, there are serious problems. The experimental fact of the heavy top implies the existence of large radiative corrections proportional to the square of the top mass \( (M_{\text{top}}) \), which are typical signatures to the spontaneous symmetry breaking in the SM. As stressed frequently, one of the most reliable quantities to know the radiative corrections due to the top is that related to the \( Z \rightarrow b \bar{b} \) vertex, especially \( R_{bh} = \Gamma(Z \rightarrow b \bar{b})/\Gamma(Z \rightarrow \text{hadrons}) \) which is almost independent of the Higgs mass, \( \alpha(M_Z) \) and \( \alpha_s(M_Z) \) and almost uniquely determined provided that \( M_{\text{top}} \) is given. In the SM, \( R_{bh} \) decreases as \( M_{\text{top}} \) increases and becomes \( \sim 0.2155 \) for \( M_{\text{top}} = 170 \) GeV, which is too small compared with the data \( 0.220 \pm 0.0027 \). The data do not show a small \( R_{bh} \) required by the SM and rather suggest that \( \Gamma(Z \rightarrow b \bar{b}) \) and \( R_{bh} \) are greater than even their tree level values (the excess of \( \Gamma(Z \rightarrow b \bar{b}) \) is \( \sim 3 \) MeV). The large radiative corrections due to the heavy top have not been found also in other observables in \( Z \) decays, as shown by the fact that the LEP data are described in a good approximation by the tree level standard model with pure QED and QCD radiative corrections. Contrary to the expectation, the fundamental concepts of the SM, especially the spontaneous symmetry breakdown through the Higgs mechanism, do not receive a support experimentally. Although only future experiments can give a final answer, it seems to be strongly suggested that the Glashow-Salam-Weinberg model is not a fundamental theory but merely a low energy effective one which can describe weak interaction
phenomena only approximately. In our model $W(Z)$ and other members of $(8, 1)$ are effective gauge bosons working only at low energy. The situation seems to fit to our model.

In our model, the masses of vector bosons are dynamically generated by the underlying preon dynamics. Therefore, Higgs scalars and so the large radiative corrections due to the heavy top do not exist. However, due to the existence of $D_1$, deviations from the SM are predicted in a definite way with only one adjustable parameter ($=M_Z/M_0$). As seen from Eq. (18), the ratio of the vector coupling to the axial coupling of $eeZ$ is independent of $M_Z/M_0$. The ratio would not also be significantly affected by QED radiative corrections. Hence, from the data on the ratio, we can determine $s_w$ as

$$s_w^2 = 0.2318 \pm 0.0010.$$\hspace{1cm} (27)

The ratio of the axial coupling of $b$-quark to that of electron, which is $1+\varepsilon_b$ in the notation of Ref. 18), is predicted as $1+2as_w^2/3$. Hence,

$$\varepsilon_b = 2as_w^2/3,$$\hspace{1cm} (28)

which is predicted to be positive while $\varepsilon_b$ is negative in the SM ($\sim -7 \times 10^{-3}$ for $M_{top} = 170$ GeV). Negative $\varepsilon_b$ is an origin of small $\Gamma(Z \rightarrow b \bar{b})$. If $M_D \sim 7M_Z$, $\varepsilon_b$ is predicted to be $\sim 4 \times 10^{-3}$, which is compared with the data $4.4 \pm 7.0 \times 10^{-3}$. The data on $\varepsilon_b$ require that $M_D > 4M_Z$.

Equation (18) implies that, at the tree level,

$$\Gamma(Z \rightarrow d \bar{d})/\Gamma_{SM}(Z \rightarrow d \bar{d}) \approx 1 + 0.263x,$$

$$\Gamma(Z \rightarrow u \bar{u})/\Gamma_{SM}(Z \rightarrow u \bar{u}) \approx 1 - 0.221x,$$

$$\Gamma(Z \rightarrow \text{hadrons})/\Gamma_{SM}(Z \rightarrow \text{hadrons}) \approx 1 + 0.098x,$$

$$\Gamma(Z \rightarrow e^+e^-)/\Gamma_{SM}(Z \rightarrow e^+e^-) \approx 1 - 0.221x,$$

$$\Gamma(Z \rightarrow \nu \bar{\nu})/\Gamma_{SM}(Z \rightarrow \nu \bar{\nu}) \approx 1 + 0.120x,$$

$$R_{bh}/R_{bh,SM} \approx 1 + 0.164x$$

and

$$R/R_{SM} \approx 1 + 0.319x,$$\hspace{1cm} (29)

where $x = M_Z^2/M_0^2$, $R_{bh} = \Gamma(Z \rightarrow b \bar{b})/\Gamma(Z \rightarrow \text{hadrons})$, $R = \Gamma(Z \rightarrow \text{hadrons})/\Gamma(Z \rightarrow e^+e^-)$, and the suffix SM implies the tree level value in the SM (namely $x=0$). In Eq. (29), $s_w^2 = 0.23$ is assumed. In our model, compared with the tree level SM, the decay width of $Z$ into any down-type quark pair and so $\Gamma(Z \rightarrow b \bar{b})$ become a bit larger (by $\sim 2$ MeV if $x=1/50$), $\Gamma(Z \rightarrow \text{up-type quark pair})$ does a bit smaller (by $\sim 1.3$ MeV if $x=1/50$) and $\Gamma(Z \rightarrow \text{hadrons})$ does a bit larger ($\sim 3.4$ MeV if $x=1/50$). Consequently, in our model, $R_{bh}$ has some excess compared with the tree level SM ($R_{bh} \approx 0.219$ if $x=1/50$), in agreement with the data, and $\alpha_s(M_Z)$ determined without taking into account the effects of $D_1$ becomes a bit larger than the true value. If the excess of $\Gamma(Z \rightarrow \text{hadrons})$ due to the effect of $D_1$ is attributed to the larger $\alpha_s(M_Z)$, the excess of $\alpha_s(M_Z)$ is $\sim 0.006$.
in the case $x=1/50$. Thus the effects of the existence of $D_1$ on $Z$ decays have a tendency required by the data. However, unfortunately, the data are not precise at present enough to show definitely the necessity of the $D_1$ effects. Future precise data will clarify this point.

For the $W$ boson mass, we obtain that $M_W = M_{Zc}w(1 + atw^2sw^2/6)$. This implies that $M_W$ is only slightly larger than the tree level value. If $M_D \sim 7M_Z$, $M_W$ becomes 79.94 GeV for $M_Z = 91.187$ GeV. The SM predicts a larger value for $M_W$ due to heavy top ($\sim 80.4$ GeV for $M_{top} = 170$ GeV). Some experiments have found the $W$ mass consistent with our prediction (79.91 ± 0.39 GeV \cite{19a} and 79.86 ± 0.40 GeV \cite{19b}). However, there also exist experiments \cite{19b,19c} which seem to favor the SM. In addition, the experimental errors are too large to make a discussion on a subtle problem. At the present stage, it seems hard to draw a definite conclusion.

\section{Remarks}

The existence of neutral vector bosons besides $Z$ which can mix with the photon is dangerous since it may destroy the success of the SM. Based on the current mixing model, we have shown that the existence of $D_1$ does not affect the $W(Z)$ physics if $D_1$ is sufficiently heavy. The existence of $D_1$ predicts some deviations from the SM in a definite manner. It is amazing that the existence of $D_1$ is rather favorable to explain the precise data at LEP. Future more precise data at LEP and at TEVATRON will clarify this point. In the sense that new heavy neutral vector boson is introduced, our model is similar to models with an extended gauge group. However, the existence of heavy neutral vector boson pushes the $Z$ boson mass down and so results in a larger $\Delta \rho$ parameter in spite of the fact that, if $\Delta \rho$ is calculated based on the SM, even the contribution from the heavy top exceeds the experimental value of $\Delta \rho$. The existence of heavy neutral vector boson is allowed only in a model in which the Higgs mechanism does not work and so large effects due to the heavy top do not exist.

We cannot determine the Weinberg angle at the present stage, although it is predicted to be less than $\pi/3$. The experimental data show that the Weinberg angle is very large ($\sim \pi/6$) compared with the corresponding value of the $\gamma - \rho^0$ transition. This will be due to the fact that $\Lambda_P$ is much greater than $M_Z$, while $\Lambda_{QCD}$ is comparable to the $\rho^0$ mass. Compared with $\Lambda_P$, the $Z$ boson mass is nearly the same as the photon mass. Hence, the preon dynamics may see the $Z$ boson as a particle similar to the photon, while the $\rho$ meson is a very different particle from the photon in QCD. In principle, the $\gamma - W_3$ transition constant varies with $q^2$. However, so long as $q^2 \ll \Lambda_P^2$, neglecting it will be allowed.

In our model, the emergence of the Glashow-Weinberg-Salam model relies on the concepts, which are valid only approximately, such as massive vector bosons as a gauge boson at low energy due to the zero slope limit of a string amplitude and the lowest lying pole dominance. Then, the GWS model is only an effective theory. Considering this, the striking success of the GWS model is rather surprising. One of the most important origins of this may also be the fact that the preon dynamics scale is very huge compared with the mass of the relevant particle and the energy probed experimentally. Due to this fact, the gauge boson nature of vector bound states and
the lowest lying pole dominance would become a very good concept at low energy (corrections to them would be of $O(M^2/\Lambda^2)$). Since BSP's are point-like objects in a very good approximation at low energy, they would be described by a local quantum field theory with excellent accuracy at such energy. Of course, only when preon dynamics is made clear in detail and the properties of bound states are clarified thoroughly, the secret of the success of the GWS model would be disclosed.

The left-handed coupling is required for the vertex of orthofermion-orthofermion-vector BSP by the experiments. In our model the underlying dynamics has a parity violating property and so it is natural that the BSP vertex has a parity violating coupling. However, the maximal parity violation is surprising. It is one of the important unsettled problems to our model to clarify a mechanism responsible for this phenomenon. This may be intimately related to another unsettled problem of the masslessness of leptons and quarks. In massless fermions, a maximal parity violation naturally occurs. Perhaps, due to a phase transition related to the emergence of massless fermions induced by the super-strong interactions among preons, parity violation might be maximally enhanced. If this is the case, a right-handed coupling is expected to also exist, since leptons and quarks really have a mass. However it is expected to be very small, e.g., of the order of the quark mass/\Lambda^2 \sim 10^{-4} or of (quark mass/\Lambda) \sim 10^{-8} if it arises from a (\alpha')^1 term in the \alpha' expansion of the string amplitude. Vertices involving parafermions would have a right-handed coupling similar to left-handed one in magnitude, since they have a mass of $O(\Lambda^2)$. In the SM and its extension, the left-handed coupling is an input assumption. However, in our model, there is a possibility that we can explain why so, if the bound state dynamics is fully clarified.

If, as strongly suggested by the COBE data, the cold dark matter(CDM) is the dominant matter in the Universe and it is a stable weakly-interacting-massive-particle (WIMP), it is highly probable that there exist many particles which belong to the same class as the CDM particle does. In our model, \textit{U}-bosons which have weak isospin 1/2 and lepton number and lepto-quark fermion $q' = [c_\alpha c_\beta] \bar{h}$ which carries both lepton and baryon number are some of such particles. The structure of our model predicts that they have a mass of $O(100 \text{ GeV})$. A detection of them is crucial to our model as well as the confirmation of $l_5$ as the CDM particle. If, fortunately, $U^+$ is lighter than 100 GeV, the existence of it will be easily confirmed through the process $e^+e^\to U^+U^-$ at LEP200 and Eq. (23) will be tested. The elastic $l_5$-quark scattering is dominantly governed by $D_1$. The LEP data require that the mass of $D_1$ is sufficiently heavy (say $\sim 500 \text{ GeV}$). An experiment sensitive to $D_1$ of 500 GeV mass is awaited.

Acknowledgements

The author would like to thank Dr. M. Yasuè for valuable comments and reading of the original manuscript.

References

16) The CDF Collaboration. Recently we have heard that $M_{top}=174\pm17$ GeV.
b) D. Saltzberg, Fermilab-Conf-93-355-E.
c) Q. Zhu, Talk at the 9th Topical Workshop on Proton-Antiproton Collider Physics, Univ. of Tsukuba, Oct. 1993.