New Physics from
U(3)-Family Nonet Higgs Boson Scenario

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Abstract

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* Talk presented at the INS Workshop “Physics of $e^+e^-, e^-\gamma$ and $\gamma\gamma$ collisions at linear accelerators”, INS, University of Tokyo, December 20 – 22, 1995.
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New Physics from U(3)-Family Nonet Higgs Boson Scenario

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Abstract

Being inspired by a phenomenological success of a charged lepton mass formula, a model with U(3)-family nonet Higgs bosons is proposed. Here, the Higgs bosons \( \phi_L (\phi_R) \) couple only between light fermions (quarks and leptons) \( f_L (f_R) \) and super-heavy vector-like fermions \( F_R (F_L) \), so that the model leads to a seesaw-type mass matrix \( M_f \approx m_L M_F^{-1} m_R \) for quarks and leptons \( f = u, d, \nu \) and \( e \). Lower bounds of the physical Higgs boson masses are deduced from the present experimental data and possible new physics from the present scenario is speculated.

1 Motives

One of my dissatisfactions with the standard model is that for the explanation of the mass spectra of quarks and leptons, we must choose the coefficients \( y_{ij}^f \) in the Yukawa coupling

\[
\sum_f \sum_{i,j} \bar{f}_L^i \phi_{0j}^r f_R^j \quad (f = \nu, e, u, d, \text{ and } i, j \text{ are family indices})
\]

“by hand”. In order to reduce this dissatisfaction, for example, let us suppose U(3)_{family} nonet Higgs fields which couple with fermions as \( \sum_f \sum_{i,j} \bar{f}_L (\phi_{0j}^i) f_R^j \). Unfortunately, we know that the mass spectra of up- and down-quarks and charged leptons are not identical and the Kobayashi-Maskawa \[1\] (KM) matrix is not a unit matrix. Moreover, we know that in such multi-Higgs models, in general, flavor changing neutral currents (FCNC) appear unfavourably.

Nevertheless, I would like to dare to challenge to a model with U(3)_{family} nonet Higgs bosons which leads to a seesaw-type quark and lepton mass matrix

\[
M_f \approx m_L M_F^{-1} m_R .
\]

My motives are as follows.

One of the motives is a phenomenological success of a charged lepton mass relation \[2\]

\[
m_e + m_\mu + m_\tau = \frac{2}{3} (\sqrt{m_e} + \sqrt{m_\mu} + \sqrt{m_\tau})^2 ,
\]

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which predicts $m_\tau = 1776.96927 \pm 0.00052 \pm 0.00005$ MeV for the input values [3] of $m_e = 0.510999906 \pm 0.00000015$ MeV and $m_\mu = 105.658389 \pm 0.000034$ MeV (the first and second errors in (1.2) come from the errors of $m_\mu$ and $m_e$, respectively). Recent measurements [4] of tau lepton mass $m_\tau = 1776.96^{+0.18+0.20}_{-0.19-0.16}$ MeV excellently satisfies the charged lepton mass relation (2). An attempt to derive the mass relation (2) from a Higgs model has been tried [5]: We assumed U(3)$_{\text{family}}$ nonet Higgs bosons $\phi^j_i$ $(i,j = 1,2,3)$, whose potential is given by

$$V(\phi) = \mu^2 \text{Tr}(\phi\phi^\dagger) + \frac{1}{2}\lambda \left[\text{Tr}(\phi\phi^\dagger)\right]^2 + \eta \phi_s\phi_s^\dagger \text{Tr}(\phi_{\text{oct}}\phi_{\text{oct}}^\dagger).$$  \hspace{1cm} (3)

Here, for simplicity, the SU(2)$_L$ structure of $\phi$ has been neglected, and we have expressed the nonet Higgs bosons $\phi^j_i$ by the form of $3 \times 3$ matrix,

$$\phi = \phi_{\text{oct}} + \frac{1}{\sqrt{3}} \phi_s \mathbf{1},$$  \hspace{1cm} (4)

where $\phi_{\text{oct}}$ is the octet part of $\phi$, i.e., $\text{Tr}(\phi_{\text{oct}}) = 0$, and $\mathbf{1}$ is a $3 \times 3$ unit matrix. For $\mu^2 < 0$, conditions for minimizing the potential (3) lead to the relation

$$v^*_sv_s = \text{Tr} \left( v_{\text{oct}}^\dagger v_{\text{oct}} \right),$$  \hspace{1cm} (5)

together with $v = v^\dagger$, where $v = \langle \phi \rangle$, $v_{\text{oct}} = \langle \phi_{\text{oct}} \rangle$ and $v_s = \langle \phi_s \rangle$, so that we obtain the relation

$$\text{Tr} \left( v^2 \right) = \frac{2}{3} |\text{Tr}(v)|^2.$$  \hspace{1cm} (6)

If we assume a seesaw-like mechanism for charged lepton mass matrix $M_e$, $M_e \simeq m M_{E^{-1}} m$, with $m \propto v$ and heavy lepton mass matrix $M_E \propto \mathbf{1}$, we can obtain the mass relation (2).

Another motives is a phenomenological success [6] of quark mass matrices with a seesaw-type form (1), where

$$m_L \propto m_R \propto M_{e^{1/2}} \equiv \begin{pmatrix} \sqrt{m_e} & 0 & 0 \\ 0 & \sqrt{m_\mu} & 0 \\ 0 & 0 & \sqrt{m_\tau} \end{pmatrix},$$  \hspace{1cm} (7)

$$M_F \propto \mathbf{1} + b_F e^{i\beta_F} 3X \equiv \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} + b_F e^{i\beta_F} \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix}.$$  \hspace{1cm} (8)

The model can successfully provide predictions for quark mass ratios (not only the ratios $m_u/m_c$, $m_c/m_t$, $m_d/m_s$ and $m_s/m_b$, but also $m_u/m_d$, $m_c/m_s$ and $m_t/m_b$) and KM matrix parameters.

These phenomenological successes can be reasons why the model with a U(3)$_{\text{family}}$ nonet Higgs bosons, which leads to a seesaw-type mass matrix (1), should be taken seriously.
2 Outline of the model

The model is based on SU(2)$_L \times$ SU(2)$_R \times$ U(1)$_Y \times$ U(3)$_{family}$ symmetries. These symmetries except for U(3)$_{family}$ are gauged. The prototype of this model was investigated by Fusaoka and the author \[8\]. However, their Higgs potential leads to massless physical Higgs bosons, so that it brings some troubles into the theory. In the present model, the global symmetry U(3)$_{family}$ will be broken explicitly, and not spontaneously, so that massless physical Higgs bosons will not appear.

The quantum numbers of our fermions and Higgs bosons are summarized in Table I.

| \(Y\) | SU(2)$_L$ | SU(2)$_R$ | U(3)$_{family}$ |
|---|---|---|---|
| \(f_L\) \((\nu, e)_L^{Y=-1}, (u, d)_L^{Y=1/3}\) | 2 | 1 | 3 |
| \(f_R\) \((\nu, e)_R^{Y=-1}, (u, d)_R^{Y=1/3}\) | 1 | 2 | 3 |
| \(f_L\) \(N_L^Y=0, E_L^Y=-2, U_L^Y=4/3, D_L^Y=-2/3\) | 1 | 1 | 3 |
| \(f_R\) \(N_R^Y=0, E_R^Y=-2, U_R^Y=4/3, D_R^Y=-2/3\) | 1 | 1 | 3 |
| \(\phi_L\) \((\phi^+, \phi^0)_L^{Y=1}\) | 2 | 1 | 8+1 |
| \(\phi_R\) \((\phi^+, \phi^0)_R^{Y=1}\) | 1 | 2 | 8+1 |
| \(\Phi_F\) \(\Phi^Y=0, \Phi_X^Y=0\) | 1 | 1 | 1, 8 |

Note that in our model there is no Higgs boson which belongs to \((2, 2)\) of SU(2)$_L \times$ SU(2)$_R$. This guarantees that we obtain a seesaw-type mass matrix (2) by diagonalization of a 6×6 mass matrix for fermions \((f, F)\):

\[
\begin{pmatrix}
0 & m_L \\
m_R & M_F
\end{pmatrix} \Rightarrow \begin{pmatrix}
M_f & 0 \\
0 & M'_F
\end{pmatrix},
\]

where \(M_f \simeq -m_L M_F^{-1} m_R\) and \(M'_F \simeq M_F\) for \(M_F \gg m_L, m_R\). (See Fig. 1.)
3 Higgs potential and “nonet” ansatz

We assume that $\langle \phi_R \rangle \propto \langle \phi_L \rangle$, i.e., each term in $V(\phi_R)$ takes the coefficient which is exactly proportional to the corresponding term in $V(\phi_L)$. This assumption means that there is a kind of “conspiracy” between $V(\phi_R)$ and $V(\phi_L)$. However, in the present stage, we will not go into this problem moreover. Hereafter, we will drop the index $L$ in $\phi_L$.

The potential $V(\phi)$ is given by

$$V(\phi) = V_{\text{nonet}} + V_{\text{Oct.Singl}} + V_{\text{SB}} ,$$

(10)

where $V_{\text{nonet}}$ is a part of $V(\phi)$ which satisfies a “nonet” ansatz stated below, $V_{\text{Oct.Singl}}$ is a part which violates the “nonet” ansatz, and $V_{\text{SB}}$ is a term which breaks U(3)$_{\text{family}}$ explicitly.

The “nonet” ansatz is as follows: the octet component $\phi_{\text{oct}}$ and singlet component $\phi_s$ of the Higgs scalar fields $\phi_L (\phi_R)$ always appear with the combination of (4) in the Lagrangian. Under the “nonet” ansatz, the SU(2)$_L$ invariant (and also U(3)$_{\text{family}}$ invariant) potential $V_{\text{nonet}}$ is, in general, given by

$$V_{\text{nonet}} = \mu^2 \text{Tr}(\phi\phi) + \frac{1}{2} \lambda_1 (\overline{\phi}_i^j \phi_j^i)(\overline{\phi}_k^l \phi_l^k)$$

$$+ \frac{1}{2} \lambda_2 (\overline{\phi}_i^j \phi_k^j)(\overline{\phi}_l^k \phi_l^i) + \frac{1}{2} \lambda_3 (\overline{\phi}_i^j \phi_j^i)(\overline{\phi}_k^l \phi_l^k) + \frac{1}{2} \lambda_4 (\overline{\phi}_i^j \phi_k^i)(\overline{\phi}_l^j \phi_l^k)$$

$$+ \frac{1}{2} \lambda_5 (\overline{\phi}_i^j \phi_k^j)(\overline{\phi}_l^j \phi_l^i) + \frac{1}{2} \lambda_6 (\overline{\phi}_i^j \phi_k^k)(\overline{\phi}_j^i \phi_l^l) + \frac{1}{2} \lambda_7 (\overline{\phi}_i^j \phi_k^i)(\overline{\phi}_l^j \phi_l^k) ,$$

(11)

where $(\overline{\phi}\phi) = \phi^- \phi^+ + \phi^0 \phi^0$.

On the other hand, the “nonet ansatz” violation terms $V_{\text{Oct.Singl}}$ are given by

$$V_{\text{Oct.Singl}} = \eta_1 (\overline{\phi}_s^i \phi_s^i) \text{Tr}(\phi_{\text{oct}} \phi_{\text{oct}}) + \eta_2 (\overline{\phi}_s (\phi_{\text{oct}})^i_j) ((\phi_{\text{oct}})^i_j \phi_s)$$

$$+ \eta_3 (\overline{\phi}_s (\phi_{\text{oct}})^i_j) (\overline{\phi}_s (\phi_{\text{oct}})^i_j \phi_s) + \eta_3^* (\overline{\phi}_s (\phi_{\text{oct}})^i_j) (\overline{\phi}_s (\phi_{\text{oct}})^i_j \phi_s) .$$

(12)

For a time, we neglect the term $V_{\text{SB}}$ in (10). For $\mu^2 < 0$, conditions for minimizing the potential (10) lead to the relation

$$v^2_s = \text{Tr}(v^2_{\text{oct}}) = \frac{-\mu^2}{2(\lambda_1 + \lambda_2 + \lambda_3) + (\eta_1 + \eta_2 + 2\eta_3)} ,$$

(13)

under the conditions $\lambda_4 + \lambda_5 + 2(\lambda_6 + \lambda_7) = 0$, and $v = v^i$, where we have put $\eta_3 = \eta_3^*$ for simplicity.

Hereafter, we choose the family basis as

$$v = \begin{pmatrix} v_1 & 0 & 0 \\ 0 & v_2 & 0 \\ 0 & 0 & v_3 \end{pmatrix} .$$

(14)

For convenience, we define the parameters $z_i$ as

$$z_i \equiv \frac{v_i}{v_0} = \sqrt{\frac{m_i^2}{m_e + m_\mu + m_\tau}} ,$$

(15)
where
\[ v_0 = (v_1^2 + v_2^2 + v_3^2)^{1/2}, \] (16)
so that \((z_1, z_2, z_3) = (0.016473, 0.23687, 0.97140)\).

We define two independent diagonal elements of \(\phi_{oct}\) as
\[ \phi_x = x_1\phi_1^1 + x_2\phi_2^2 + x_3\phi_3^3, \]
\[ \phi_y = y_1\phi_1^1 + y_2\phi_2^2 + y_3\phi_3^3, \] (17)
where the coefficients \(x_i\) and \(y_i\) are given by
\[ x_i = \sqrt{2}z_i - 1/\sqrt{3}, \] (18)
\[ (y_1, y_2, y_3) = (x_2 - x_3, x_3 - x_1, x_1 - x_2)/\sqrt{3}. \] (19)

Then, the replacement \(\phi^0 \rightarrow \phi^0 + v\) means that \(\phi_s^0 \rightarrow \phi_s^0 + v_s; \phi_x^0 \rightarrow \phi_x^0 + v_x; \phi_y^0 \rightarrow \phi_y^0; \)
\((\phi^0)_i^j \rightarrow (\phi^0)_i^j (i \neq j)\), where \(v_i = v_s/\sqrt{3} + x_i v_x\). This means that even if we add a term
\[ V_{SB} = \xi \left( \overline{\phi}_y \phi_y + \sum_{i \neq j} \overline{\phi}_i^j \phi_i^j \right), \] (20)
in the potential \(V_{nonet} + V_{Oct\cdot Singl}\), the relation (13) are still unchanged.

### 4 Physical Higgs boson masses

For convenience, we define:
\[ \left( \begin{array}{c} \phi^+ \\ \phi^0 \end{array} \right) = \frac{1}{\sqrt{2}} \left( i\sqrt{2} \lambda^+ \right), \] (21)
\[ \left( \begin{array}{c} \phi_1 \\ \phi_2 \\ \phi_3 \end{array} \right) = \left( \begin{array}{ccc} z_1 & z_2 & z_3 \\ z_1 - \sqrt{2} & z_2 - \sqrt{2} & z_3 - \sqrt{2} \\ \sqrt{2}(z_2 - z_3) & \sqrt{2}(z_3 - z_1) & \sqrt{2}(z_1 - z_2) \end{array} \right) \left( \begin{array}{c} \phi_1^1 \\ \phi_2^2 \\ \phi_3^3 \end{array} \right). \] (22)

Then, we obtain masses of these Higgs bosons which are sumalized in Table II.

| \(\phi\) | \(H^0\) | \(\chi^0\) | \(\chi^\pm\) |
|---|---|---|---|
| \(m^2(\phi_1)\) | \(2(\lambda_1 + \lambda_2 + \lambda_3) + \eta_1 + \eta_2 + 2\eta_3\) | 0 | 0 |
| \(m^2(\phi_2)\) | \(-\eta_1 + \eta_2 + 2\eta_3\) | \(-2(\lambda_3 + 2\eta_3)\) | \(-(\lambda_2 + \lambda_3 + \eta_2 + 2\eta_3)\) |
| \(m^2(\phi_3)\) | \(\xi\) | \(\xi - 2(\lambda_3 + \eta_3)\) | \(\xi - [\lambda_2 + \lambda_3 + \frac{1}{2}(\eta_2 + 2\eta_3)]\) |
| \(m^2(\phi^1)\) | \(m^2(H_3^0)\) | \(m^2(\chi_3^0)\) | \(m^2(\chi_3^\pm)\) |

The massless states \(\chi_1^\pm\) and \(\chi_1^0\) are eaten by weak bosons \(W^\pm\) and \(Z^0\), so that they are not physical bosons. The mass of \(W^\pm\) is given by \(m_W^2 = g^2 v_0^2 / 2\), so that the value of \(v_0\) defined by (16) is \(v_0 = 174\) GeV.
5 Interactions of the Higgs bosons

(A) Interactions with gauge bosons

Interactions of $\phi_L$ with gauge bosons are calculated from the kinetic term $\text{Tr}(D_\mu \bar{\phi}_L D^\mu \phi_L)$. The results are as follows:

$$H_{EW} = +i \left( e A_\mu + \frac{1}{2} g_z \cos 2\theta W Z_\mu \right) \text{Tr}(\chi^- \bar{\chi} \gamma_\mu \chi^+) + \frac{1}{2} g z \text{Tr}(\phi_0 \bar{\phi} \gamma_\mu H^0)$$

$$+ \frac{1}{2} \left( W_\mu^+ \left[ \text{Tr}(\chi^- \bar{\chi} \gamma_\mu H^0) - i(\chi^- \bar{\chi} \gamma_\mu \chi^+) + h.c. \right] \right)$$

$$+ \frac{1}{2} \left( 2 g m_w W_\mu^+ W_\mu^{\alpha} + g_z m_Z Z_\mu Z_{\alpha} \right) H_0^0,$$

where $g_z = g / \cos \theta_W$ and $\chi^\pm_1 = \chi_1^0 = 0$.

Note that the interactions of $H_1^0$ are exactly same as that of $H^0$ in the standard model.

(B) Three-body interactions among Higgs bosons

$$H_{\phi\phi\phi} = \frac{1}{2} \frac{m^2(H_1^0)}{v_0} H_1^0 \text{Tr}(H^0 H^0) + \frac{1}{2} \frac{m^2(H_2^0)}{v_0} \left( H_1^0 H_2^0 H_2^0 - H_1^0 H_1^0 H_2^0 \right) + \cdots .$$

The full expression will be given elsewhere.

(C) Interactions with fermions

Our Higgs particles $\phi_L$ do not have interactions with light fermions $f$ at tree level, and they can couple only between light fermions $f$ and heavy fermions $F$. However, when the $6 \times 6$ fermion mass matrix is diagonalized as (9), the interactions of $\phi_L$ with the physical fermion states (mass eigenstates) become

$$\left( \begin{array}{cc} 0 & \Gamma_L \\ 0 & 0 \end{array} \right) \implies \left( \begin{array}{cc} \Gamma_{11} & \Gamma_{12} \\ \Gamma_{21} & \Gamma_{22} \end{array} \right),$$

where $\Gamma_L = y_f \phi_L$, and

$$\Gamma_{11} \approx U_f^T \phi_L v^{-1} U_f^T D_f.$$ (26)

For charged leptons, since $U_{eL} = 1$, the interactions of $\phi_1^0$ are given by

$$H_{Yukawa}^{\text{lepton}} = \frac{1}{2} \sqrt{2} \sum_{i,j} \left[ \overline{e}_i (a_{ij} - b_{ij} \gamma_5) e_j (H^0)_i^j + i \overline{e}_i (b_{ij} - a_{ij} \gamma_5) e_j (H_1^0)_i^j \right],$$

$$a_{ij} = \frac{m_i}{v_i} + \frac{m_j}{v_j}, \quad b_{ij} = \frac{m_i}{v_i} - \frac{m_j}{v_j}.$$ (27)

Therefore, in the pure leptonic modes, the exchange of $\phi_L$ cannot cause family-number non-conservation.

For quarks, in spite of $U_{uL}^q \neq 1$, the Higgs boson $H_1^0$ still couples with quarks $q_i$ diagonally:

$$H_{Yukawa}^{\text{quark}} = \frac{1}{\sqrt{2}} \sum_i m^q_i \left( \overline{q}_i q_i \right) H_1^0 + \cdots .$$

(29)

However, the dotted parts which are interaction terms of $\phi_2$, $\phi_3$ and $\phi_i^j (i \neq j)$ cause family-number non-conservation.
6 Family-number changing and conserving neutral currents

(A) Family-number changing neutral currents

In general, the Higgs boson \( H_1^0 \) do not contribute to flavor-changing neutral currents (FCNC), and only the other bosons contribute to \( \overline{P}^0-P^0 \) mixing. The present experimental values \[ \Delta m_K = m(K_L) - m(K_S) = (0.5333 \pm 0.0027) \times 10^{10} \text{fs}^{-1}, \]
\[ |\Delta m_D| = |m(D^0_1) - m(D^0_2)| < 20 \times 10^{10} \text{fs}^{-1}, \Delta m_B = m(D_H) - m(D_L) = (0.51 \pm 0.06) \times 10^{12} \text{fs}^{-1}, \]
and so on, give the lower bound of Higgs bosons \( m(H_2^0), m(\chi_2^0) > 10^5 \text{GeV} \). For the special case of \( m(H) = m(\chi) \), we obtain the effective Hamiltonian

\[
H_{FCNC} = \frac{1}{3} \left( \frac{1}{m^2(H_2^0)} - \frac{1}{m^2(H_3^0)} \right) \sum_{i \neq j} \sum_{k} \frac{m_i m_j}{v_0^2} \left( \frac{1}{z_k^2} + \frac{z_k - z_l - z_m}{z_1 z_2 z_3} \right)
\times (U_i^k U_j^k)^* \left[ (f_i f_j)^2 - (\bar{f}_i \gamma_5 f_j)^2 \right],
\]

where \((k, l, m)\) are cyclic indices of \((1, 2, 3)\), so that the bound can reduce to \( m(H_2^0) = m(\chi_2^0) > \) a few TeV. Note that FCNC can highly be suppressed if \( m(H_2) \approx m(H_3) \).

(B) Family-number conserving neutral currents

The strictest restriction on the lower bound of the Higgs boson masses comes from

\[
\frac{B(K_L \to e^+ \mu^+)}{B(K_L \to \pi^0 \ell^+ \nu)} \approx \left( \frac{v_0}{m_H} \right)^4 \times 1.94 \times 10^{-6}.
\]

The present data \[ B(K_L \to e^+ \mu^+)_\text{exp} < 3.3 \times 10^{-11} \] leads to the lower bound \( m_{H3}/v_0 > 12 \), i.e., \( m_{H3} > 2.1 \text{ TeV} \).

7 Productions and decays of the Higgs bosons

As stated already, as far as our Higgs boson \( H_1^0 \) is concerned, it is hard to distinguish it from \( H^0 \) in the standard model. We discuss what is a new physics expected concerned with the other Higgs bosons.

(A) Productions

Unfortunately, since masses of our Higgs bosons \( \phi_2 \) and \( \phi_3 \) are of the order of a few TeV, it is hard to observe a production

\[
e^+ + e^- \to Z^* \to (H^0)^j_i \quad + \quad (\chi^0)^j_i,
\]

\[\leftrightarrow f_i + \bar{f}_j \quad \leftrightarrow f_j + \bar{f}_i, \quad (32)\]

even in \( e^+e^- \) super linear colliders which are planning in the near future. Only a chance of the observation of our Higgs bosons \( \phi_i^0 \) is in a production

\[
u \to t + (\phi)^2_1, \quad (33)\]
at a super hadron collider with several TeV beam energy, for example, at LHC, because the coupling $a_{tu}$ ($b_{tu}$) is sufficiently large:

$$a_{tu} \simeq \frac{m_t}{v_3} + \frac{m_u}{v_1} = 1.029 + 0.002,$$

(34)

[c.f. $a_{bd} \simeq (m_b/v_3) + (m_d/v_1) = 0.026 + 0.003$].

(B) Decays

Dominant decay modes of $(H^0)^2_3$ and $(H^0)^1_3$ are hadronic ones, i.e., $(H^0)^2_3 \rightarrow t\bar{c}, b\bar{s}$ and $(H^0)^1_3 \rightarrow i\tau, b\bar{d}$. Only in $(H^0)^1_2$ decay, a visible branching ratio of leptonic decay is expected:

$$\Gamma(H^1_2 \rightarrow c\bar{u}) : \Gamma(H^1_2 \rightarrow s\bar{d}) : \Gamma(H^1_2 \rightarrow \mu^- e^+)$$

$$\simeq 3 \left[ \frac{(m_c^2)}{v_2} + \frac{(m_u^2)}{v_1} \right] : 3 \left[ \frac{(m_s^2)}{v_2} + \frac{(m_d^2)}{v_1} \right] : \left[ \frac{(m_{\mu}^2)}{v_2} + \frac{(m_e^2)}{v_1} \right]$$

$$= 73.5% : 24.9% : 1.6%.$$  

(35)

8 Summary

We have proposed a U(3)-family nonet Higgs boson scenario, which leads to a seesaw-type quark and lepton mass matrix $M_f \simeq m_L M_F^{-1} m_R$.

It has been investigated what a special form of the the potential $V(\phi)$ can provide the relation

$$m_e + m_\mu + m_\tau = \frac{2}{3}(\sqrt{m_e} + \sqrt{m_\mu} + \sqrt{m_\tau})^2,$$

and the lower bounds on the masses of $\phi_L$ have been estimated from the data of $P^0 - \bar{P}^0$ mixing and rare meson decays.

Unfortunately, the Higgs bosons, except for $H^0_1$, in the present scenario are very heavy, i.e., $m_H \simeq m_\chi \sim$ a few TeV. We expect that our Higgs boson $(\phi^0)^3_1$ will be observed through the reaction $u \rightarrow t + (\phi^0)^3_1$ at LHC.

The present scenario is not always satisfactory from the theoretical point of view:

(1) A curious ansatz, the “nonet” ansatz, has been assumed.

(2) The potential includes an explicitly symmetry breaking term $V_{SB}$.

These problems are future tasks of our scenario.

Acknowledgments

 Portions of this work (quark mass matrix phenomenology) were begun in collaboration with H. Fusaoka [6]. I would like to thank him for helpful conversations. The problem of the flavor-changing neutral currents in the present model was pointed out by K. Hikasa. I would sincerely like to thank Professor K. Hikasa for valuable comments. An improved version of this work is in preparation in collaboration with Prof. M. Tanimoto. I am indebted to Prof. M. Tanimoto for helpful comments. I would also like to thank the organizers of this workshop, especially, Professor R. Najima for a successful and enjoyable
workshop. This work was supported by the Grant-in-Aid for Scientific Research, Ministry of Education, Science and Culture, Japan (No.06640407).

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