Calculability of quark masses and V_{CKM} in THDM within USY hypothesis

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Abstract

We investigate the calculability of the quark masses and Cabbibo-Kobayashi-Maskawa matrix (V_{CKM}) in a Two Higgs Doublet Model (THDM) within the Universality of Strength for Yukawa couplings (USY) hypothesis. It is assumed in this model that all the Yukawa couplings have the same moduli. The two Higgs doublets are also supposed to develop vacuum expectation values (vev's) with almost the same moduli. In favor of this USY mechanism, the quark mass hierarchical relations not only $m_u, m_c \ll m_t$, m_d , $m_s \ll m_b$ but also $m_b \ll m_t$ are naturally explained, as confirmed by a numerical calculation.

1. Introduction

In a previous study we investigated a THDM restricted by the USY hypothesis [1]. Both Higgs doublets couple to the u-type quarks and d-type quarks, and the moduli of the Yukawa couplings are the same. Moreover the vev's of the two Higgs doublets take the same absolute values. As a result, the quark mass hierarchical relations not only $m_u, m_c \ll m_t$, m_d , $m_s \ll m_b$ but also $m_b \ll m_t$ are naturally explained. Furthermore, scalar mediated FCNC's are generated at the tree level, while Z mediated FCNC's do not in this model. We showed roughly that the six quark masses and V_{CKM} are reproduced.

In this study, we investigate systematically the calculability of the quark masses and V_{CKM} in the THDM within USY hypothesis.

This article is organized as follows. In Sec 2, the model is presented, and the quark mass matrices are diagonalized. In Sec 3, the formulation to analyze the quark masses and V_{CKM} is explained, and a numerical result is presented. Sec 4 is devoted to summary.

2. The model and quark mass matrices

In the THDM within USY hypothesis, three specific ansatz are considered.

- Both Higgs doublets couple to the u-type quarks and d-type quarks.
- The moduli of the Yukawa couplings for the up-type quarks are the same as those for the down-type quarks.
- The vev's of the two Higgs doublets take almost the same absolute values.

2-1. Higgs potential

The two Higgs doublets are given as

$$H_1 = \begin{bmatrix} H_1^+ \\ H_1^{0\prime} \end{bmatrix}, \quad H_2 = \begin{bmatrix} H_2^+ \\ H_2^{0\prime} \end{bmatrix}. \tag{2.1}$$

By the spontaneous symmetry breaking, they are expressed as

$$H_1 = \begin{bmatrix} H_1^+ \\ \dfrac{v_1 + H_1^0 + i\chi_1^0}{\sqrt{2}} \end{bmatrix}, \quad H_2 = \begin{bmatrix} H_2^+ \\ \dfrac{v_2 e^{i\delta'} + H_2^0 + i\chi_2^0}{\sqrt{2}} \end{bmatrix}, \tag{2.2}$$

where $\tan\beta \equiv \dfrac{v_2}{v_1}$. The general gauge-invariant renomalizable Higgs scalar potential is given by [2]

$$
\begin{aligned}
V(H_1,H_2) = \; & \lambda_1\left[H_1^{\dagger}H_1-\left(\frac{1}{\sqrt{2}}v_1\right)^2\right]^2+\lambda_2\left[H_2^{\dagger}H_2-\left(\frac{1}{\sqrt{2}}v_2\right)^2\right]^2 \\
& +\lambda_3\left[\left\{H_1^{\dagger}H_1-\left(\frac{1}{\sqrt{2}}v_1\right)^2\right\}+\left\{H_2^{\dagger}H_2-\left(\frac{1}{\sqrt{2}}v_2\right)^2\right\}\right]^2 \\
& +\lambda_4\left[\left(H_1^{\dagger}H_1\right)\left(H_2^{\dagger}H_2\right)-\left(H_1^{\dagger}H_2\right)\left(H_2^{\dagger}H_1\right)\right] \\
& +\lambda_5\left[\mathrm{Re}\left(H_1^{\dagger}H_2\right)-\frac{1}{\sqrt{2}}v_1\cdot\frac{1}{\sqrt{2}}v_2\cdot\cos\delta'\right]^2 \\
& +\lambda_6\left[\mathrm{Im}\left(H_1^{\dagger}H_2\right)-\frac{1}{\sqrt{2}}v_1\cdot\frac{1}{\sqrt{2}}v_2\cdot\sin\delta'\right]^2 \\
& +\left[\left\{\lambda_7\left(H_1^{\dagger}H_1\right)+\lambda_8\left(H_2^{\dagger}H_2\right)\right\}\left(H_1^{\dagger}H_2\right)+h.c.\right].
\end{aligned}
\tag{2.3}
$$

In this study, in view of GUT we take the relations

- $\lambda_1=\lambda_2=\lambda'$,
- $\lambda_5=\lambda_6$,
- $\lambda_7=\lambda_8$.

In order to provide the bottom quark mass within USY hypothesis, we require the relations

- $\lambda_3,\lambda_5\ll\lambda'$,
- $\lambda_7,\lambda_8\ll\lambda'$,

or for simplicity

- $\lambda_3,\lambda_5=0$,
- $\lambda_7,\lambda_8=0$.

In view of the suppression of scalar mediated FCNC's, it is also favored that

$$\lambda_3\ll\lambda'.$$

Based on these ansaz, the Higgs potential is rewritten as

$$V(H_1,H_2)= \lambda_1\left[H_1^{\dagger}H_1-\left(\frac{1}{\sqrt{2}}v_1\right)^2\right]^2+\lambda_2\left[H_2^{\dagger}H_2-\left(\frac{1}{\sqrt{2}}v_2\right)^2\right]^2 +\lambda_4\left[\left(H_1^{\dagger}H_1\right)\left(H_2^{\dagger}H_2\right)-\left(H_1^{\dagger}H_2\right)\left(H_2^{\dagger}H_1\right)\right]. \quad (2.4)$$

2-2. Higgs masses

The scalar mass matrices can be transformed to diagonal matrices. Then, the charged scalar fields are mixed as

$$\begin{aligned} G^{\pm} &= H_1^{\pm}\cos\beta_H + H_2^{\pm}\sin\beta_H \quad \to \quad \text{N.G.bosons,} \\ H^{\pm} &= -H_1^{\pm}\sin\beta_H + H_2^{\pm}\cos\beta_H \to \quad \text{physical charged bosons,} \end{aligned} \quad (2.5)$$

where $G^{\pm}$ are the massless charged Nambu-Goldstone boson fields and $H^{\pm}$ are the physical charged boson fields. Then, the masses of the physical charged bosons are given as

$$m_{H^{\pm}} = \sqrt{2\lambda_4(v_1^2+v_2^2)} \quad . \qquad (\because \lambda_5=\lambda_7=\lambda_8=0) \quad (2.6)$$

The value of λ_4 can be taken large enough to satisfy the experimental bound on the charged Higgs boson masses.

In the same way, the CP-even neutral scalar boson mass matrix is diagonalized. Then, the two physical neutral fields are given as

$$\begin{aligned} \phi_1 &= H_1^0\cos\alpha_H + H_2^0\sin\alpha_H, \\ \phi_2 &= -H_1^0\sin\alpha_H + H_2^0\cos\alpha_H. \end{aligned} \quad (2.7)$$

The 2 × 2 mass matrix of the neutral scalar fields is given as

$$\begin{aligned} M_{2\times 2}^2 &= \begin{bmatrix} M_{11}^2 & M_{12}^2 \\ M_{21}^2 & M_{22}^2 \end{bmatrix} \\ &= \begin{bmatrix} 2v_1^2(\lambda_1+\lambda_3)+\frac{1}{2}v_2^2\lambda_5 & (2\lambda_3+\frac{1}{2}\lambda_5)v_1v_2 \\ (2\lambda_1+\frac{1}{2}\lambda_5)v_1v_2 & 2v_2^2(\lambda_1+\lambda_3)+\frac{1}{2}v_1^2\lambda_5 \end{bmatrix} \quad (2.8) \\ &= \begin{bmatrix} 2v_1^2\lambda' & 0 \\ 0 & 2v_2^2\lambda' \end{bmatrix}. \quad (\because \lambda_1=\lambda_2=\lambda',\ \lambda_3=\lambda_5=0) \end{aligned}$$

There is no mixing between H_1^0 and H_2^0, i.e.,

$$\phi_1 = H_1^0 \ ,$$
$$\phi_2 = H_2^0 \ . \quad (\because \alpha_H = 0) \tag{2.9}$$

The CP-odd neutral scalar boson mass matrix is diagonalized with

$$G^0 = \chi_1^0 \cos\beta_H + \chi_2^0 \sin\beta_H \quad \rightarrow \quad \text{N.G.boson},$$

$$A^0 = -\chi_1^0 \sin\beta_H + \chi_2^0 \cos\beta_H \, . \rightarrow \quad \text{physical neutral boson.} \tag{2.10}$$

For $\lambda_7 = \lambda_8 = 0$, there is no mixing among the neutral bosons. Then, the masses of the physical neutral bosons are given as

$$m_{\phi_1} = \sqrt{2\lambda'} v_1 ,$$

$$m_{\phi_2} = \sqrt{2\lambda'} v_2 ,$$

$$m_{A^0} = \sqrt{\frac{\lambda_5 (v_1^2 + v_2^2)}{2}} = 0 \, . \tag{2.11}$$

2-3.Yukawa couplings and quark masses

Yukawa couplings are given by ,

$$\begin{aligned} L_{Yukawa} &= \lambda_Y \exp[i\theta_{uij}^{(1)}] \overline{q_{iL}} H_1 u_{jR} + \lambda_Y \exp[i\theta_{uij}^{(2)}] \overline{q_{iL}} H_2 u_{jR} \\ &+ \lambda_Y \exp[i\theta_{dij}^{(1)}] \overline{q_{iL}} \phi \tilde{H}_1 d_{jR} + \lambda_Y \exp[i\theta_{dij}^{(2)}] \overline{q_{iL}} \tilde{H}_2 d_{jR} \end{aligned} \quad , \tag{2.12}$$

where $q_{iL} = \begin{bmatrix} u_i \\ d_i \end{bmatrix}$. Then, the neutral Yukawa couplings are

$$L_{Yukawa(n)}^{(u)} = \frac{\lambda_Y}{\sqrt{2}} \exp[i\theta_{uij}^{(1)}] \overline{u_{iL}} \phi_1 u_{jR} + \frac{\lambda_Y}{\sqrt{2}} \exp[i\theta_{uij}^{(2)}] \overline{u_{iL}} \phi_2 u_{jR} ,$$

$$L_{Yukawa(n)}^{(d)} = -\frac{\lambda_Y}{\sqrt{2}} \exp[i\theta_{dij}^{(1)}] \overline{d_{iL}} \phi_1 d_{jR} - \frac{\lambda_Y}{\sqrt{2}} \exp[i\theta_{dij}^{(2)}] \overline{d_{iL}} \phi_2 d_{jR} \ . \tag{2.13}$$

The quark mass matrices are provided as

$$M_u = \frac{\lambda_Y v_1}{\sqrt{2}} \exp[i\theta_{uij}^{(1)}] + \frac{\lambda_Y v_2}{\sqrt{2}} \exp[i(\delta + \theta_{uij}^{(2)})],$$

$$M_d = \frac{\lambda_Y v_1}{\sqrt{2}} \exp[i\theta_{dij}^{(1)}] + \frac{\lambda_Y v_2}{\sqrt{2}} \exp[i(\delta + \theta_{dij}^{(2)})]. \qquad (2.14)$$

Because of the hierarchy $m_t \gg m_u, m_c$, and $m_b \gg m_d, m_s$, we assume that the quark mass matrices M_u and M_d are nearly equal to a democratic matrix as follows:

$$M_u \simeq \frac{\lambda_Y (v_1 + v_2 e^{i\delta})}{\sqrt{2}} \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}, \qquad (2.15)$$

$$M_d \sim \frac{\lambda_Y (v_1 e^{i\alpha_d} - v_2 e^{i\beta_d'})}{\sqrt{2}} \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}, \qquad (2.16)$$

where α_d and β_d' represet the center of pertubative calculation, which will be determined in Sec.3.

The 3 × 3 democratic matrix is diagonalized as

$$\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} \Rightarrow F_\alpha^T \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} F_\alpha = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 3 \end{bmatrix}, \qquad (2.17)$$

where F_α is an orthogonal matrix composed of the three eigenvectors of M_α ($\alpha = u, d$). Here, it is naturally seen that the quark masses of the third generation are much larger than those of the first and second generations. The eigenvalues and eigenvectors of M_d are shown in Table 1.

Table1.The eigenvalues and eigenvectors of M_d .

eigenvalues	eigenvectors
$m_1 = 0$	$\mathbf{x_1} = \left(\frac{1}{\sqrt{2}}, -\frac{1}{\sqrt{2}}, 0 \right)$
$m_2 = 0$	$\mathbf{x}_2 = \left(\frac{1}{\sqrt{6}}, \frac{1}{\sqrt{6}}, -\frac{2}{\sqrt{6}} \right)$
$m_3 = 3$	$\mathbf{x}_3 = \left(\frac{1}{\sqrt{3}}, \frac{1}{\sqrt{3}}, \frac{1}{\sqrt{3}} \right)$

Because of the two degenerate eigenvalues, $m_1 = m_2 = 0$, their eigenvectors may be arbitrary linear combinations of $\mathbf{x_1}$ and $\mathbf{x}_2$.

We start with the basis of the down-type quarks as

$$F_d = \begin{bmatrix} \mathbf{x_1} \\ \mathbf{x}_2 \\ \mathbf{x}_3 \end{bmatrix} = \begin{bmatrix} 1/\sqrt{2} & -1/\sqrt{2} & 0 \\ 1/\sqrt{6} & 1/\sqrt{6} & -2/\sqrt{6} \\ 1/\sqrt{3}1 & 1/\sqrt{3} & 1/\sqrt{3} \end{bmatrix} . \qquad (2.18)$$

The eigenvectors of, M_u, $\mathbf{x_1}'$, $\mathbf{x}_2'$ and $\mathbf{x}_3'$, are given as

$$\begin{cases} \mathbf{x_1}' = \mathbf{x_1} \cos\theta + \mathbf{x}_2 \sin\theta \\ \mathbf{x}_2' = -\mathbf{x_1} \sin\theta + \mathbf{x}_2 \cos\theta \\ \mathbf{x}_3' = \mathbf{x}_3 \end{cases} , \qquad (2.19)$$

providing the basis of the up-type quarks,

$$F_u = \begin{bmatrix} \mathbf{x_1}' \\ \mathbf{x}_2' \\ \mathbf{x}_3' \end{bmatrix} = \begin{bmatrix} \mathbf{x_1} \cos\theta + \mathbf{x}_2 \sin\theta \\ \mathbf{x_1} \sin\theta - \mathbf{x}_2 \cos\theta \\ \mathbf{x}_3 \end{bmatrix} , \qquad (2.20)$$

where $\mathbf{x_1}'$, $\mathbf{x}_2'$ and $\mathbf{x}_3'$ are orthogonal each other. The CKM matrix is given by

$$V_{CKM} \sim F_u F_d^{\dagger} , \qquad (2.21)$$

which in the democratic limit becomes as

$$V_{CKM} \sim \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} . \tag{2.22}$$

By taking the input value $\theta = 0.227$ [rad], the experimental value of the quark mixing between the first and second generations is naturally reproduced in the democratic limit.

The quark mass matrices, which are supposed to be Hermitian, are diagonalized by unitarity matrices $V_{\alpha L}$'s as

$$M_\alpha \;\Rightarrow\; V_{\alpha L} M_\alpha V_{\alpha L}^\dagger = \begin{bmatrix} m_{\alpha 1} & 0 & 0 \\ 0 & m_{\alpha 2} & 0 \\ 0 & 0 & m_{\alpha 3} \end{bmatrix} , \tag{2.23}$$

where $m_{u1} = m_u$, $m_{u2} = m_c$, $m_{u3} = m_t$, $m_{d1} = m_d$, $m_{d2} = m_s$, $m_{d3} = m_b$. Because the hierarchy of the up-type quark masses is larger than that of the down-type ones, we suppose that

$$\begin{aligned} V_{uL} &\simeq F_u \;, \\ V_{dL} &\sim F_d \;. \end{aligned} \tag{2.24}$$

Then, we obtain

$$\begin{aligned} V_{dL} &= V_{CKM}^\dagger V_{uL} \simeq V_{CKM}^\dagger F_u \;, \\ M_d &= V_{dL}^\dagger M_{d.diag} V_{dL} \simeq F_u^T V_{CKM} M_{d.diag} V_{CKM}^\dagger F_u \\ &= \frac{m_b}{3}\left[\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} + P_{ij} + iQ_{ij}\right] , \end{aligned} \tag{2.25}$$

where

$$P_{ij} = \begin{bmatrix} 0.05257 & 0.06777 & -0.06171 \\ 0.06777 & 0.09052 & -0.04435 \\ -0.06171 & -0.04435 & -0.06616 \end{bmatrix} ,$$

$$Q_{ij} = \begin{bmatrix} 0 & -0.008104 & -0.005279 \\ 0.008104 & 0 & 0.002101 \\ 0.005279 & -0.002101 & 0 \end{bmatrix}. \tag{2.26}$$

3. Determination of the USY phases

There are four conditions in this model as

1. $\left|v_1 + v_2 e^{i\delta}\right| = 256\,[\mathrm{GeV}]$ from m_Z,
2. $\dfrac{\lambda_Y}{\sqrt{2}}\left|v_1 + v_2 e^{i\alpha_u'}\right| = \dfrac{m_t}{3}$ from m_t ,
3. $114.4[\mathrm{GeV}] \le \sqrt{2\lambda'}v_1, \sqrt{2\lambda'}v_2 \le 191[\mathrm{GeV}]$ from m_{ϕ_1} and m_{ϕ_2},
4. Eq.(2.25) $M_d \simeq \dfrac{m_b}{3}\left[\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} + P_{ij} + iQ_{ij}\right]$ for the d-type quark masses. (3.1)

The mass matrix of the down-type quarks is expanded perturbatively as

$$\begin{aligned}
M_d &= \frac{\lambda_Y}{\sqrt{2}}\left(v_1 e^{i\alpha_d} \cdot e^{i\theta_{dij}^{(1)\prime}} - v_2 e^{i\beta_d'} \cdot e^{i\theta_{dij}^{(2)\prime}}\right)\overline{d_{iL}}d_{jR} \\
&= \frac{\lambda_Y}{\sqrt{2}}\left[v_1(\cos\alpha_d + i\sin\alpha_d)(1 + i\theta_{dij}^{(1)\prime}) - v_2(\cos\beta_d' + i\sin\beta_d')\,(1 + i\theta_{dij}^{(2)\prime})\right] \\
&= \left(\frac{\lambda_Y v_1}{\sqrt{2}} e^{i\alpha_d} - \frac{\lambda_Y v_2}{\sqrt{2}} e^{i\beta_d'}\right) + \frac{\lambda_Y}{\sqrt{2}}(-v_1\theta_{dij}^{(1)\prime}\sin\alpha_d + v_2\theta_{dij}^{(2)\prime}\sin\beta_d') + \\
&\qquad i\frac{\lambda_Y}{\sqrt{2}}(v_1\theta_{dij}^{(1)\prime}\cos\alpha_d - v_2\theta_{dij}^{(2)\prime}\cos\beta_d') \\
&= \frac{m_b}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} + \frac{\lambda_Y}{\sqrt{2}}(-v_1\theta_{dij}^{(1)\prime}\sin\alpha_d + v_2\theta_{dij}^{(2)\prime}\sin\beta_d') + \\
&\qquad i\frac{\lambda_Y}{\sqrt{2}}(v_1\theta_{dij}^{(1)\prime}\cos\alpha_d - v_2\theta_{dij}^{(2)\prime}\cos\beta_d')
\end{aligned} \tag{3.2}$$

with

$$\theta_{dij}^{(1)} = \alpha_d + \theta_{dij}^{(1)\prime} = \alpha_d{}' + \delta + \theta_{dij}^{(1)\prime} (\alpha_d{}' = \alpha_d - \delta) \ ,$$

$$\theta_{dij}^{(2)} = \beta_d + \theta_{dij}^{(2)\prime} = \beta_d{}' - \delta + \pi + \theta_{dij}^{(2)\prime} (\ \beta_d{}' = \beta_d - \delta + \pi\ ). \qquad (3.3)$$

The α_d and $\beta_d{}'$ for the center of perturbation are given as (see Fig. 1)

$$\cos\alpha_d = \frac{3}{2m_b v_1} \cdot \frac{\sqrt{2}}{\lambda_Y} \left[\left(\frac{\lambda_Y}{\sqrt{2}} \right)^2 (v_1^2 - v_2^2) + \frac{m_b{}^2}{9} \right],$$

$$\cos\beta_d{}' = \frac{3}{2m_b v_2} \cdot \frac{\sqrt{2}}{\lambda_Y} \left[\left(\frac{\lambda_Y}{\sqrt{2}} \right)^2 (v_1^2 - v_2^2) - \frac{m_b{}^2}{9} \right],$$

$$\sin\alpha_d = \frac{3}{2m_b v_1} \cdot \frac{\sqrt{2}}{\lambda_Y} \sqrt{ \frac{m_b{}^2 \lambda_Y^2}{9} (v_1^2 + v_2^2) - \left(\frac{\lambda_Y}{\sqrt{2}} \right)^4 (v_1^2 - v_2^2) - \frac{m_b{}^2}{9} } \ ,$$

$$\sin\beta_d{}' = \frac{3}{2m_b v_2} \cdot \frac{\sqrt{2}}{\lambda_Y} \sqrt{ \frac{m_b{}^2 \lambda_Y^2}{9} (v_1^2 + v_2^2) - \left(\frac{\lambda_Y}{\sqrt{2}} \right)^4 (v_1^2 - v_2^2) - \frac{m_b{}^2}{9} } \ . \qquad (3.4)$$

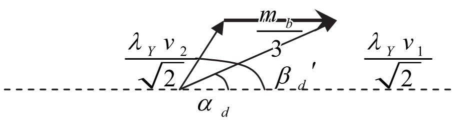

Fig1. The center of perturbation.

From Eqs. (3.1) and (3.2), the USY phases are detemined as

$$\theta_{dij}^{(1)\prime} = \frac{\sqrt{2} m_b}{3 v_1 \lambda_Y} \cdot \frac{(P_{ij} \cos\beta_d{}' + Q_{ij} \sin\beta_d{}')}{\sin(\alpha_d - \beta_d{}')} \ (\theta_{dij}^{(1)} = \alpha_d + \theta_{dij}^{(1)\prime}),$$

$$\theta_{dij}^{(2)\prime} = -\frac{\sqrt{2} m_b}{3 v_2 \lambda_Y} \cdot \frac{(P_{ij} \cos\alpha_d + Q_{ij} \sin\alpha_d)}{\sin(\alpha_d - \beta_d{}')} \ (\theta_{dij}^{(2)} = \beta_d{}' + \theta_{dij}^{(2)\prime}). \qquad (3.5)$$

We present a numerical result by taking the following values for the input parameters.

- Phases of the Yukawa couplings

$\theta_{uij}^{(1)} \simeq 0,\ \theta_{uij}^{(2)} \simeq 0,$

$\theta_{d11}^{(1)} = 1.531,\ \theta_{d12}^{(1)} = 1.523,\ \theta_{d13}^{(1)} = 1.525,\ \theta_{d21}^{(1)} = 1.539,\ \theta_{d22}^{(1)} = 1.531,$

$\theta_{d23}^{(1)} = 1.532,\ \theta_{d31}^{(1)} = 1.536,\ \theta_{d32}^{(1)} = 1.528,\ \theta_{d33}^{(1)} = 1.530,$

$\theta_{d11}^{(2)} = 4.710,\ \theta_{d12}^{(2)} = 4.702,\ \theta_{d13}^{(2)} = 4.700,\ \theta_{d21}^{(2)} = 4.718,\ \theta_{d22}^{(2)} = 4.711,$

$\theta_{d23}^{(2)} = 4.708,\ \theta_{d31}^{(2)} = 4.710,\ \theta_{d32}^{(2)} = 4.704,\ \theta_{d33}^{(2)} = 4.705,$

- Vacuum expectation values

$v_1 = 128.053,\ v_2 = 127.951,$

- Moduli of the Yukawa couplings

$\lambda_Y = 0.438\ .$

The output values are given as

$$V_{CKM} = \begin{bmatrix} 0.9739 & 0.2269 - 0.009i & 0.0021 - 0.0034i \\ -0.2267 - 0.009i & 0.9731 & 0.0406 \\ 0.0072 - 0.0029i & -0.0401 & 0.9992 \end{bmatrix}, \quad (3.6)$$

$m_u = 0.003[\mathrm{GeV}],\ m_c = 1.25[\mathrm{GeV}],\ m_t = 174.2[\mathrm{GeV}],$

$m_d = 0.005[\mathrm{GeV}],\ m_s = 0.095[\mathrm{GeV}],\ m_b = 4.21[\mathrm{GeV}]$

and, $J = 3.1 \times 10^{-5}$. They are all consistent with the experimental values [3].

4. Summary

The THDM within USY hypothesis provides a possible solution to the flavor problem in the SM. In this study, three ansatz are imposed as follows.

- Both Higgs doublets couple to the u-type quarks and d-type quarks.
- The moduli of the Yukawa couplings for the up-type quarks are the same as those for the down-type quarks.
- The vev's of the two Higgs doublets take almost the same absolute values.

Based on these ansatz, the USY phases are determined systematically. It is confirmed by a numerical calculation that the experimental values are all reproduced for the quark masses, V_{CKM}, and the rephrasing invariant CP violation measure J. A detailed investigation of the scalar mediated FCNC's is deserved for a future task.

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