Chiral two-Higgs doublet models and flavor-changing neutral currents at tree level

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The two-Higgs model and benefits

Benefits of having a second Higgs doublet

- The scalar sector of the 2HDM can provide a solution to the CP problem.
- The inert model, one kind of 2HDM, could be a candidate to explain dark matter.
- It could explain the fermion mass spectrum, which is related to the 2HDM Yukawa couplings between the Higgs field and the fermions.

The two-Higgs doublet model elements

There are 5 Higgs bosons H h A $\rightarrow$ 3 Neutral

(1)

And $H^{\pm}$ $\rightarrow$ 2 Charged

(2)

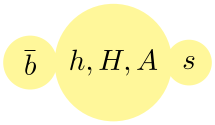
The Yukawa sector in 2HDM

The Yukawa sector of quarks in the 2HDM

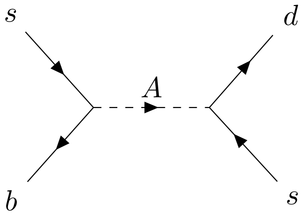
- There is no reason to expect that both Yukawa couplings $Y_{ij}^{d(1)}$, $Y_{ij}^{d(2)}$ or $Y_{ij}^{u(1)}$, $Y_{ij}^{u(2)}$ are diagonal in the same basis.

$$\begin{aligned}\mathcal{L}_{Yukawa_{2HDM}} &= Y_{ij}^{d(1)}\bar{Q}'_{Li}\Phi_1 d'_{Rj} + Y_{ij}^{d(2)}\bar{Q}'_{Li}\Phi_2 d'_{Rj} \\ &+ Y_{ij}^{u(1)}\bar{Q}'_{Li}\tilde{\Phi}_1 u'_{Rj} + Y_{ij}^{u(2)}\bar{Q}'_{Li}\tilde{\Phi}_2 u'_{Rj}\end{aligned} \tag{3}$$

Flavor-changing neutral currents (FCNC) in the 2HDM



This will induce FCNC at tree level via the interchange of a neutral bosons



Feynman diagram at tree level flavor processes in a 2HDM

(4)

Flavor-changing neutral currents (FCNC) in the 2HDM

How to suppress the FCNC?

- The problem can be avoided by forcing one of the matrices to be zero.
- Type I 2HDM and Type II 2HDM contain a discrete symmetry that suppress and thus avoid FCNC, however, they are artificial.

Flavor-changing neutral currents (FCNC) in the 2HDM

How to suppress the FCNC?

- For example, we use the type I 2HDM, and we obtain:

$$\begin{aligned}\mathcal{L}_{Yukawa_{2HDM_{TypeI}}} &= Y_{ij}^{d(1)}\bar{Q}'_{Li}\Phi_1 d'_{Rj} + Y_{ij}^{d(2)}\bar{Q}'_{Li}\Phi_2 d'_{Rj} \\ &+ Y_{ij}^{u(1)}\bar{Q}'_{Li}\tilde{\Phi}_1 u'_{Rj} + Y_{ij}^{u(2)}\bar{Q}'_{Li}\tilde{\Phi}_2 u'_{Rj}\end{aligned} \tag{5}$$

$$\mathcal{L}_{Yukawa_{2HDM_{TypeI}}} = \underbrace{Y_{ij}^{d(2)}\bar{Q}'_{Li}\Phi_2 d'_{Rj} + Y_{ij}^{u(2)}\bar{Q}'_{Li}\tilde{\Phi}_2 u'_{Rj}} \tag{6}$$

The chiral two-Higgs doublet model

Features

- It has the following representation:

$$\begin{aligned} &\gamma^0\Phi_1 \to \gamma_R\gamma^0\Phi_1\gamma_L, \quad \gamma_{R,L} = \frac{1}{2}(1\pm\gamma^5), \\ &\gamma^0\Phi_2 \to \gamma_L\gamma^0\Phi_2\gamma_R, \end{aligned} \tag{7}$$

and

$$\begin{aligned} &\gamma^0\tilde{\Phi}_1 \to \gamma_R\gamma^0\tilde{\Phi}_1\gamma_L, \\ &\gamma^0\tilde{\Phi}_2 \to \gamma_L\gamma^0\tilde{\Phi}_2\gamma_R \end{aligned} \tag{8}$$

The chiral two-Higgs doublet model

Where does it come from?

- This chiral type of 2HDM emerges naturally in the (7+1)-d spin basis, of the spin extended model.

The chiral two-Higgs doublet model

How does it help with the problem of FCNC?

- Introducing eq(6) and eq(7) into the $\mathcal{L}_{Yukawa_{2HDM}}$, we get

$$\mathcal{L}_{Yukawa_{2HDM_{Chiral}}} = Y_{ij}^{d(1)} Q_{Li}^{\dagger\prime} \gamma_R \gamma^0 \Phi_1 \gamma_L d'_{Rj} + Y_{ij}^{d(2)} Q_{Li}^{\dagger\prime} \gamma_L \gamma^0 \Phi_2 \gamma_R d'_{Rj} + Y_{ij}^{u(1)} Q_{Li}^{\dagger\prime} \gamma_R \gamma^0 \tilde{\Phi}_1 \gamma_L u'_{Rj} + Y_{ij}^{u(2)} Q_{Li}^{\dagger\prime} \gamma_L \gamma^0 \tilde{\Phi}_2 \gamma_R u'_{Rj} \quad (9)$$

The chiral two-Higgs doublet model

How does it help with the problem of FCNC?

- Finally we obtain

$$\mathcal{L}_{Yukawa_{2HDM_{Chiral}}} = Y_{ij}^{d(2)} \bar{Q}'_{Li} \Phi_2 d'_{Rj} + Y_{ij}^{u(2)} \bar{Q}'_{Li} \tilde{\Phi}_2 u'_{Rj} \qquad (10)$$

The Type I 2HDM and the chiral 2HDM

Comparing both models

- We see that

$$\mathcal{L}_{Yukawa_{2HDM_{TypeI}}} = Y_{ij}^{d(1)} \bar{Q}'_{Li} \Phi_1 d'_{Rj} + Y_{ij}^{u(1)} \bar{Q}'_{Li} \tilde{\Phi}_1 u'_{Rj}. \qquad (11)$$

$$\mathcal{L}_{Yukawa_{2HDM_{Chiral}}} = Y_{ij}^{d(1)} \bar{Q}'_{Li} \Phi_1 d'_{Rj} + Y_{ij}^{u(1)} \bar{Q}'_{Li} \tilde{\Phi}_1 u'_{Rj} \qquad (12)$$

Main points

Main points

- The 2HDM is useful, as for solving the CP problem.
- However, it generates FCNC at tree level.
- The chiral 2HDM presented is a type I model, and thus avoids them.
- This type chiral model is predicted by the Spin Extended Model.

Main points

Gracias Amigous