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Missing Partner Mechanism in SO(10) Grand Unification

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SUSY SU(5) GUT

Higgs sector $\longrightarrow$ $\mathbf{5}$, $\overline{\mathbf{5}}$, $\mathbf{24}$

$$\langle \mathbf{24} \rangle = \mathbf{V} \times \mathbf{diag}(1, 1, 1, -3/2, -3/2)$$

$$\mathbf{SU(5)} \rightarrow \mathbf{SU(3)_c \times SU(2)_L \times U(1)_Y}$$

$$\mathbf{5} = \mathbf{h_u}(1, 2, 1/2) + \mathbf{T}(3, 1, -1/3)$$
$$\overline{\mathbf{5}} = \mathbf{h_d}(1, 2, -1/2) + \overline{\mathbf{T}}(\overline{3}, 1, 1/3)$$

$$\mathbf{W} \supset \mathbf{M_5 5} \cdot \overline{\mathbf{5}} + \lambda\ \mathbf{5} \cdot \overline{\mathbf{5}} \cdot \mathbf{24}$$

$\mathbf{m_D = M_5 - (3/2)\lambda V}$ and $\mathbf{m_T = M_5 + \lambda V}$

The possible mechanisms

- The Missing VEV Mechanism
- The Sliding-singlet Mechanism
- The pseudo–Goldstone mechanism
- The Missing Partner Mechanism

The Missing VEV Mechanism
SUSY SO(10) GUT

$$\mathbf{3\times 16,\ 10,\ 10',\ 45,\ 54,\ ....}$$

Yukawa interaction $: 16\cdot 16\cdot 10$

$$\langle \mathbf{45}\rangle = \mathrm{diag}(\mathbf{a,a,a,0,0})\otimes \mathbf{i}\tau_{\mathbf{2}}.$$

$$\mathbf{W} \supset \mathbf{M_{10}10'10' + \lambda\ 10\cdot 10'\cdot 45},$$

The mass matrix for color-triplets is

$$(\bar{\mathbf{3}}\ \bar{\mathbf{3}})\begin{pmatrix} 0 & \lambda_1 \mathbf{a} \\ -\lambda_1 a & \mathbf{M_{10}} \end{pmatrix}\begin{pmatrix} \mathbf{3} \\ \mathbf{3} \end{pmatrix},$$

The mass matrix for doublets is

$$(\bar{\mathbf{2}}\ \bar{\mathbf{2}})\begin{pmatrix} \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{M_{10}} \end{pmatrix}\begin{pmatrix} \mathbf{2} \\ \mathbf{2} \end{pmatrix},$$

Realization of Missing VEV Mechanism for SUSY SU(N) GUT see: J. L. Chkareuli, I. G. Gogoladze and A. B. Kobakhidze, Phys. Rev. Lett. 80 (1998) 912.

The Sliding-singlet Mechanism
SUSY SU(5) GUT

$$\mathbf{W = \bar{5} \cdot (24 + 1) \cdot 5}$$

$$\langle \mathbf{24} \rangle = \mathbf{V}\mathrm{diag}(-\frac{2}{3}, -\frac{2}{3}, -\frac{2}{3}, \mathbf{1}, \mathbf{1})$$

$$\mathbf{F_5 = 0 \Rightarrow (\langle 24 \rangle - \langle 1 \rangle) \cdot \langle \bar{5} \rangle = 0}$$

Since the SM Higgs doublet develops VEV

$$\langle \mathbf{1} \rangle = -\mathbf{V} \Rightarrow \langle \mathbf{24} \rangle + \langle \mathbf{1} \rangle = \mathbf{V}\mathrm{diag}(-\frac{5}{3}, -\frac{5}{3}, -\frac{5}{3}, \mathbf{0}, \mathbf{0})$$

Unfortunately the mechanism dos't works in SU(5) case. To make it work one needs to go SU(6) theory.

The pseudo–Goldstone mechanism
SUSY SU(6) GUT

$\mathbf{35}$ dos't couple to $(\mathbf{6}+\bar{\mathbf{6}})$

$$\Rightarrow \mathbf{SU(6)_{35}} \otimes \mathbf{SU(6)_{6,\bar{6}}}$$

$$\langle \mathbf{35} \rangle = \mathbf{V} \cdot \text{diag}(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1},-\mathbf{2},-\mathbf{2})$$

$\mathbf{SU(6)_{35}} \to \mathbf{SU(4)} \times \mathbf{SU(2)} \times \mathbf{U(1)}$:

$\mathbf{35} - (\mathbf{15}+\mathbf{3}+\mathbf{1}) = \mathbf{16}$

$\mathbf{SU(6)_{(6,\bar{6})}} \to \mathbf{SU(5)}$:

$\mathbf{35} - \mathbf{24} = \mathbf{11}$

$\mathbf{SU(6)} \to \mathbf{SU(3)_C} \times \mathbf{SU(2)_L} \times \mathbf{U(1)_Y}$:

$\mathbf{35} - (\mathbf{8}+\mathbf{3}+\mathbf{1}) = \mathbf{23}$

$\mathbf{16}+\mathbf{11}-\mathbf{23} = \mathbf{4} = \mathbf{2}+\mathbf{2}$

The Missing Partner Mechanism SUSY SU(5) GUT

Higgs sector

$$\mathbf{5+\bar{5}(h+\bar{h}),\ 50+\overline{50}(\psi+\bar{\psi}),\ 75(\phi)}$$

$$\mathbf{SU(5) \to SU(3)_c \times SU(2)_L \times U(1)_Y}$$

$$\mathbf{5 = (3,1)_{-2} + (1,2)_3}$$
$$\mathbf{50 = (1,1)_{-12} + (3,1)_{-2} + (3,2)_{-7} + (6,3)_{-2}}$$
$$+(6,1)_8 + (8,2)_3$$
$$\mathbf{75 = (1,1)_0 + (3,1)_{10} + (3,2)_{-5} \ldots\ldots}$$

$$\mathbf{W} \supset \phi\mathbf{h}\bar{\psi} + \phi\bar{\mathbf{h}}\psi + \mathbf{M}_\psi\bar{\psi}\psi \quad \text{after} \quad \langle\phi\rangle \sim \mathbf{V}_\phi$$

$$\left(\bar{\mathbf{T}}_\mathbf{h}\ \bar{\mathbf{T}}_\psi\right)\begin{pmatrix} 0 & \mathbf{V}_\phi \\ V_\phi & \mathbf{M}_\psi \end{pmatrix}\begin{pmatrix} \mathbf{T}_\mathbf{h} \\ \mathbf{T}_\psi \end{pmatrix},$$

At this level the doublets from $5+\overline{5}$ are massless since there are no doublets in the $50+\overline{50}$.

SUSY SO(10) GUT

The lowest dimensional Higgs representations which has a missing doublet in **SO(10)** is the $126 + \overline{126}$

$\mathbf{SU(5) \times U(1)}$ decomposition

$$\mathbf{126 = 1_{-10} + \bar{5}_{-2} + 10_{-6} + \overline{15}_{6} + 45_{2} + \overline{50}_{-2}}$$

$$\mathbf{16 \cdot 16 \cdot 10 \;\; \Rightarrow \;\; 10 \cdot 126 \cdot (210 + 1050)}$$

$$\mathbf{210 = 1_{0} + 24_{0} + 75_{0} + 5_{-8} + \bar{5}_{8} \ldots.}$$

$$\mathbf{120 = 5_{2} + \bar{5}_{-2} + 10_{-6} + \overline{10}_{6} + 45_{2} + \overline{45}_{-2}}$$

$$\mathbf{210 \cdot 126 \cdot (10 + 120) + 210 \cdot \overline{126} \cdot (10 + 120)}$$
$$\mathbf{+ M_{\Delta} 126 \cdot \overline{126}}$$

$\langle 126 \rangle = \langle 1\bar{2}6 \rangle = 0$ and $\langle 210 \rangle \neq 0$

$$\mathbf{126 + \overline{126} \supset 2 \times (2 + 2) + 3 \times (3 + \bar{3})}$$

$$120 \supset 2 \times (2 + 2) + 2 \times (3 + \bar{3})$$

$$10 \supset 1 \times (2 + 2) + 1 \times (3 + \bar{3})$$

One needs to forbid the couplings

$$\mathbf{M_{1} 120 \cdot 120 + M_{2} 10 \cdot 10 + 120 \cdot 10 \cdot 210}$$

Explicit SO(10) Models

It is much more convenient if the $\mathbf{126}$-plets involved in the DT splitting have no VEVs.

For the rank breaking we can use either a scalar $\mathbf{16}+\overline{16}$-plets or another $\mathbf{126}+\overline{126}$-plets.

$$\begin{array}{lll} (\mathbf{a}) \ : & C = 16 & \bar{C} = \overline{16} \\ (\mathbf{b}) \ : & C = 126 & \bar{C} = \overline{126} \end{array}$$

The goal is to have all order DT splitting. We introduce additional $U(1)_A$ symmetry. $U(1)$ charges of the superfield are

$$\begin{array}{l} H(10) : 1, \ \Sigma(120) : 1, \ \Delta(126) : -1, \\ \overline{\Delta}(\overline{126}) : -1, \ \Phi(210) : 0, \ 16_i : -1/2 \\ C(16) : 3/2, \ \overline{C}(\overline{16}) : -3/2 \\ C(126) : 3, \ \overline{C}(\overline{126}) : -3 \\ X : 2 \end{array}$$

$$W_{\mathrm{DT}} = \Phi\Delta(H+\Sigma) + \Phi\bar{\Delta}(H+\Sigma) + X\bar{\Delta}\Delta$$

The couplings important for the symmetry breaking are

$$\mathbf{W(\Phi, C)} = \frac{\lambda}{3}\mathbf{\Phi^3} + \frac{M_\Phi}{2}\mathbf{\Phi^2} + \mathbf{\bar{C}C(M_C} + \sigma\mathbf{\Phi)}$$

$$\langle \Phi \rangle \simeq \langle C \rangle \simeq \bar{C} = M_{GUT}$$

Having $U(1)_A$ symmetry we can forbid $\mathbf{H^2, \Sigma^2, \Phi H \Sigma}$ coupling and it also guarantees that $\langle \mathbf{\Delta} \rangle = \mathbf{0}$. Because operators such as $\overline{\Delta}\Delta(H^2 + \Sigma^2)$ will destroy DT splitting.

Yukawa Sector

$$\sum_{k=0} \left(\frac{\Phi}{M}\right)^k 16_i 16_j 10 + \sum_{k=0} \left(\frac{\Phi}{M}\right)^k 16_i 16_j 120$$

only renormalizable couplings $16 \cdot 16 \cdot 10$ and $16 \cdot 16 \cdot 120$ do not give desirable fermion mass pattern.

Majorana masses for the right handed neutrinos

$$\frac{X^2}{M_*^3} 16_i 16_j \bar{C}\bar{C}$$

such couplings can be generated from renormalizable interactions.

Conclusion

we have proposed a new solution of the DT splitting problem within $\mathrm{SO}(10)$ GUT via a missing partner mechanism. For this mechanism to be realized through renormalizable superpotential couplings we have considered the scalar superfield content $\mathbf{10}+\mathbf{120}+\mathbf{126}+\overline{\mathbf{126}}+\mathbf{210}$ and the $\mathrm{SO}(10)$ rank breaking states $C, \bar{C}$. For the latter, two possibilities **(a):** $\mathrm{C}=16, \bar{\mathrm{C}}=\overline{16}$ and **(b):** $C=126, \bar{C}=\overline{126}$ can be considered with equal success.

- Gauge coupling perturbativity above the GUT scale.

- Proton stability

- more detailed study with accurate calculation of the mass spectrum is needed