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Proton Stability In SUSY SU(5)
[by Split Multiplet Mechanism]

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Outline

- Motivations for GUTs
- Problems & Shortcomings
  → Calling for Mechanisms
- Baryon Number Violation -
  (in SUSY) d=5 Proton Decay
- Solution: Split Multiplet Mechanism
  SU(5) Model → Prediction for $\tau_p (\geq \tau_p^{\exp})$
- Summary

Supersymmetric Grand Unification (SUSY GUT)

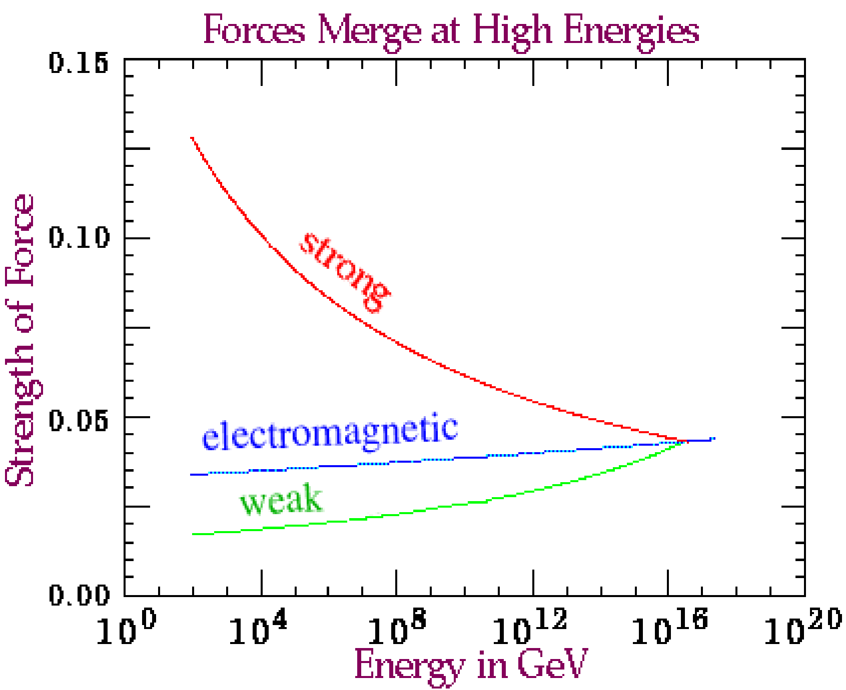
→ Solution of some problems/puzzles.

- **Unification of Forces**

$$SU(3)_c \times SU(2)_L \times U(1)_Y \subset G[= SU(5), SO(10), E_6, \cdots]$$

$\rightarrow$ Single coupling - $g_1 = g_2 = g_3$ at $M_{\rm GUT}$

(consistent with SUSY) →



SUSY →

- Solution of Hierarchy problem
- SUSY "Zoo" near TeV…
- Automatic coupling unification

- # Matter Unification

In $SU(5)$: $(q,\ u^c,\ e^c) = \mathbf{10}\ ,\quad (d^c,\ l) = \bar{\mathbf{5}}$

In $SO(10)$: $(q,\ u^c,\ e^c,\ d^c,\ l, \nu_R) = \mathbf{16}$

Unified Multiplets

- $\rightarrow$ Charge Quantization - $\frac{Y(q)}{Y(u^c)} = -\frac{1}{4},\ \frac{Y(q)}{Y(e^c)} = \frac{1}{6}\ , \cdots$
- $\rightarrow$ Some GUT Relations - In $SU(5)$: $\lambda_b = \lambda_\tau$

In $SO(10)$: $\lambda_t = \lambda_b = \lambda_\tau$

Good

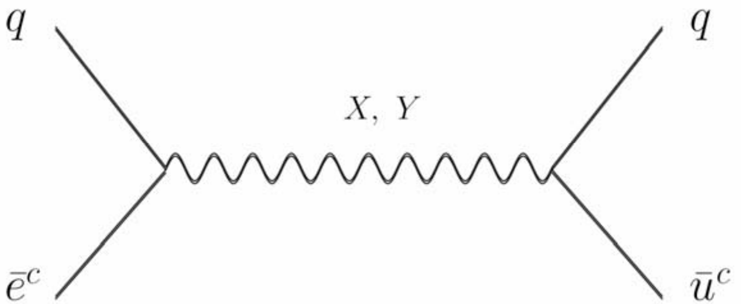
In SU(5): $m_\mu = m_s,\ m_e/m_\mu = m_d/m_s$ **Problematic**

GUT Main Prediction:

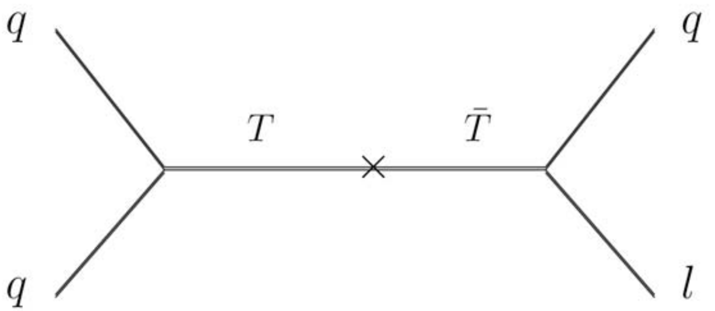
Baryon Number Violation: $\Delta B \neq 0$ → Proton Decay

- Gauge Mediated d=6 Decay

  X, Y $\subset$ GUT/SM



- In SUSY: new d=5 Decays



$T, \bar{T} \subset$ "Unified Higgses" :

$H(5)=(h_u, T)$, $\bar{H}(\bar{5})=(h_d, \bar{T})$

Too Fast Decay

SUSY GUT →

- Charge Quantization
- Successful Coupling Unification
- Stabile Hierarchy (Light Higgs) ← low SUSY scale
- B-violation → proton decay

Unified Multiplets → Fast d=5 decay and wrong mass relations

In $SU(5)$: **Matter** $(q,\ u^c,\ e^c) = \mathbf{10}\ ,\quad (d^c,\ l) = \bar{\mathbf{5}}$

Higgses $H(5) = h_u(1,2)_{-3} + T(3,1)_2 \qquad \bar{H}(\bar{5}) = h_d(1,2)_3 + \bar{T}(\bar{3},1)_{-2}$

Unified Couplings:

$$\begin{cases} \lambda 10 \cdot 10 H = \lambda \left(q u^c h_u + q q T + e^c u^c T \right) \\ \lambda' 10 \cdot \bar{5} \bar{H} = \lambda' \left(q d^c h_d + e^c l h_d + q l \bar{T} + u^c d^c \bar{T} \right) \end{cases}$$

$$\hat{M}_E = \hat{M}_D \quad , \qquad \frac{\lambda\lambda'}{M_T} (qqql)_F \ , \qquad \frac{\lambda\lambda'}{M_T} (u^c u^c d^c e^c)_F$$

Problematic Couplings

Minimal SUSY SU(5): $\tau(p \to K^{+}\nu)/4.5 * 10^{27}$ years

Units

$\tau_p^{\text{exp}}(p \to K\nu) \gtrsim 7 \cdot 10^{32}$ yrs

$m_{\tilde{W}}$ / $m_{\tilde{q}}$	100 GeV	200 GeV	500 GeV	1 TeV	5 TeV	10 TeV
100 GeV	0.04	0.03	0.04	0.07	0.54	1.48
200 GeV	0.31	0.16	0.13	0.17	0.84	2.14
500 GeV	7.7	2.6	1	0.78	1.8	4.0
1 TeV	$1.1 \cdot 10^2$	30.7	7.8	4	4.2	7.4
5 TeV	$6.3 \cdot 10^4$	$1.6 \cdot 10^4$	$2.7 \cdot 10^3$	$7.7 \cdot 10^2$	10^2	78
10 TeV	10^6	$2.5 \cdot 10^5$	$4.1 \cdot 10^4$	$1.1 \cdot 10^4$	$7.8 \cdot 10^2$	$4 \cdot 10^2$

Unnatural choice

Z. Berezhiani, Z. T., M. Vysotsky, hep-ph/9809301

Solution: Split Multiplet Mechanism [In SU(5)]

- Quarks and Leptons Come From Different GUT States

Matter Extension: add $15+15^*$

$$15 = q(3,2)_{-1} + S(6,1)_4 + \Delta(1,3)_{-6}$$

LH-quark Exotic states

Mixing coupling: $10\Sigma\bar{15} + M_{15} 15 \cdot \bar{15}$

IF $\langle\Sigma(24)\rangle >> M_{15}$ Multiplets will split

$$15 \supset q \;, \qquad 10 \supset \epsilon q \qquad \text{with} \qquad \epsilon \equiv \frac{M_{15}}{M_G} \qquad u^c \;, e^c \subset 10$$

$$Y\frac{\Sigma}{M_*} 15 \cdot 10 H \to Y_U \left(q u^c h_u + \epsilon q q T\right)$$

Suppression

No $e^c u^c T$ Coupling

Similar Can Happen including 3 Families

$$Y_U = \begin{array}{c} \\ q_1 \\ q_2 \\ q_3 \end{array}\!\!\begin{array}{c} \begin{array}{ccc} u_1^c & u_2^c & u_3^c \end{array} \\ \begin{pmatrix} a_1 & a_{12} & a_{13} \\ a_{21} & a_2 & a_{23} \\ a_{31} & a_{32} & a_3 \end{pmatrix} \end{array}$$

Up Quark Yukawas

$$Y_{qq} \simeq \begin{array}{c} \\ q_1 \\ q_2 \\ q_3 \end{array}\!\!\begin{array}{c} \begin{array}{ccc} q_1 & q_2 & q_3 \end{array} \\ \begin{pmatrix} \epsilon_1 a_1 & \epsilon_{12}\bar{a}_{12} & \epsilon_{13}\bar{a}_{13} \\ \epsilon_{12}\bar{a}_{12} & \epsilon_2 a_2 & \epsilon_{23}\bar{a}_{23} \\ \epsilon_{13}\bar{a}_{13} & \epsilon_{23}\bar{a}_{23} & \epsilon_3 a_3 \end{pmatrix} \end{array}$$

$\mathcal{E}$ **-Suppressions of qqT cpuplings**

Suppression of $ql\bar{T}$ by 5* -Splitting

Matter Extension: add $\bar{5}' + 5'$, $\Psi(50) + \bar{\Psi}(\bar{50})$

No SU(2)L Doublets

$$
\begin{array}{c} \\ d^c_{\bar{5}} \\ d^c_{\bar{5}'} \\ d^c_{\bar{\Psi}} \end{array}
\begin{array}{c} \begin{array}{cc} \bar{d}^c_{5'} & \bar{d}^c_{\Psi} \end{array} \\
\begin{pmatrix} M_5 & 0 \\ 0 & M_G \epsilon_G \\ M_G \epsilon_G & M_\Psi \end{pmatrix} \end{array} , \qquad
\begin{array}{c} \\ l_{\bar{5}'} \\ l_{\bar{5}} \end{array}
\begin{array}{c} \bar{l}_{5'} \\ \begin{pmatrix} 0 \\ M_5 \end{pmatrix} \end{array}
$$

Splitting is realized

$$\bar{5} \supset d^c \ , \quad \bar{5}' \supset l \ , \epsilon'' d^c \ ,$$

$$\epsilon'' = \frac{M_5}{\tilde{M}} \ll 1 \ , \quad \tilde{M} \sim \rho\bar{\rho} \frac{M_G^2}{M_\Psi} \epsilon_G^2 \ .$$

$$Y_D 15 \cdot \bar{5} \bar{H} \rightarrow Y_D q d^c h_d \ ,$$

$$Y_E 10 \cdot \bar{5}' \bar{H} \rightarrow Y_E \left(e^c l h_d + \underbrace{\epsilon q l \bar{T}} + \underbrace{\epsilon'' u^c d^c \bar{T}} \right)$$

Suppressions

Similar Can Happen with 3 Families

$$Y_E = \begin{array}{c} \\ e_1^c \\ e_2^c \\ e_3^c \end{array} \begin{array}{c} \begin{array}{ccc} l_1 & l_2 & l_3 \end{array} \\ \begin{pmatrix} b_1 & b_{12} & b_{13} \\ b_{21} & b_2 & b_{23} \\ b_{31} & b_{32} & b_3 \end{pmatrix} \end{array}$$

Ch. Lepton Yukawas

$\mathcal{E}$ -Suppressions of qlT* cpuplings

$$Y_{ql} \simeq \begin{array}{c} \\ q_1 \\ q_2 \\ q_3 \end{array} \begin{array}{c} \begin{array}{ccc} l_1 & l_2 & l_3 \end{array} \\ \begin{pmatrix} \epsilon_1 b_1 & \epsilon_1 b_{12} & \epsilon_1 b_{13} \\ \epsilon_2 b_{21} & \epsilon_2 b_2 & \epsilon_2 b_{23} \\ \epsilon_3 b_{31} & \epsilon_3 b_{32} & \epsilon_3 b_3 \end{pmatrix} \end{array}$$

Suppression of d=5 operator

$$\epsilon^2 \frac{Y_U Y_E}{M_T} qqql$$

NO $u^c u^c d^c e^c$

Suppression of d=6 B-viol. Operators

Multiplets Splitting Insure proper suppression:

$$\left(\bar{5}'^{\dagger} e^{-gV} \bar{5}'\right)_D \rightarrow \epsilon'' g \left(l^{\dagger} V_X d^c + d^{c\dagger} V_Y l\right)_D$$

$$(10^{\dagger} e^{gV} 10)_D \rightarrow \quad \epsilon g \left(V_X (q^{\dagger} e^c + q u^{c\dagger}) + V_Y (q e^{c\dagger} + q^{\dagger} u^c)\right)_D$$

Suppression of d=6 operator

$$\frac{g^2}{M_G^2} \left[\epsilon^2 q q u^{c\dagger} e^{c\dagger} + \epsilon\epsilon'' q l u^{c\dagger} d^{c\dagger} + \text{h.c.}\right]_D$$

Realization: Realistic SU(5) Model

Goals: a) Split Multiplets→ Suppression of p-decay
b) Realistic Fermion Pattern
c) Maintein nice properties (coupling unification etc)
d) Predictions (flavor pattern is needed)

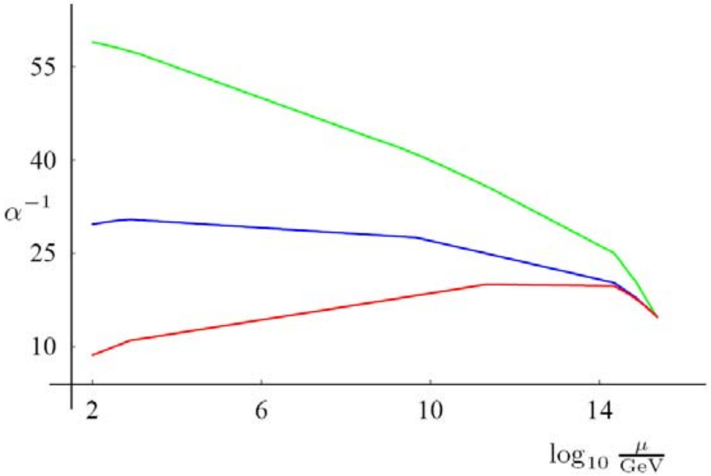
Achievements: a)Suggested matter extention →Multiplet Splittings:

$$q_{1,2} \subset 15_{1,2}\ , \quad q_3 \subset 10'\ , \qquad (u^c, e^c)_{1,2,3} \subset 10_{1,2,3}$$

$$10_1 \supset \epsilon_1 q_1\ , \quad 10_2 \supset \epsilon q_2\ , \quad 10_3 \supset \epsilon q_3 \qquad \bar{5} \supset d^c\ , \quad \bar{5}' \supset l\ , \epsilon'' d^c$$

b) Split Multiplets→ Realistic fermon masses

c) Scale selection is allowed
to have coupling unification:



d) Flavor structure: Simple Assumption

Y_U, Y_E ~Diag, $Y_D \rightarrow V_{CKM}$

Outcome:

$$Y_{ql} = \text{Diag}\left(\epsilon_1 \lambda_e \ , \ \epsilon \lambda_\mu \ , \ \epsilon \lambda_\tau\right)$$

$$Y_{qq} = \text{Diag}\left(\epsilon_1 \lambda_u \ , \ \epsilon \lambda_c \ , \ \epsilon \lambda_t\right)$$

This Flavor Structure predicts:

$$\tau_{d=5}(p \to K^+ \nu_e) \simeq 0.7 \cdot \tau_{d=5}(p \to K^0 \mu^+) \simeq$$

$$1.3 \cdot 10^{34} \text{ years} \times \left(\frac{\sin 2\beta}{0.50} \right)^2$$

$$\tau_{d=6}(p \to \pi^0 e^+) = \frac{1}{\Gamma_{d=6}(p \to \pi^0 e^+)} \simeq 5 \cdot 10^{33} \text{ years}$$

Compatible with exp. Bounds:

$$\tau^{\exp}(p \to K^+ \nu) \gtrsim 6.7 \cdot 10^{32} \text{ yrs.}$$

$$\tau^{\exp}(p \to K^0 \mu^+) \gtrsim 1.2 \cdot 10^{32} \text{ yrs.}$$

$$\tau^{\exp}(p \to \pi^0 e^+) \gtrsim 1.6 \cdot 10^{33} \text{ yrs.}$$

Summary

- Split Multiplet Mechanism can insure proton stability and solution of fermion flavor problem within GUTs
- Its desirable to build more elaborated models of flavor (Fl. Symmetries) & make predictions
- Generalize and realize the mechanism within other GUTs [SO(10), SU(6),… – more motivated]