SO(10) Grand Unified Theory

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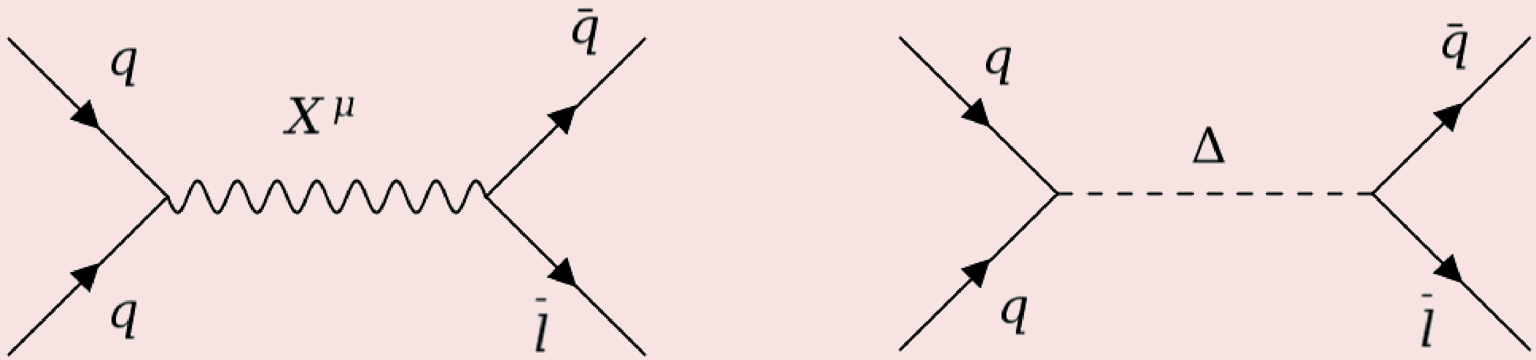
Inherently quantum model

$$SO(10) \supset SU(3)_C \times SU(2)_L \times U(1)_Y$$

Proton decay



Proton decay width robust with respect to Planck effects

Numerical model analysis

→ Proton lifetime estimate

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General features

- Gauge fields in 45_G

$$45_G = G^b_\mu \oplus A^a_\mu \oplus B_\mu, Y_\mu \oplus (3,1,\tfrac{2}{3}) \oplus (3,2,-\tfrac{5}{6}) \oplus (3,2,\tfrac{1}{6}) \oplus (1,1,1) + h.c.$$

- Matter fields in 16_F

$$16_F = L_L \oplus \overline{d}_L \oplus Q_L \oplus \overline{u}_L \oplus \overline{e}_L \oplus N^c_L$$

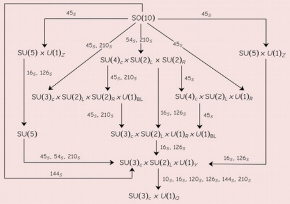
➔ Anomaly cancellation

Minimal scalar sector (SSB)

- SO(10) to Intermediate symmetry: 45_S
  - Preserves rank
  - Two real SM singlets $\langle(1,1,1,0)\rangle \sim \omega_{BL}$, $\langle(1,1,3,0)\rangle \sim \omega_R$

($3_c 2_L 2_R 1_{BL}$ notation)

- Intermediate symmetry to SM: 126_S
  - Renormalizable Yukawa interaction
  - One complex SM singlet $\langle(1,1,3,2)\rangle \sim \sigma$
  - Seesaw scale $|\sigma| \ll \max(\omega_{BL}, \omega_R)$
- SM to $SU(3)_c$x$U(1)_Q$: 10_S



Tree level scalar spectrum

Contains tachyonic scalars

$$\mathrm{M}^2_S[(8,1,0)] = 2a_2(\omega_{BL} - \omega_R)(\omega_R + 2\omega_{BL}),$$

$$\mathrm{M}^2_S[(1,3,0)] = 2a_2(\omega_R - \omega_{BL})(2\omega_R + \omega_{BL}),$$

$$M^2[(1,1,0)] = a_2\left(-\frac{45\omega^4_{BL}}{3\omega^2_{BL} + 2\omega^2_R} + 13\omega^2_{BL} - 2\omega_{BL}\omega_R - 2\omega^2_R\right) + O\left(a^2_2, \frac{\sigma^2}{\omega^2}\right)$$

if not near the flipped SU(5)xU(1) breaking chain.

- Pseudo-Goldstone bosons correspond to global O(45) symmetry broken by $\frac{\sigma}{\omega}$ and a_2 coupling.
- If $|a_2|$ is small, loop corrections are dominant and model is consistent only at one-loop.

One-loop remedy

Effective potential approach

To consistently calculate corrections to the scalar masses one can invoke the effective potential V_{eff}. At one-loop level, $V_{eff} = V_0 + V_1$ where

$$V_1 = \frac{1}{64\pi^2}\mathrm{Tr}\left[M^4_S(\Phi)\left(\log\frac{M^2_S(\Phi)}{\mu^2_R} - \frac{3}{2}\right)\right] + \frac{3}{64\pi^2}\mathrm{Tr}\left[M^4_G(\Phi)\left(\log\frac{M^2_G(\Phi)}{\mu^2_R} - \frac{5}{6}\right)\right]$$

in the MS renormalization scheme with vanishing external momenta. One-loop effective mass is calculated as

$$\mathcal{M}^2 = \left.\frac{\partial^2 V_0}{\partial\Phi\partial\Phi^*}\right|_v + \left.\frac{\partial^2 V_1}{\partial\Phi\partial\Phi^*}\right|_{v_0}$$

using vacuum v= v_0 + v_1 determined from modified stationarity conditions. Moreover, for the pseudo-Goldstone mass holds

$$\mathcal{M}^2 - \mathcal{M}^2_{phys} = \mathrm{IR\ diverging\ logs} + \mathrm{two\text{-}loop\ effects}.$$

Beta functions

Effective potential can be also used to partially calculate beta functions of scalar parameters. If

$$\lambda = \frac{\partial^4 V_0(\Phi)}{\partial\Phi^4}$$

then

$$\beta_\lambda = \frac{1}{32\pi^2}\frac{\partial^4}{\partial\Phi^4}\left(\mathrm{Tr}\left[M^4_S(\Phi)\right] + 3\mathrm{Tr}\left[M^4_G(\Phi)\right]\right).$$

However, the anomalous dimension part of the beta function cannot be recovered using this method.

[Coleman,Weinberg: Phys.Rev. D7(1973)]

Proton decay analysis

Proton decay is mediated by heavy gauge bosons

$$X^\mu = (\overline{3}, 2, \tfrac{5}{6}), (\overline{3}, 2, -\tfrac{1}{6}), \ldots$$

and scalars

$$\Delta = (\overline{3}, 1, \tfrac{1}{3}), (\overline{3}, 1, \tfrac{4}{3}), \ldots$$

Planck scale effects

- Non-renormalizable operator influencing GUT scale $-\frac{c}{M_{Pl}}\frac{1}{2}\mathrm{Tr}(F^{\mu\nu}\Phi F_{\mu\nu})$

  is absent if $\Phi = 45_S$.
- Non-renormalizable operator effecting flavour sector $\sum_{f;i,j}\frac{\kappa^f_{i,j}}{M_{Pl}} f_i f_j HS + h.c.$

  doesn't have any significant influence on total proton decay width in SO(10). [Kolesova,Malinsky:2016]

Proton decay cookbook