SO(10) Non-SUSY Grand Unification

Yukawa Sector

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MITP Summer School 2018

02/08/2018

Outline

The Original GUT

VOLUME 32, NUMBER 8 PHYSICAL REVIEW LETTERS 25 FEBRUARY 1974

Unity of All Elementary-Particle Forces

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(Received 10 January 1974)

Strong, electromagnetic, and weak forces are conjectured to arise from a single fundamental interaction based on the gauge group SU(5).

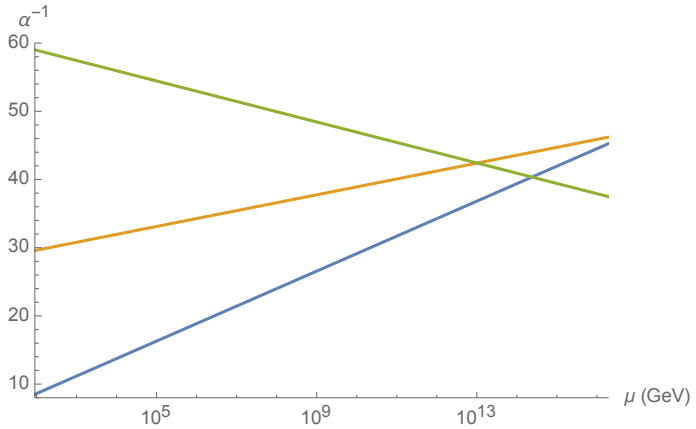
We present a series of hypotheses and speculations leading inescapably to the conclusion that SU(5) is the gauge group of the world—that all elementary particle forces (strong, weak, and electromagnetic) are different manifestations of the same fundamental interaction involving a single coupling strength, the fine-structure constant. Our hypotheses may be wrong and our speculations idle, but the uniqueness and simplicity of our scheme are reasons enough that it be taken seriously.

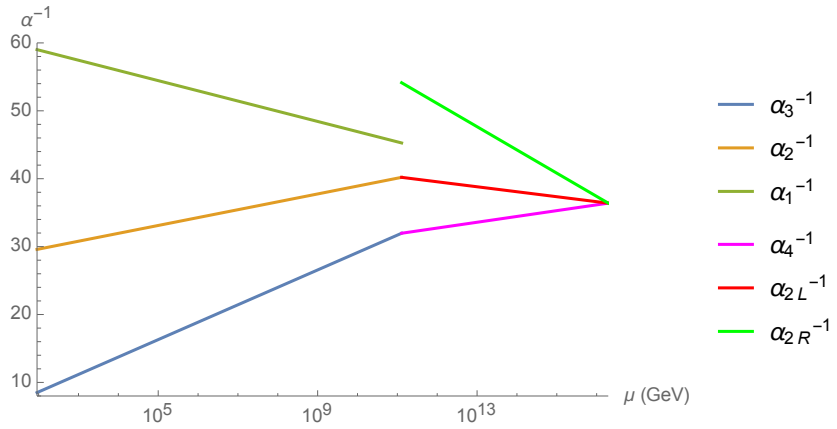
of the GIM mechanism with the notion of colored quarks[4] keeps the successes of the quark model and gives an important bonus: Lepton and hadron anomalies cancel so that the theory of weak and electromagnetic interactions is renormalizable.[5]

The next step is to include strong interactions. We assume that *strong interactions are mediated by an octet of neutral vector gauge gluons* associated with local color SU(3) symmetry, and that there are no fundamental strongly interacting scalar-meson fields.[6] This insures that

Gauge Coupling Unification (almost...)

- Gauge couplings almost unify at $M_{\mathrm{GUT}} \sim 10^{15-16}$ GeV in SM
- SO(10) allows for intermediate gauge groups that provide unification
- Suggests new physics at GUT-scale

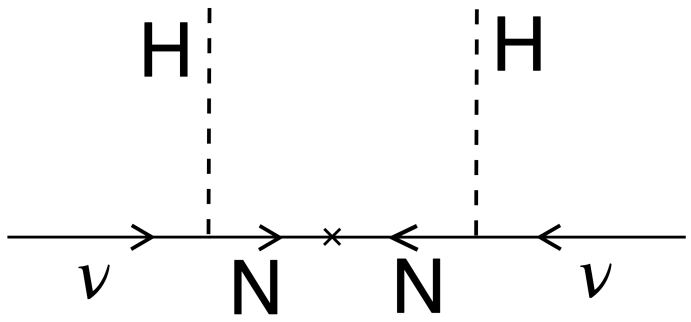




$$\mathrm{SU(3)_C} \otimes \mathrm{SU(2)_L} \otimes \mathrm{U(1)_Y} \subset \mathcal{G}_{\mathrm{GUT}}$$

Neutrino Masses

- Weinberg operator ($d = 5$): $\mathcal{L}_{\text{eff}} \supset \frac{c}{\Lambda} LLHH$



- Λ is scale of new physics: $\Lambda \sim 10^{12-14}$ GeV if $c \sim \mathcal{O}(1)$
- Suggests new physics near the GUT-scale or an intermediate scale

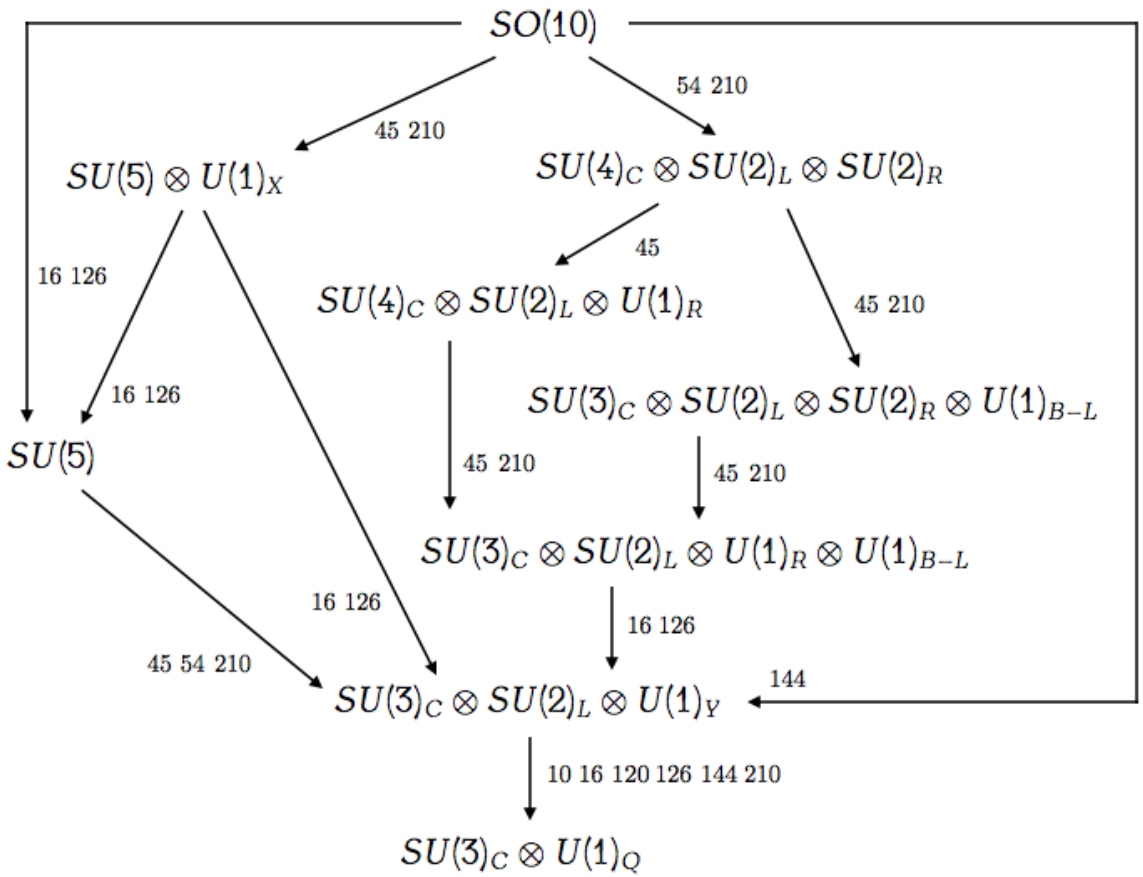
SO(10) GUTs

$$16_F = \begin{bmatrix} u_L^R \\ u_L^G \\ u_L^B \\ u_R^{cR} \\ u_R^{cG} \\ u_R^{cB} \\ d_L^R \\ d_L^G \\ d_L^B \\ d_R^{cR} \\ d_R^{cG} \\ d_R^{cB} \\ e_L \\ e_R^c \\ \nu_L \\ N_R^c \end{bmatrix}$$

- All SM fermions and RH neutrinos fit into one 16-dimensional representation per generation
  $16_F \to (3,2,\frac{1}{6}) \oplus (\overline{3},1,\frac{1}{3}) \oplus (\overline{3},1,-\frac{2}{3}) \oplus (1,2,-\frac{1}{2}) \oplus (1,1,1) \oplus (1,1,0)$
- RH neutrino naturally provides neutrino masses, leptogenesis
- Anomaly free, independent of charge assignment: $\mathrm{Tr}(\{t^a,t^b\}t^c) = 0$ due to properties of the generators

Breaking Patterns

SO(10) is rank 5 $\Longrightarrow$ admits intermediate breaking steps

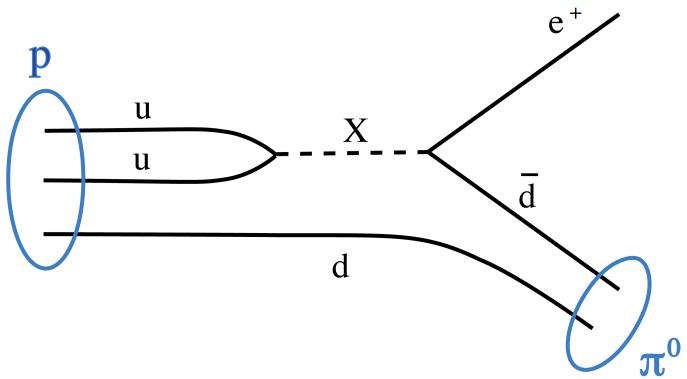


[arXiv: 1110.3210]

Proton Decay

- Leptoquark vector or scalar bosons can mediate proton decay via $d = 5$ or $d = 6$ operators
- Most dangerous decay channels: $p \to e^+\pi^0$ and $p \to K^+\overline{\nu}$
- Proton lifetime bound $\tau_p \sim 10^{34}$ yrs [PDG]

$$\tau_p \sim \frac{M_X^4}{\alpha_{\mathrm{GUT}}^2 M_p^5} \implies M_{\mathrm{GUT}} \gtrsim 10^{16}\mathrm{GeV}$$



SO(10) Yukawa Sector

- Three possibilities for SM Higgs: 10_H, $\overline{126}_H$, 120_H
- 10_H and $\overline{126}_H$ most interesting
  - $10_H \to (1,2,-\frac{1}{2}) \oplus (1,2,\frac{1}{2}) \oplus \cdots$
  - $\overline{126}_H \to (1,2,-\frac{1}{2}) \oplus (1,2,\frac{1}{2}) \oplus (1,1,0) \oplus \cdots$

$$\mathcal{L}_{\text{Yuk}} = 16_F(Y_{10}10_H + Y_{126}\overline{126}_H)16_F$$

SM fermion masses:

$$M_u = v_{10}^u Y_{10} + v_{126}^u Y_{126} \qquad M_\nu = v_{10}^u Y_{10} - 3v_{126}^u Y_{126}$$
$$M_d = v_{10}^d Y_{10} + v_{126}^d Y_{126} \qquad M_\ell = v_{10}^d Y_{10} - 3v_{126}^d Y_{126}$$

Summary

- Embedding of SM in SO(10)
- Two-step symmetry breaking
- Playground for a lot of physics: neutrino masses, leptogenesis, leptoquarks, ...
- Constraints from non-observation of proton decay
- Can reproduce SM masses and mixing parameters

Questions?