SU(6) Grand Unification of 3-3-1 Model

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Abstract. We discuss a sequential variant of the $SU(3)_c \otimes SU(3)_L \otimes U(1)_X$ model which can fit within a minimal SU(6) grand unification. Interestingly, this minimal SU(6) embedding can allow a $SU(3)_c \otimes SU(3)_L \otimes U(1)_X$ symmetry breaking scale within the reach of LHC and with seesaw-type neutrino masses.

Keywords: grand unification, 3-3-1 model, SU(6)

Introduction: The $SU(3)_c \otimes SU(3)_L \otimes U(1)_X$ [1] gauge extension of the SM provides a strong promise of new physics that can be observed at the LHC or the next generation accelerators [2, 3] and also can provide novel ways to understand neutrino masses . The $SU(3)_c \otimes SU(3)_L \otimes U(1)_X$ model proposed by Singer, Valle and Schechter (SVS) [2] is not anomaly free for each generation of fermions, however, when all the three generations of fermions are included the theory becomes anomaly free. Consequently, different multiplets of the $SU(3)_c \otimes SU(3)_L \otimes U(1)_X$ group appear with different multiplicity and it becomes difficult to unify the model within usual grand unified theories. In Ref. [4] we have studied how such a theory can be unified in a SU(6) gauge theory that can emerge from a E(6) Grand Unified Theory (GUT). Interestingly, the SVS 3-3-1 model can readily be refurbished into an anomaly free multiplet structure which can be right away embedded in a minimal anomaly free combination of representations of SU(6) as an E(6) subgroup. We refer to this new 3-3-1 model as the sequential 3-3-1 model. This scheme is particularly intriguing since this SU(6) embedding does not require any bulk exotics to account for the chiral families; and in that sense it provides a truly minimal unification scenario in the same spirit akin to the minimal SU(5) construction [5].

The sequential $\mathrm{SU}(3)_\mathrm{c}\otimes\mathrm{SU}(3)_\mathrm{L}\otimes\mathrm{U}(1)_\mathrm{X}$ **Model:** In this model we assign the fields in such a way that the anomalies are cancelled for each generation separately. The multiplet structure is given by

$$\begin{aligned} Q_{aL} &= \left(u_{aL},\, d_{aL},\, D_{aL}\right)^T \equiv [3,3,0],\;\; u_{aR}\equiv[3,1,2/3],\;\; d_{aR}\equiv[3,1,-1/3],\\ D_{aR} &\equiv [3,1,-1/3], \psi_{aL} = \left(e^-_{aL}\;\nu_{aL}\;N^1_{aL}\right)^T \equiv [1,3^*,-1/3], \qquad (1)\\ \xi_{aL} &= \left(E^-_{aL},\, N^2_{aL},\, N^3_{aL}\right)^T \equiv [1,3^*,-1/3],\;\; \chi_{aL} = \left(N^4_{aL},\, E^+_{aL},\, e^+_{aL}\right) \equiv [1,3^*,2/3]. \end{aligned}$$

In order to drive symmetry breaking and generate the charged fermion masses, we assume a Higgs sector similar to the SVS 3-3-1 model. The Yukawa Lagrangian for the quark sector is given by

$$\mathcal{L}_{\text{quarks}} = y_{u_a}\overline{Q_{aL}}u_{aR}\phi^*_0 + y^i_{d_a}\overline{Q_{aL}}d_{aR}\phi^*_i + y^i_{D_a}\overline{Q_{aL}}D_{aR}\phi^*_i + \text{h.c.} \quad , \qquad (2)$$

where $a=1,2,3$, $i=1,2$ (neglecting any flavour mixing). In the leptonic sector the relevant Yukawa interactions are given by

$$\mathcal{L}_{\text{leptons}} = \epsilon_{\alpha\beta\gamma}\left[\psi^T_{\alpha L}C^{-1}\left(y_1\xi_{\beta L}\phi_{0\gamma} + y^i_2\chi_{\beta L}\phi_{i\gamma}\right) + \xi^T_{\alpha L}C^{-1}y^i_3\chi_{\beta L}\phi_{i\gamma}\right] + \text{h.c.} \quad (3)$$

where α,β,γ are the $\mathrm{SU}(3)_\mathrm{L}$ tensor indices giving antisymmetric Dirac mass terms, C is the charge conjugation matrix, and $i=1,2$. After the symmetry breaking, the 5×5 neutrino mass matrix for each generation can be diagonalized to obtain two quasi-Dirac heavy neutrinos with mass around $\mathrm{SU}(3)_\mathrm{c}\otimes\mathrm{SU}(3)_\mathrm{L}\otimes\mathrm{U}(1)_\mathrm{X}$ symmetry breaking scale, two Dirac states with mass of the order of the electroweak symmetry breaking scale and a light seesaw Majorana neutrino.

SU(6) Grand Unification: It is easy to verify that each generation of the fermionic multiplets of the sequential 3-3-1 model written in Eq. (1) can be embedded perfectly in the anomaly free combination of SU(6) representations: $\bar{6}+\bar{6}'+15$, where $\bar{6}$ contains $d^c_L\equiv[3,1,-1/3]$ and $\psi_L\equiv[1,3^*,-1/3]$; $\bar{6}'$ contains $D^c_L\equiv[3,1,-1/3]$ and $\xi_L\equiv[1,3^*,-1/3]$; and 15 contains $u^c_L\equiv[3^*,1,-2/3]$, $\chi_L\equiv[1,3^*,2/3]$ and $Q_L\equiv[3,3,0]$. Now the E(6) fundamental representation 27 decomposes under the maximal $\mathrm{SU}(2)\otimes\mathrm{SU}(6)$ subgroup as $27=[2,\,\bar{6}]+[1,\,15]$. Three 27s of E(6) containing three sets of $\bar{6}+\bar{6}'+15$ can accommodate three generations of the fermionic multiplets of the sequential 3-3-1 model. However, the minimal content of the sequential 3-3-1 model does not lead to a successful unification scenario. Interestingly, by adding three generations of the fermionic octets leads to a successful gauge coupling unification.

The one-loop beta-coefficients for the phase between the electroweak symmetry breaking and the $\mathrm{SU}(3)_\mathrm{c}\otimes\mathrm{SU}(3)_\mathrm{L}\otimes\mathrm{U}(1)_\mathrm{X}$ symmetry breaking (M_Z to M_X) are given by $b_{2L}=-19/6$, $b_Y=41/10$, $b_{3C}=-7$. The one-loop beta-coefficients for the phase between the $\mathrm{SU}(3)_\mathrm{c}\otimes\mathrm{SU}(3)_\mathrm{L}\otimes\mathrm{U}(1)_\mathrm{X}$ symmetry breaking scale and the octet mass scale (M_X to M_8) are given by $b_{3L}=-9/2$, $b_X=13/2$, $b^{331}_{3C}=-5$. Finally, he one-loop beta-coefficients for the phase between the octet mass scale to the unification scale (M_8 to M_U) are given by $b^8_{3L}=2n-9/2$, where n is the number of generations of the fermionic octets ($\Omega\equiv[1,8^*,0]$),

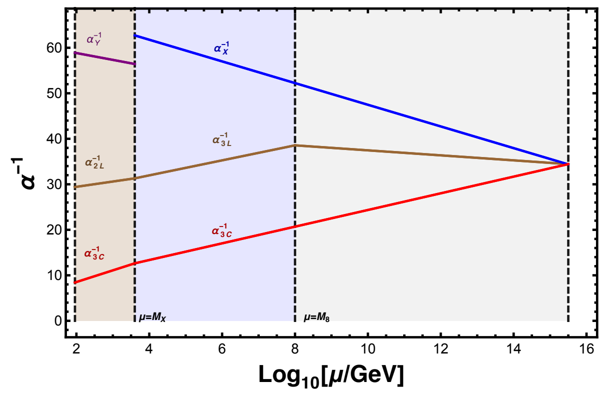

Fig. 1. The running of the gauge couplings in the sequential 3-3-1 Model with three generations of fermionic octets with $\mathrm{SU(3)_c \otimes SU(3)_L \otimes U(1)_X}$ symmetry breaking scale $M_X = 4000$ GeV and octet mass scale $M_8 = 10^8$ GeV, demonstrating successful gauge unification at the scale $M_U = 10^{15.5}$ GeV with $n_Y = \sqrt{5/3}$ and $n_X = 2/\sqrt{3}$.

$b_X^8 = 13/2$, $b_{3C}^8 = -5$. Fig. 1 shows the gauge coupling running of the sequential $\mathrm{SU(3)_c \otimes SU(3)_L \otimes U(1)_X}$ model and three generations of fermionic octets with $\mathrm{SU(3)_c \otimes SU(3)_L \otimes U(1)_X}$ symmetry breaking scale $M_X = 4000$ GeV and octet mass scale $M_8 = 10^8$ GeV, demonstrating successful gauge unification at the scale $M_U = 10^{15.5}$ GeV with $n_Y = \sqrt{5/3}$ and $n_X = 2/\sqrt{3}$. Taking $M_U = 10^{15.5}$ GeV and $\alpha_{\mathrm{GUT}}^{-1} \sim 35$ in sequential 3-3-1 model, the lifetime of the proton decay mode $p \to e^+\pi^0$ is roughly $\sim 10^{34}$ yrs, which is consistent with the current experimental limit [6].

Concluding Remarks: We have discussed a minimal SU(6) grand unification of the sequential variant of the $\mathrm{SU(3)_c \otimes SU(3)_L \otimes U(1)_X}$ model which allows for a TeV scale $\mathrm{SU(3)_c \otimes SU(3)_L \otimes U(1)_X}$ model as well as seesaw-induced neutrino masses. The gauge coupling unification can be associated to the presence of sequential leptonic octets at some intermediate scale between the 3-3-1 scale and the unification scale. The presence of the octet scale can have interesting implications for radiative origin of neutrino masses [7].

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