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$\mathsf{SU}(5)\times\mathsf{SU}(5)$ SUSY GUT unification

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The idea of grand unification in a minimal supersymmetric $\mathsf{SU}(5)\times\mathsf{SU}(5)$ framework is revisited. It is shown that the unification of gauge couplings into a unique coupling constant can be achieved at a high-energy scale compatible with proton decay constraints. This requires the addition of a minimal particle content at intermediate energy scales. In particular, the introduction of the $\mathsf{SU}(2)_\mathsf{L}$ triplets belonging to the $(15,1)+(\overline{15},1)$ representations, as well as of the scalar triplet Σ_3 and octet Σ_8 in the $(24,1)$ representation, turns out to be crucial for unification. The masses of these intermediate particles can vary over a wide range, and even lie in the TeV region. In contrast, the exotic vector-like fermions must be heavy enough and have masses above 10^{10} GeV. We also show that, if the $\mathsf{SU}(5)\times\mathsf{SU}(5)$ theory is embedded into a heterotic string scenario, it is not possible to achieve gauge coupling unification with gravity at the perturbative string scale.

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On the quest for the theory beyond the Standard Model (SM), supersymmetric grand unified theories (SUSY GUTs) have revealed many attractive features which can solve some of the aspects left unexplained in the SM. This idea is supported by the unification of the gauge couplings that occurs, through renormalisation group evolution, at a scale around 10^{16} GeV in the minimal supersymmetric standard model (MSSM). Since the appearance of the simplest GUT models proposed in 1974 by Georgi and Glashow, and based in the gauge group $\mathsf{SU}(5)$ [1], the search for gauge groups compatible with a unification scheme has been actively pursued in the literature.

Going beyond the simplest $\mathsf{SU}(5)$ unification, it is also conceivable that the unification group has a semi-simple structure, as in the original left-right symmetric Pati-Salam model [2, 3]. In this direction, the SUSY left-right $\mathsf{SU}(5)\times\mathsf{SU}(5)$ model [4, 5] has many attractive features that are absent in minimal realizations of the $\mathsf{SU}(5)$ theory. Indeed, with an appropriate choice of Higgs representations, R-parity can be automatically conserved and proton decay is suppressed because heavy and light fermions do not mix and dangerous higher dimension operators are absent. Furthermore, the doublet-triplet splitting problem is alleviated [6, 5], a generalized seesaw mechanism for fermion masses can be easily incorporated, and nonvanishing neutrino masses are naturally explained. $\mathsf{SU}(5)\times\mathsf{SU}(5)$ theories can also be easily embedded in superstring constructions [7, 8] which aim at unifying gravity with electroweak and strong forces. In what concerns unification, it is worth noticing that the same discrete permutation symmetry that guarantees the left-right nature of $\mathsf{SU}(5)\times\mathsf{SU}(5)$ (i.e. the one-to-one correspondence among left and right matter field representations) also leads to the unification of gauge couplings into a single constant.

Our model based in the GUT group $\mathsf{SU}(5)\times\mathsf{SU}(5)$ is fully described in Ref. [9]. For simplicity we assume that all intermediate scale that leads to the SM are at GUT scale Λ, where the unification relation holds as

$$\alpha_U = 2\,\alpha_s(\Lambda) = \alpha_w(\Lambda) = \frac{13}{3}\,\alpha_y(\Lambda)\,, \tag{1}$$

so that the contribution to $\sin^2\theta_W = 3/16$ at Λ.

The model consists of the introduction of four matter chiral multiplets: $\psi\sim(\bar{5},1)$, $\chi\sim(10,1)$ and their conjugate partners $\psi^c\sim(1,5)$, $\chi^c\sim(1,\overline{10}$. In order to fully determine the breaking pattern, we add large Higgs chiral multiplets: $\Phi_L\sim(24,1)$ and $\Phi_R\sim(1,24)$, for the first breaking of $\mathsf{SU}(5)_\mathsf{L}\times\mathsf{SU}(5)_\mathsf{R}$ at the scale Λ but preserve the discrete left-right symmetry. Left-right symmetry breaking at the scale Λ_{LR}: $\omega\sim(5,\bar{5})$, $\overline{\omega}\sim(\bar{5},5)$, $\Omega\sim(10,\overline{10})$ and $\overline{\Omega}\sim(\overline{10},10)$. The last two steps in order to finally achieve the SM are driven by the additional Higgs fields $\phi_R\sim(1,\bar{5})$, $\phi_R^c\sim(1,5)$ and $\phi_L\sim(5,1)$, $\phi_L^c\sim(\bar{5},1)$, respectively. Moreover, the representations $T_L\sim(15,1)$, $T_L^c\sim(\overline{15},1)$, $T_R\sim(1,\overline{15})$ and $T_R^c\sim(1,15)$ are introduced. They are crucial for unification and for the Majorana masses of neutrinos generation. Nevertheless, we have numerically verified that this field content is not enough for having string scale unification.

The low-energy fermionic content in the matter representation apart form the SM fermions are three generations of vector-like quarks U,U^c, D,D^c and the charged lepton pair E,E^c, which must be heavy enough to guarantee unification in such a way a see-saw mechanism can be performed for the light fermion fields to acquire their masses. On the other hand, light neutrinos acquire Dirac-type masses. The existence of $\mathsf{SU}(2)$ triplets contented in $(15,1)$ and $(\overline{15},1)$ may generate type-II see-saw Majorana masses for neutrinos. In Fig. 1, we sketch the necessary scales which are need for successful unification, with only two or four Higgs doublets at the electroweak scale.

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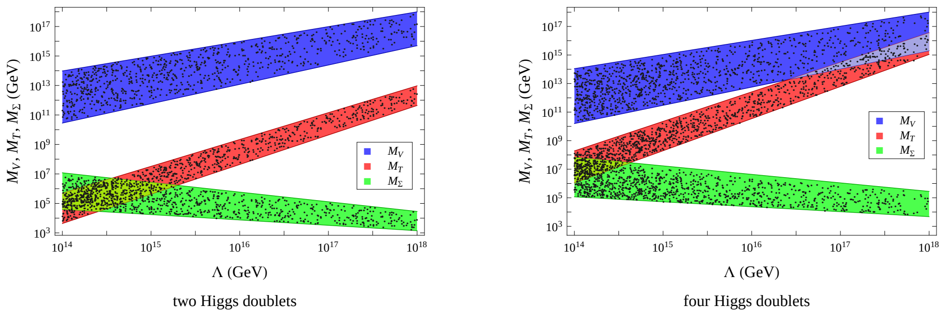

Figure 1: Intermediate scales necessary for having correct Unification.

Proton decay via dimension-six operators through heavy gauge bosons is suppressed, since at tree level the latter do not mediate transitions involving only light fermions. The presence of colour Higgs triplets H_C^L and H_C^R induce proton decay through dimension-five operators: $\chi\chi\chi\psi$ and $\chi^c\chi^c\chi^c\psi^c$, which lead to the effective operators $QQQL$. This requires that the mass scales of left and right colour Higgs triplets should be heavy enough. In the absence of the fields $\phi_{L,R}$ and $\phi^c_{L,R}$ not only proton is stable at the renormalisable level.

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