

**SUPPRESSING DIMENSION FIVE OPERATORS IN GENERAL  $SU(5)$   
MODELS \***

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**Abstract**

We discuss dimension-5 operators in supersymmetric models containing extra hypercharge-1/3 colour-triplets. We derive a general formula relating dimension-5 operator to the colour-triplet mass matrix. We show that certain zeros in the triplet mass-matrix together with some triplet coupling selection rules can lead to elimination of dimension-5 operators. In particular we focus on  $SU(5)$  models and show that

- (a) Dimension-5 operators can be eliminated in the standard  $SU(5)$  model by the introduction of an extra pair of  $\mathbf{5} + \bar{\mathbf{5}}$  Higgses with specific couplings
- (b) Flipped  $SU(5)$  models with extra  $\mathbf{10} + \bar{\mathbf{10}}$  Higgses are free of dimension-5 operators
- (c) Flipped  $SU(5)$  models with extra  $\mathbf{5} + \bar{\mathbf{5}}$  and/or extra  $\mathbf{10} + \bar{\mathbf{10}}$  Higgses can be made free of dimension-5 operators for a textured form of the triplet mass-matrix accompanied by constraints on the 5-plet couplings to matter.

Our analysis is motivated by the recently put forward M-theory phenomenological framework that requires a strong string coupling and reintroduces the problem of eliminating dimension-5 operators.

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# 1 Introduction

The Standard Model and its  $N = 1$  supersymmetric extension[1], the Minimal Supersymmetric Standard Model (MSSM), can be naturally embedded in a Grand Unified Theory [2] (GUT) with interesting phenomenological and cosmological consequences. GUTs can successfully predict the electroweak mixing angle  $\sin^2 \theta_W$  [3], fermion mass relations as well as provide a mechanism for the creation of the baryon asymmetry of the Universe[4]. A GUT can be in principle accommodated in the framework of Superstring Theory[5].

Proton decay is a generic feature of any unification scheme since the unification of quarks and leptons in a common multiplet introduces extra interactions that violate baryon number. Proton decay rates and modes are a prediction of GUT models that play a crucial role in their phenomenological viability. In fact, proton decay has turned out to be the nemesis of many GUT and Superstring models. It is a welcome prediction that can be used to test GUTs. In supersymmetric GUTs with conserved  $R$ -parity the dominant baryon number violating operators are dimension  $D = 5$ , while  $D = 6$  operators are in general suppressed due to the increase of the unification scale in comparison to its non-supersymmetric values.  $D = 5$  operators are proportional to the Yukawa couplings and to the inverse of the heavy mass [6]. In minimal models the Yukawa couplings involved are associated with the fermion masses. The values of these couplings play an important role in the final value of the proton decay rate and the resulting hierarchy of existing modes. Nevertheless, Superstring embeddable models [7] or models of phenomenologically oriented GUTs that treat the fermion mass problem [8], come out with an extended Higgs sector. Similarly, several attempts for the construction of phenomenologically viable string models have yielded up to now models with extra Higgses [9]. Motivation for an extended Higgs sector can also be found in fixed-point considerations [10]. In addition, the presence of extra hypercharge  $1/3$  colour-triplets turns out to be a necessary ingredient of models that raise the GUT unification scale close to the string scale [11, 12].

The Yukawa couplings of Higgs fields to matter multiplets are constrained phenomenologically by the observed quark and lepton mass-matrices. Nevertheless, in the presence of more than one pair of Higgses not all coupling constants are constrained. In unified models these same Yukawa coupling constants determine the strength of Baryon number violating interactions. Therefore, not all Yukawas appearing in front of dimension-5 Baryon number violating operators are necessarily small from fermion mass considerations. Since the proton decay rate through such operators

$$\mathcal{O}\left(\frac{\alpha}{16\pi}\right)\left(\frac{Y^2}{m_{\tilde{H}}m_S}\right)(QQQL)$$

is predicted to be not very far away from the experimental limit, the presence of large, i.e. not as small as the fermion mass matrix requires, Yukawas could be disastrous. Very roughly, the imposed constraint is  $Y \leq 10^{-6}/M_P$ . Instead of extending the fermion mass constraint to all Yukawas one could investigate other ways, such as symmetries or selection rules imposed by the Higgs mass matrix, that could lead to the elimination or suppression of the related dangerous dimension-5 operators. Various ideas have been reported to the literature in order to sufficiently suppress such operators [13].

Additional motivation comes from the recent theoretical developments have put forward a version of  $M$ -theory which yields the *strong coupling* limit of the  $E_8 \times E_8$  heterotic string [14]. This formulation involves a 11-dimensional “bulk” space with 10-dimensional “walls” at each of each ends. This construction circumvents the discrepancy between the string unification scale and the grand unification scale. In an “ $M$ -phenomenology” framework a generic non-renormalizable interaction that violates Baryon number would be of the form  $\mathcal{O}(1) \frac{g_s^{N+1}}{M^{N+1}} \Phi^N (QQQL)$  where  $M \sim 10^{16}$  GeV,  $\Phi/M \sim \mathcal{O}(1)$  and  $g_s \sim \mathcal{O}(1)$  [15]. Therefore, it is clear that in such a framework dimension-5 operators have to be eliminated in a drastic way since the standard suppression argument is not sufficient. Of course non-renormalizable interactions are not the only source of dimension-5 operators in string derived models. As in the case of GUTs an effective dimension-5 operator can be formed by gluing together renormalizable interactions of the effective langangian and this class of operators needs also to be suppressed as it will involve some strong Yukawa couplings.

In this paper we examine dimension-5 operators in the context of general GUT models containing extra hypercharge 1/3 colour triplets and particularly in  $SU(5)$  models. We propose a mechanism for eliminating or suppressing such operators based on the use of textures of the hypercharge 1/3 mass-matrix accompanied by certain constraints of the extra triplet coupling to matter.

## 2 Dimension-5 operators in models with extra D-quark triplets

Let us consider a general supersymmetric model containing some extra hypercharge-1/3 colour-triplets <sup>1</sup>. The effective  $SU(3)_c \times SU(2)_L \times U(1)_Y$  superpotential describing the couplings of quarks and leptons to the extra coloured triplets of the  $D$ -quark type

$$f_{ij}^\alpha Q_i Q_j D_\alpha + y_{ij}^\alpha Q_i L_j \bar{D}_\alpha + r_{ij}^\alpha E_i^c U_j^c \bar{D}_\alpha , \quad (1)$$

where  $i, j = 1, 2, 3$  are the usual generation indices and  $\alpha = 1, \dots, N$  is an extra index describing the multiplicity of triplets and repeated indices are summed. In addition the effective triplet mass matrix will be of the form

$$(\mathcal{M}_3)_{\alpha\beta} D_\alpha \bar{D}_\beta \quad (2)$$

where  $\mathcal{M}_3$  is in general non-diagonal.

We can always go to a basis in which the triplet mass-matrix is diagonal

$$D_\alpha = S_{\alpha\beta} D'_\beta , \quad \bar{D}_\alpha = U_{\alpha\beta} \bar{D}'_\beta \quad (3)$$

$$\mathcal{M}_{3D} \equiv \text{diag}(m_1, m_2, \dots, m_N) = S^T \mathcal{M}_3 U \quad (4)$$

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<sup>1</sup>This superpotential arises in the case of the standard  $SU(5)$  with extra Higgs 5-plets or from the flipped  $SU(5) \times U(1)$  with both extra Higgs 5-plets and 10-plets. However the results of Sections 1 and 2 apply to the wider class of GUTs that share the same effective superpotential.

where the matrices  $S$  and  $U$  are unitary. In this basis we can easily evaluate  $D = 5$  operators resulting from Higgs triplet fermion exchange, and then recast the result in the original basis. Assuming that all triplets are massive ( $m_i \neq 0, i = 1, \dots, N$ ), operators with the structure  $Q_i Q_j Q_k L_n$  will be proportional to <sup>2</sup>

$$\begin{aligned} \mathcal{O}_{ijkl}^{QQQL} &= \sum_{\alpha, \beta, \gamma=1}^N f_{ij}^\alpha S_{\alpha\gamma} (\mathcal{M}_3^{-1})_\gamma U_{\beta\gamma} y_{kn}^\beta \\ &= \sum_{\alpha, \beta=1}^N f_{ij}^\alpha (\mathcal{M}_3^{-1})_{\alpha\beta}^T y_{kn}^\beta = \frac{1}{\det(\mathcal{M}_3)} \sum_{\alpha, \beta=1}^N f_{ij}^\alpha \text{cof}(\mathcal{M}_3)_{\alpha\beta} y_{kn}^\beta \end{aligned} \quad (5)$$

Analogous formulas hold for  $D = 5$  operators of the type  $Q_i Q_j U_k^c E_k^c$ .

### 3 How to suppress dimension–5 operators in effective models with extra triplets

Suppose now that we want to eliminate all dimension five operators. Assuming that the Yukawa couplings  $f_{ij}^\alpha$  and  $y_{ij}^\beta$  are in general unrelated and  $\det \mathcal{M}_3 \neq 0$ , equation (5) implies that *the necessary and sufficient condition for vanishing of the  $\mathcal{O}_{ijkl}^{QQQL}$  operator is that for every pair of triplets ( $D^\alpha, \bar{D}^\beta$ ,  $\alpha, \beta = 1, \dots, N$ ) that do couple to quarks and leptons respectively ( $f_{ij}^\alpha \neq 0$  and  $h_{ij}^\beta \neq 0$ ) the cofactor of the corresponding triplet mass matrix element  $(\mathcal{M}_3)_{\alpha\beta}$  vanishes*<sup>3</sup>

$$\mathcal{O}_{ijkl}^{QQQL} = 0 \iff \text{cof}(\mathcal{M}_3)_{\alpha\beta} = 0 \quad \forall (\alpha, \beta) \in \Xi = \{(\alpha, \beta) : f_{ij}^\alpha \neq 0 \text{ and } h_{kl}^\beta \neq 0\} . \quad (6)$$

It is obvious that in the case where all triplets ( $D$ 's and  $\bar{D}$ 's) couple to matter the suppression of dimension five operators (5) is not possible since (6) leads to  $\det(\mathcal{M}_3) = 0$ . Nevertheless, if for some reason (discrete symmetry, R–parity, anomalous  $U(1)$ , accidental symmetry) some of the  $f_{ij}^\alpha$  and/or  $y_{kl}^\beta$  are zero and the triplet mass matrix is such that the cofactors of the appropriate matrix elements are zero then the associated dimension–5 operator vanishes.

The previous discussion leads to the possibility that *in a model with extra  $D$ –quark triplets dimension–5 operators can be eliminated by using textures of triplet mass matrices and the triplet–matter couplings.*

To be concrete let us give a simple example of such an effective theory. Consider the case of an effective theory with two extra triplets. Only the first couples to matter through the superpotential terms

$$f_{ij}^1 Q_i Q_j D_1 + y_{ij}^1 Q_i L_j \bar{D}_1 + r_{ij}^1 E_i^c U_j^c \bar{D}_1 \quad (7)$$

<sup>2</sup>The corresponding four–fermion operator, assuming roughly an overall universal supersymmetry breaking scale  $m_S$ , will involve  $\frac{(\mathcal{M}_3)^{-1}}{m_S} - 4m_S(\mathcal{M}_3)^{-3} \log \frac{(\mathcal{M}_3)}{m_S}$ .

<sup>3</sup>We consider here the triplet  $D^\alpha$  as coupled to quarks and leptons if at least one  $f_{ij}^\alpha \neq 0$  and similarly for anti–triplets.

and their mass–matrix has the form

$$\mathcal{M}_3 = \begin{pmatrix} \mu_{11} & \mu_{12} \\ \mu_{21} & 0 \end{pmatrix}. \quad (8)$$

Since  $f_{ij}^2 = y_{ij}^2 = 0$  evaluation of (5) leads to

$$\mathcal{O}_{ijkl}^{QQQL} = f_{ij}^1 \text{cof}(\mathcal{M}_3)_{11} y_{kn}^1 \sim \text{cof}(\mathcal{M}_3)_{11} = 0 \quad (9)$$

It is remarkable that if we remove the second pair of triplets of the model (which do not couple directly to matter) the usual dimension–5 operators reappear. We shall study below that this nice property can be incorporated in  $SU(5)$  models.

Trying to generalize the previous model, let us consider an effective model that contains  $N_c$  triplets that directly couple to matter and  $N_u$  triplets that do not couple directly to matter. The most general superpotential will be still that of equation (1) while the triplet mass matrix will be of the form

$$\mathcal{M}_3 = \begin{pmatrix} \mu_{\alpha\beta} & v_{\alpha A} \\ \bar{v}_{A\beta} & m_{AB} \end{pmatrix} \quad (10)$$

where  $A, B = 1, \dots, N_u$ ,  $\alpha, \beta, \gamma = 1, \dots, N_c$  and we assume that all triplets are heavy, i.e.  $\det \mathcal{M}_3 \neq 0$ .

For simplicity let us first consider the case  $N_c = 1$ . In that case only one matrix element gives rise to proton decay and it is proportional to

$$\text{cof}(\mathcal{M}_3)_{11} = \frac{\det m}{\det \mathcal{M}_3} \quad (11)$$

which means that proton decay is absent only in the case that the restricted mass–matrix of the triplets not coupled to matter has

$$\det m = 0 \quad (12)$$

We will see in Section 5 how this constrain naturally arises in the context of the flipped  $SU(5) \times U(1)$  model.

We can now generalize this idea by considering a model with  $N_c$  and  $N_u$  arbitrary. In this case we can prove that the  $N_c \times N_c$  submatrix of  $\mathcal{M}_3^{-1}$  involved in the generation of  $D = 5$  operators will vanish in theories with  $N_u \geq N_c$  when the matrix  $m$  has a number  $N_c$  of null eigenvalues.

Although we do not give here a formal proof of the last statement, it is easy to illustrate it by considering the case of a model with  $N_c = N_u$ .  $D = 5$  operators can be eliminated when  $m$  is a null matrix, which implies

$$\mathcal{M}_3^{-1} = \begin{pmatrix} 0 & \bar{v}^{-1} \\ v^{-1} & -v^{-1} \mu \bar{v}^{-1} \end{pmatrix} \quad (13)$$

In effective theories with  $N_c > N_u$  it is not possible to make all the cofactors of the triplets coupled to matter vanish while keeping  $\det(\mathcal{M}_3) \neq 0$ . In effective theories with  $N_u > N_c$  a number  $N_c$  of null eigenvalues of the submatrix  $m$  (the mass matrix of the triplets that do not couple directly to matter) is required in order to eliminate  $D = 5$  operators, while all the triplets remain heavy.

## 4 An $SU(5)$ model without dimension–5 operators

Supersymmetric  $SU(5)$  models predict proton decay through  $D = 5$  operators. The predicted rates for the dominant mode  $p \rightarrow \bar{\nu} K^+$  are in the range of the experimental searches [16]. It is interesting to analyze how this channel can be suppressed in models with several triplets.

Let us consider now an  $SU(5)$  model with two pairs of Higgs pentaplets  $h_\alpha, \bar{h}_\alpha, \alpha = 1, 2$  of which only the first couples to matter. The quarks and leptons are assigned to  $\phi(\mathbf{5}) + \psi(\mathbf{10})$  representations of  $SU(5)$ . The part of the superpotential related to dimension–5 decay will be

$$f_{ij} \psi_i \psi_j h_1 + y_{ij} \psi_i \phi_j \bar{h}_1 + \sum_{\alpha, \beta=1}^2 (\mu_{\alpha\beta} h_\alpha \bar{h}_\beta + \lambda_{\alpha\beta} h_\alpha \Sigma \bar{h}_\beta) , \quad (14)$$

where the symbol  $\Sigma$  stands for the adjoint Higgs superfield in the  $\mathbf{24}$  representation. The isodoublet and colour–triplet mass matrices are correspondingly of the form

$$\mathcal{M}_2 = \mu - 3\lambda V , \quad (15)$$

$$\mathcal{M}_3 = \mu + 2\lambda V \quad (16)$$

The well known fine–tuning that guarantees a massless pair of isodoublets amounts to

$$\det(\mathcal{M}_2) = 0 . \quad (17)$$

The proton decay rate through  $D = 5$  operators is, according to equation (5), determined by the cofactor of the 1 – 1 element of the triplet mass matrix

$$\text{cof}(\mathcal{M}_3)_{11} = (\mu_{22} + 2\lambda_{22}V) . \quad (18)$$

Hence, choosing  $\mu_{22} = -2\lambda_{22}V$  dimension–5 operators vanish. This condition is perfectly compatible with the previous fine–tuning condition (17). It is very interesting that proton decay through  $D = 5$  operators can be set to zero through a condition on the couplings<sup>4</sup>.

In the framework of our standard  $SU(5)$  example the required zero in the inverse triplet mass matrix does not correspond to any symmetry and is in a sense a second fine–tuning [18]. Nevertheless, the general conclusion is that zeros of the triplet mass matrix, perhaps attributable to symmetries, can stabilize the proton.

The superpotential considered above in (14) is not the most general one. In fact, the case that all 5–plets couple to matter cannot be reduced to (14) since it would require a different Higgs 5–plet rotation for each generation of matter. Therefore, as shown in Section 3, in order to suppress dimension–5 operators in models with more than one ( $N_c$ ) 5–plets coupled to matter must have an equal or bigger number ( $N_u$ ) of uncoupled 5–plets. In addition the mass matrix of the uncoupled 5–plets should have a number of  $N_c$  null eigenvalues. This means we need in general  $N_c$  fine–tunings in addition to the one related to the doublet–matrix.

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<sup>4</sup> Of course, proton decay still goes through at the (suppressed) rate of  $D = 6$  operators.

The suppression of  $D = 5$  operators by heavy triplet masses, as it is required in the minimal  $SU(5)$  is very restricted [17]. Therefore constraints imposed by proton decay rule out most of the parameter space for this model [18]. We should emphasize the fact that in  $SU(5)$  models with non minimal Higgs content, the constraints imposed by proton decay on the parameter space and triplet masses can be relaxed.

## 5 Dimension–5 operators in extensions of the flipped $SU(5)$

In the minimal flipped  $SU(5) \times U(1)$  model [19] matter fields come in the representations

$$F_i(\mathbf{10}, 1/2) , \quad f_i^c(\bar{\mathbf{5}}, -3/2) , \quad l_i^c(\mathbf{1}, 5/2) \quad (19)$$

while Higgses in

$$h(\mathbf{5}, -1) , \quad \bar{h}(\bar{\mathbf{5}}, 1) , \quad (20)$$

and in

$$F_h(\mathbf{10}, 1/2) , \quad \bar{F}_h(\bar{\mathbf{10}}, -1/2) . \quad (21)$$

A great advantage of the “flipped”  $SU(5)$  model over the ordinary one is that of the realization of the “triplet–doublet splitting” mechanism through which the Higgs isodoublets that are about to achieve the electroweak breaking stay massless while the colour triplet Higgses obtain a large mass. This mechanism allows us to naturally suppress dimension–6 operators but not the dimension–5 ones. The suppression of dimension–5 operators in the minimal  $SU(5) \times U(1)$  model is due to the triplet mass matrix texture and it is a subcase of the mechanism described in Section 1. It is crucial that R–parity does not allow the Higgs 10–plets to mix with matter and the effective superpotential has the form (7). We denote  $D_1, \bar{D}_1$  the triplet pair that lies in the  $(\mathbf{5}, \mathbf{1}) + (\bar{\mathbf{5}}, \mathbf{1})$  reps. The triplet mass matrix has the form (8) (with  $\mu_{11} = 0$  in the minimal model). Another nice feature here that should be stressed is that  $\mu_{22} = 0$  as dictated by F–flatness. The pair  $F_h \bar{F}_h$  has to be massless in order to realize the  $SU(5) \times U(1)$  breaking to the standard model.

In spite of the nice features of the minimal flipped  $SU(5)$  model, all attempts to obtain such a model from strings have yielded up to now non–minimal models. Such models include

- (a) extra pairs of low energy Higgses  $(h, \bar{h})$  and/or
- (b) extra pairs of  $SU(5) \times U(1)$  breaking Higgses  $(F_h, \bar{F}_h)$ .

We are thus motivated to study the presence of dimension–5 operators in such models. As we shall see contrary to the minimal case, such extensions of the flipped  $SU(5)$  model are not automatically free of dimension–5 operators.

The relevant part of the superpotential assuming  $N_5$  pairs of Higgs 5–plets  $(h_\alpha, \bar{h}_\alpha, \alpha = 1, \dots, N_5)$  that couple to matter and  $N_{10}$  pairs of Higgs 10–plets  $(F_{h\alpha}, \bar{F}_{hA}, A = 1, \dots, N_{10})$  that do not couple to matter, will have the form

$$\begin{aligned} f_{ij}^\alpha F_i F_j h_\alpha + y_{ij}^\alpha F_i f_j^c \bar{h}_\alpha + r_{ij}^\alpha l_i^c f_j^c \bar{h}_\alpha + \mu_{\alpha\beta} h_\alpha \bar{h}_\beta + m_{AB} F_{hA} \bar{F}_{hB} \\ + \lambda_{AB\gamma} F_{hA} F_{hB} h_\gamma + \bar{\lambda}_{AB\gamma} \bar{F}_{hA} \bar{F}_{hB} \bar{h}_\gamma \end{aligned} \quad (22)$$

where  $A, B = 1, \dots, N_{10}$ ,  $\alpha, \beta, \gamma = 1, \dots, N_5$ . Assuming GUT symmetry breaking to an arbitrary direction in the Higgs 10-plet space  $((V_1, V_2, \dots, V_{N_{10}})$  and similarly for bars)<sup>5</sup>, we obtain the triplet mass matrix<sup>6</sup>

$$\mathcal{M}_3 = \begin{pmatrix} \mu_{\alpha\beta} & v_{\alpha A} \\ \bar{v}_{A\beta} & m_{AB} \end{pmatrix} \quad (23)$$

where  $\mu_{\alpha\beta}$  is the doublet mass-matrix and  $v_{\alpha A} = 2\lambda_{AB\alpha}V_B$ ,  $\bar{v}_{A\beta} = 2\bar{\lambda}_{AB\beta}\bar{V}_B$

Let us now start our study by a simple example. Consider the flipped model with two pairs of Higgs 5-plets and one pair of Higgs 10-plets. Assuming for simplicity that the 5-plet mass matrix is diagonal, the explicit form of the triplet matrix is<sup>7</sup>

$$\mathcal{M}_3 = \begin{pmatrix} 0 & 0 & \lambda_1 V \\ 0 & \mu & \lambda_2 V \\ \bar{\lambda}_1 \bar{V} & \bar{\lambda}_2 \bar{V} & 0 \end{pmatrix} \quad (24)$$

and  $\det(\mathcal{M}_3) = \lambda_1 \bar{\lambda}_1 \bar{V}$  The transpose of inverse triplet matrix entering in formula (5) is

$$(\mathcal{M}_3^{-1})^T = \begin{pmatrix} \frac{\lambda_2 \bar{\lambda}_2}{\lambda_1 \bar{\lambda}_1 \mu} & -\frac{\lambda_2}{\lambda_1 \mu} & \cdot \\ -\frac{\lambda_2}{\lambda_1 \mu} & \frac{1}{\mu} & \cdot \\ \cdot & \cdot & \cdot \end{pmatrix} \quad (25)$$

where the dots stand for elements which are irrelevant. It is now obvious that in this model dimension five operators cannot be eliminated since even in the case  $\bar{\lambda}_2 = \lambda_2 = 0$  the 22 element does not vanish. If we want to eliminate them we have two solutions :

(i) assume that the extra pair of 5-plets does not couple to matter. In this case only the 11 element of the matrix in (25) is relevant and it vanishes for  $\lambda_2 = 0$  (or  $\bar{\lambda}_2 = 0$ ).

(ii) make the milder assumption that one of the 5-plets (e.g.  $h_2$ ) does not couple to the up quarks (or similarly  $\bar{h}_2$  does not couple to the down). In this case the second column (or line) of the matrix in (25) becomes irrelevant and the column (or line) left vanishes for  $\lambda_2 = 0$  (or  $\bar{\lambda}_2 = 0$ ).

Another case that could arise is the existence of extra decuplets. The simplest of these cases is for  $N_5 = 1$  and  $N_{10} = n \geq 2$ . This corresponds to the case  $N_c = 1, N_u = n$  studied in Section 3. The interesting feature here is that the requirement (12) is automatically satisfied. Since decoupled triplets have the same mass matrix as Higgs decuplets, this constraint arises as a consequence of F-flatness which demands  $\det(m) = 0$  in order to have at least one pair of massless Higgs decuplets which will realize the GUT symmetry breaking. One can actually choose  $m$  to have only one zero eigenvalue so that all remnants of the Higgs decuplets will become heavy.

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<sup>5</sup>D-flatness requires  $\sum_A V_A^2 = \sum_A \bar{V}_A^2$

<sup>6</sup>In a  $(D_1, \dots, D_{N_5}, (d_H^c)_1, \dots, (d_H^c)_{N_{10}})$  versus  $(\bar{D}_1, \dots, \bar{D}_{N_5}, (\bar{d}_H^c)_1, \dots, (\bar{d}_H^c)_{N_{10}})$  basis, where with  $D$  we denote the triplets which lie inside the Higgs 5-plets and with  $D_H$  the triplets that lie inside the Higgs 10-plets.

<sup>7</sup>We have renamed  $\lambda_1 = \lambda_{111}$ ,  $\lambda_2 = \lambda_{112}$ .



In the more general case where  $N_5$  and  $N_{10}$  are arbitrary dimension-5 operators can be suppressed only in the case  $N_5 \leq N_{10}$  according to our analysis in Section 3. Furthermore one has to require that the Higgs decuplet mass matrix has  $N_5$  zero eigenvalues. This is compatible with symmetry breaking and with the requirement of making all triplets heavy but leaves  $N_5 - 1$  pairs of  $Q(\mathbf{3}, \mathbf{2}, 1/6) + \bar{Q}(\bar{\mathbf{3}}, \mathbf{2}, -1/6)$  massless. This feature does not necessarily mean that this possibility is ruled out. On the contrary one can consider the cases where extra  $Q$ 's have intermediate masses which are small enough to sufficiently suppress dimension-5 operators but they are still compatible with renormalization group requirements. The appearance of extra vector-like pairs of  $Q$  and  $D$  type multiplets with intermediate masses is a welcomed feature in the context of flipped  $SU(5) \times U(1)$  models that raise the unification scale to the string scale [11, 20].

## 6 Conclusions

In the present article we considered the problem of dimension-5 operators that violate Baryon number. Models with extended Higgs sectors can in general have such operators and their strength cannot be assumed to be within the allowed limits since the standard Yukawa coupling suppression argument is in itself a new more or less ad hoc constraint. We, therefore, considered the problem of the elimination of these operators. An additional motivation comes about from the recently proposed M-phenomenology framework which corresponds to an effective theory with strong string coupling.

We followed a phenomenological approach trying to be general and restricting ourselves mainly on finding the necessary and sufficient conditions that can lead to the elimination of dimension-5 operators. Some of these conditions could be shown to correspond to a particular symmetry. Nevertheless, we did not insist on the point of symmetry since the theories under consideration are supposed to be effective and the symmetry structure of their renormalizable part does not always coincide with the symmetry structure of the complete theory.

Our main result is that textured zeros of the color-triplet mass-matrix as well as Yukawa selection rules can eliminate certain dimension-5 operators. In order to be specific we focused on  $SU(5)$  models. In particular, we showed that introducing an extra pair of Higgs penta-plets in the standard supersymmetric  $SU(5)$ , with specific couplings, can eliminate these operators. We also considered the case of the flipped- $SU(5)$  model with extra penta-plets and decuplets and analyzed the conditions for vanishing proton decay through dimension-5 operators. Flipped- $SU(5)$  with extra decuplets was shown to be  $D = 5$  operator-free as it happens in the case of the minimal model. However, flipped- $SU(5)$  with extra Higgs penta-plets is not automatically free of dimension-5 operators. We have proposed a solution to this problem which involves a texture of the penta-plet matrix together with certain constraints on the penta-plet couplings to matter.

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