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CAN THE "DOUBLET-TRIPLET SPLITTING" PROBLEM BE SOLVED WITHOUT DOUBLET-TRIPLET SPLITTING?

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ABSTRACT

We consider a new possible mechanism for the natural solution of the doublet–triplet splitting problem in SUSY GUTs. In contrast to the usually discussed scenarios, in our case the GUT symmetry breaking does not provide any splitting between the Higgs doublet and the triplet masses. The weak doublet and its colour triplet partner both remain light, but the triplet automatically occurs decoupled from the quark and lepton superfields and cannot induce proton decay. The advantage of the above scenario is the absence at the GUT scale of the baryon number violating the tree level $d = 5$ and $d = 6$ operators via the colour–triplet exchange. It is shown that in flipped $SU(5)$ GUT they do not appear at any scale. In the $SO(10)$ model, such operators can be induced after SUSY breaking but are strongly suppressed.

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The hierarchy problem is a generic shortcoming of Grand Unified Theories (GUTs). The existence of the two different mass scales $M_G \sim 10^{16} GeV$ and $m_W \sim 100 GeV$ requires extremely precise adjustment of parameters in all orders of the perturbation theory. It is well–known [1], that supersymmetry (SUSY) technically solves this problem; in SUSY GUTs radiative corrections do not destroy hierarchies built into the tree approximation. But the question is how to obtain the desired hierarchy at the tree level? The simplest way would be to decide is to absolutely decouple the Higgs doublet from the GUT Higgs multiplets with large ($\sim M_G$) vacuum expectation values (VEVs) in the superpotential. However, the problem is not only to provide the correct electroweak symmetry breaking (with a small $\sim m_W$ VEV of the doublet) but, at the same time, to avoid the unacceptably fast proton decay through its coloured triplet partner exchange. This is the famous doublet–triplet splitting problem in SUSY GUTs.

In the standard approach, one assumes that, due to some mechanism (usually due to coupling with heavy GUT Higgs fields in the superpotential), the GUT symmetry breaking induces splitting between the masses of the doublet and triplet components; the doublet remains massless, while its coloured partner acquires mass $\sim M_G$ and becomes harmless for proton decay. In the minimal $SU(5)$ SUSY GUT, this requires fine tuning of superpotential parameters.

Several attempts have been made to explain the above splitting in a natural way. One explanation is offered by the *missing partner mechanism* [2] which gives a group–theoretical reason for doublet being massless. Most elegantly this mechanism works in flipped $SU(5)$ GUT [3], where is provided by the lowest possible representation capable of breaking $SU(5) \otimes U(1)$ down to the Weinberg–Salam–Glashow symmetry $G_W = SU(3)_c \otimes SU(2) \otimes U(1)$ [4]. Another explanation is based on the *sliding singlet mechanism* [5] which has been criticized, however, for being unstable under SUSY breaking [6], but, as it was shown in [7], can be successfully incorporated in locally supersymmetric $SU(6)$ GUT. Several authors have noted the existence of naturally massless Higgs doublets in superstring theories [8]. Another possible mechanism for a natural explanation of the doublet–triplet hierarchy problem was suggested in [9] and [10]. In these models, the doublets are massless since they are pseudo–Goldstone bosons of certain *accidental* global symmetries of the superpotential.

As mentioned above, all mechanisms enumerated here are based on the one and the same general idea: the triplet is rendered harmless due to acquiring a mass of order M_G. However, this does not solve the whole problem in a satisfactory way, since the usual Higgs induced $d = 6$ operators are not the only danger provided by the coloured triplet in SUSY GUTs. Another problem is the $d = 5$ operators induced due to fermion superpartner (Higgsino) exchange (group and family indices are suppressed) [11]

$$\frac{1}{M_G}[QQQL]_F, \tag{1}$$

where Q and L denote quark and lepton superfields, respectively and the subscript denotes the F–component of the product. They convert quarks and leptons into superpartner states and in contrast to the usual $d = 6$ operators are suppressed only by a factor $\frac{1}{M_G}$ coming from the Higgsino propagator. Due to this in combination with other operators (capable of coverting superpartner state back to normal states) can mediate an unacceptedly fast proton decay. So even if the coloured triplet acquires mass $\sim M_G$ suppressing the $d = 6$ operators up to a rate $\sim \frac{1}{M_G^2}$, the suppression of $d = 5$ ones is still unsatisfactory. Acceptable Higgs induced the $d = 5$ operators are allowed only in some regions of the theory parameters [11,12]. Due to this, the natural suppression of the baryon number violating $d = 5$ operators is still an open problem is SUSY GUTs.

In the present paper, we discuss a new possible approach to the solution of the doublet-triplet splitting problem which automatically eliminates the disastrous $d = 5$ (as well as $d = 6$) operators. In contrast to a previously discussed scenario we assume that the GUT symmetry breaking does not induce any splitting between masses of the Higgs doublet and triplet components, but between their Yukawa coupling constants with quarks and lepton superfields. As a result, the weak doublet as well as its coloured triplet partner both remain light with masses $\sim m_W$. However, the triplet automatically decouples from light matter superfiels and cannot induce proton decay. The general mechanism providing the above effect is that the doublet is coupled to the quarks and leptons only through the large ($\sim M_G$) VEV of a certain Higgs scalar component breaking the GUT symmetry. This VEV mixes quarks and leptons with hypothetical heavy ($\sim M_G$) multiplets providing after $SU(2) \otimes U(1)$ breaking their small masses by full analogy with the well-known see-saw mechanism [13,14]. At the same time, the triplet is forced to be isolated from the light sector since there is no VEV that can couple it to matter superfields. Consequently, there are no tree level $d = 5$ and $d = 6$ operators via the coloured Higgs exchange. As it will be seen below in the $SO(10)$ model they can occur, in general, after SUSY breaking but are suppressed by the factors $\frac{m_W}{M_G^2}$ and $\frac{1}{M_G^2}$, respectively. In contrast, in the flipped $SU(5)$ model such tree level operators are absent at any scale and can be generated only at the loop level.

$SO(10)$ EXAMPLE

Let us demonstrate the above in a simple $SO(10)$ SUSY GUT. We asume that $SO(10)$ symmetry is broken down to G_W at a scale M_G by a number of Higgs superfields. We choose one of them to be a 45-plet developing a VEV of the form

$$< 45 >= diag(0,0,0,\sigma,\sigma)V \quad V \sim M_G, \tag{2}$$

where each of the diagonal elements denote a 2×2 submatrix and $\sigma = \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}$. In terms of the Pati–Salam 15] subgroup $G_{L,R} = SU(2)_L \otimes SU(2)_R \otimes SU(4)$, the above VEV is transforming as $(1.3.1)$ and breaks the $SU(2)_R$ symmetry to $U(1)_R$. The $SO(10)$ assignment of other heavy Higgs representations is unimportant for our analysis. Thus we simply assume that in addition to the 45, the model includes some set of heavy multiplets capable of breaking $SO(10) \to G_W$. We assume that the electroweak doublet as well as its triplet partner transforming under $G_{L,R}$ as $(2.2.1)$ and $(1.1.6)$, respectively are placed in the fundamental 10-plet. The requirement of our mechanism is the absence of any direct coupling of 10 with 45 (as well as with other heavy Higgs multiplets) in the superspace potential. Note that for the 45-plet this requirement is satisfied

automatically, since the only possible invariant $45 \otimes 10 \otimes 10$ vanishes due to the antisymmetricity of the 45 representation. Thus the only allowed self-interaction term for the 10 in the superpotential is

$$W_{10} = m 10 \otimes 10 \tag{3}$$

providing the equal supersymmetric mass m for both the doublet and triplet components. Obviously, one has to assume that $m \lesssim m_W$ in order to provide a correct $SU(2) \otimes U(1)$ symmetry breaking after SUSY breaking and radiative corrections will be included [16].

In the standard versions of SUSY $SO(10)$ model, the masses of quarks and leptons living in the 16-dimensional spinor representation are generated by means of the tree level *Yukawa* couplings with the Higgs 10-plet (or/and with 126 or 120 representations) in the superpotential

$$g 10 \otimes 16 \otimes 16, \tag{4}$$

where g stands for a coupling constant and group as well as generation indices are suppressed. However, this coupling in our case is disastrous since it will provide a very fast proton decay via light Higgs triplet exchange. Thus it must be excluded from the superpotential. To forbid (4), one can impose e.g. a discrete symmetry under $10 \to -10$, or some global $U(1)$-symmetry. In general, however, such a global symmetry is anomalous and could serve as a Peccei–Quinn symmetry [17]. In our case this can be related with cosmological problems, since as we shall see below a 45-plet has necessarily to transform nontrivially under this symmetry and thus breaks it at a GUT scale giving rise to cosmologically unacceptable domain walls [18] or invisible axions. [19]. Another possibility is to forbid coupling (4) due to a group-theoretical reason. As seen below this is automatically in the case of flipped $SU(5)$ GUT. In the $SO(10)$ model this can be achieved if 45 and 10 will be replaced by larger representations of $SO(10)$.

One way or the other in our (the simplest in $SO(10)$) illustrative example we simply assume that the coupling (4) is excluded from the superpotential. Morover, as the SUSY allows to do this even without symmetry reasons due to a non-renormalization theorem [20]. In order to generate quark and lepton masses we introduce a pair of hypothetical heavy supermultiplets $144 + \overline{144}$ which couple to 45, 10 and 16 in the following way (generation and $SO(10)$-spinor indices are suppressed while the tensor ones $i, k, = 1, \ldots, 10$ are written explicitly)

$$W = g 16 \gamma_i \overline{144}_k \otimes 45_{ik} + M_{144} \overline{144}_k \otimes 144_k + g\prime 16 \otimes 144_k \otimes 10_k\,, \tag{5}$$

where γ_i are generalized γ-matrices from $SO(10)$ Clifford algebra, $g, g\prime$ are coupling constants and M_{144} is a mass of order M_G. In full analogy with the Dirac see-saw mechanism [13], for energies below M_G, the above set of couplings is equivalent to the following effective operator

$$\frac{gg\prime}{M_{144}} 45_{ik} 10_k \otimes 16 \gamma_i 16 \tag{6}$$

This can be easily seen from the tree diagram in Fig.1. After the substitution of the 45-plet by its VEV (2) in (6), one obtains the following decomposition into $G_{L,R}$-invariant pieces

$$\frac{gg\prime}{M_{144}} \langle(1.3.1)\rangle_{45} (2.2.1)_{10} \otimes (2.1.4)_{16} \otimes (1.2.\bar{4})_{16}, \tag{7}$$

where the subscript denotes from which $SO(10)$ representation the given $G_{L,R}$–fragment comes. Thus after the GUT symmetry breaking coupling (5, 6) is reduced to the usual Pati–Salam type interaction of doublets $(2.2.1)_{10}$ with effective constants $\lambda_d = \frac{gg'}{M_{144}}\langle(1.3.1.)_{45}\rangle$. At the same time, the triplet $(1.1.6)_{10}$ has automatically decoupled from the light matter fields. This is obvious since the component $(1.1.15)_{45}$ which would couple the triplet to quarks and leptons in $G_{L,R}$–invariant way has zero VEV. The key point is that after the substitution of VEV $\langle(1.1.3)_{45}\rangle$ the triplet component $(1.1.6)$ of the effective 10–plet living in the $SO(10)$ tensor product

$$45 \otimes 10 = 10 + 120 + 320 \tag{8}$$

vanishes automatically.

Let us verify the above result by a direct analysis of quark and lepton mass matrices. The latter after the substitution of the VEVs $\langle(1.3.1)_{45}\rangle \sim M_G$ and $\langle(2.2.1)_{10}\rangle \sim m_W$ take the following form

$$\begin{array}{cc} & (1.2.\overline{4})_{16} \quad (2.3.\overline{4})_{\overline{144}} \\ \begin{array}{c}(2.1.4)_{16} \\ (2.3.4)_{144}\end{array} & \begin{pmatrix} 0 & g\langle(1.3.1)_{45}\rangle \\ g'\langle(2.2.1)_{10}\rangle & M_{144} \end{pmatrix} \end{array} \quad \begin{array}{cc} & (2.1.4)_{16} \quad (1.2.4)_{\overline{144}} \\ \begin{array}{c}(1.2.\overline{4})_{16} \\ (1.2.\overline{4})_{144}\end{array} & \begin{pmatrix} 0 & g\langle(1.3.1)_{45}\rangle \\ g'\langle(2.2.1)_{10}\rangle & M_{144} \end{pmatrix} \end{array} \tag{9}$$

It is obvious that after the diagonalization of the above matrices, the quark and lepton superfield masses of the desired magnitude

$$m_{16} \sim \frac{gg'}{M_{144}}\langle(1.3.1)_{45}\rangle\langle(2.2.1.)_{10}\rangle \sim gg'm_W \tag{10}$$

are induced in the usual Dirac see-saw [13] way. In the process of this diagonalization the left–handed $(2.1.4)_{16}$ and anti left–handed (right–handed) $(1.2.\overline{4})_{16}$ quark and lepton superfields from the 16–plet are mixed (by the weight $\simeq \langle(1.3.1)_{45}\rangle\frac{g}{M}$, where $M = \sqrt{M_{144}^2 + V^2}$) with their hypothetical heavy partners from $(2.3.4)_{144}$ and $(1.2.\overline{4})_{144}$, respectively. The mixing between other components of 16 and $144 + \overline{144}$ is negligible $(\sim \frac{m_W}{M_G})$.

At the same time, the reduced $G_{L,R}$–invariant *Yukawa* couplings of the light triplet $(1.1.6)_{10}$ in the superpotential have the form

$$g'(1.1.6)_{10}\left[(2.1.4)_{16}(2.1.4)_{144} + (1.2.\overline{4})_{16}(1.2.\overline{4})_{144}\right]. \tag{11}$$

The fragment $(2.1.4)_{144}$ is a state with a superlarge mass M_{144}. But as we have seen above, another fragment $(1.2.\overline{4})_{144}$ contains a light superfield admixture of the form

$$\langle(1.3.1)_{45}\rangle(1.2.\overline{4})_{16}\frac{g'}{M}. \tag{12}$$

However in the $G_{L,R}$–invariant coupling (11) this admixture vanishes automatically due to the symmetricity of $SU(2)_R$ indices and antisymmetricity of the $SU(4)$ ones. Thus our light triplet cannot convert light matter fermion into light state but ony into ultraheavy ones (with mass $\sim M_G$) and troublesome tree diagrams ($d = 5$ and $d = 6$) do not occur.

Dangerous tree level operators can arise after SUSY breaking. After supersymmetry breaking (e.g. in $N = 1$ supergravity theories) the heavy GUT Higgs VEVs can (and in general will) be changed by an additional factor of order m_W due to the effect of soft SUSY–breaking terms in the potential (e.g. see [7,9]). So that in principle the 45–plet can develop a small $\sim m_W$ VEV on its $(1.1.15)_{45}$ component. This component couples the triplet Higgs to matter fermions in (6) and thus tree level $d = 5$ and $d = 6$ operators will be induced (Fig.2). But the effective coupling constant of the triplet $\lambda_T = \frac{gg'}{M_{144}}\langle(1.1.15)_{45}\rangle$ is of the order $\frac{m_W}{M_G}$ and the troublesome $d = 5$ and $d = 6$ operators will be suppressed by the factors $\sim \frac{m_W}{M_G^2}$ and $\frac{1}{M_G^2}$, respectively.

It is worth mentioning that, at the same time, the above mechanism automatically guarantees that the weak doublet, but not the colour triplet Higgs, will develop VEV $\sim m_W$ after the radiative corrections will be taken into account. This is obvious, since according to the standard scenario of radiative $SU(2) \otimes U(1)$ breaking [16], the major negative contribution to the Higgs $[\text{mass}]^2$ comes from the loops with the matter fermion and, namely, the top quark exchange (due to its largest Yukawa coupling constant). Consequently the sign of the triplet Higgs' $[\text{mass}]^2$ (whose couplings with light matter fermions are extremely suppressed) cannot be affected by these corrections.

FLIPPED $SU(5)$ EXAMPLE

Let us now consider how our mechanism can be incorporated in the SUSY flipped $SU(5)$ GUT. The $SU(5) \otimes U(1)$ model was intensively studied by a number of authors in ordinary $N = 1$ SUSY [4] as well as in the string–inspired model [21] framework. Here we briefly recall only the aspects which are relevant to the demonstration of our mechanism and of its comparison with the standard approach. The standard $SU(5) \otimes U(1)$ assignment of each generation quark and lepton superfields is the following

$$f_{10} = (10.1), \quad \overline{f}_{\overline{5}} = (\overline{5}. -3), \quad e^c = (1.5). \tag{12}$$

Besides the model includes two conjugate pairs of Higgs representations

$$\Sigma = (10.1), \quad \overline{\Sigma} = (\overline{10}, -1), \quad h = (5 -2), \quad \overline{h} = (\overline{5}.2) \tag{13}$$

In addition to the nonsinglet representations, a number of singlets is required for providing the see–saw mechanism [14] for the neutrino mass. For simplicity, we exclude them from our analysis, since the standard the see–saw mechanism (for the neutrino) remains unchanged.

The first step of $SU(5) \otimes U(1)$ symmetry breaking down to G_W is induced by the pair of $10 + \overline{10}$–plets developing the VEVs of the form

$$\langle\Sigma_{ik}\rangle = \langle\overline{\Sigma}^{ik}\rangle = [\delta_{i4}\delta_{k5} - \delta_{i5}\delta_{k4}]V \quad V \sim M_G, \tag{14}$$

where i, k are the $SU(5)$ indices and δ_{ik} is a Kronecker symbol. As it is usually assumed (e.g. see [4]) this can happen due to the existence of just one F–flat and $\mathcal{D}$–flat vacuum direction corresponding to the configuration (14) and suitable to generate a VEV of order M_G. However, it does not matter very much for our analysis that the VEV (14) is generated by this or by some other mechanism (e.g. due to a tree level coupling with some other fields in the superpotential).

The doublet–triplet mass is automatically induced after GUT symmetry breaking due to the following couplings in the superpotential (group indices are suppressed)

$$W_{\Sigma,h} = \lambda\Sigma\Sigma h + \lambda'\overline{\Sigma}\,\overline{\Sigma}\,\overline{h} \qquad (15)$$

substituting the VEVs (14) in (15), one readily finds that the colour triplets from $h + \overline{h}$ acquire masses $\sim M_G$, while the doublet components remain massless. This makes possible a correct $SU(2) \otimes U(1)$ symmetry breaking by h and $\overline{h}$ VEVs and the simultaneous generation of light fermion masses by means of the following *Yukawa* couplings in the superpotential

$$a f_{10} f_{10} h + b f_{10} \overline{f}_{\overline{5}} \overline{h} + c \overline{f}_{\overline{5}} e^c h + \text{couplings with singlets for see} - \text{saw} \ . \qquad (16)$$

In order to realize our splitting mechanism in $SU(5) \otimes U(1)$ GUT we slightly modify the $U(1)$–charges of Higgs 5–plets h and $\overline{h}$. Namely, instead of (3), we assume

$$h = (5, 3) \qquad \overline{h} = (\overline{5}, -3) \ . \qquad (17)$$

This automatically excludes couplings (15) as well as any other interaction between $\Sigma, \overline{\Sigma}$ and $h, \overline{h}$. Thus Higgs 5–plets absolutely decouple from the GUT sector in the superpotential, so that no doublet–triplet mass splitting is induced at the GUT scale. At the same time, due to a new $U(1)$–charge assignment, *Yukawa* couplings (16) are also forbidden automatically. Following the same strategy as in the $SO(10)$–model, we introduce the set of hypothetical heavy multiplets

$$F = (24, 0), \quad Y = (5, -2), \quad \overline{Y} = (\overline{5}, 2), \quad \Theta = (45, -2), \quad \overline{\Theta} = (\overline{45}, 2) \ . \qquad (18)$$

Then the following system of coupling is allowed in the superpotential ($SU(5)$–indices are written explicitly)

$$\begin{aligned} W_f &= W_\Theta + W_F + W_Y \\ W_\Theta &= \alpha(f_{10})_{ik}\Sigma_{ms}\Theta^S_{ne}\epsilon^{ikmne} + \alpha'\,\overline{\Theta}^{ne}_s\,\overline{h}^s(f_{10})_{ne} \\ W_F &= \beta(f_{10})_{ik}\overline{\Sigma}^{km}F^i_m + \beta' F^m_i h_m(\overline{f}_{\overline{5}})^i \\ W_Y &= \gamma(\overline{f}_{\overline{5}})^i\Sigma_{ik}\overline{Y}^k + \gamma' Y_k\overline{h}^k e^c \end{aligned} \qquad (19)$$

where ϵ^{ikmne} is an invariant antisymmetric tensor and $\alpha, \alpha', \beta, \beta', \gamma, \gamma'$ are constants. Remembering that new multiplets have large ($\sim M_G$) mass terms in the superpotential

$$W' = M_F F^2 + M_\Theta \Theta\overline{\Theta} + M_Y Y\overline{Y} \qquad (20)$$

it is easy to understand that (in full analogy with the $SO(10)$ case discussed above) system (19), (20) below the GUT scale is equivalent to the following set of effective couplings

$$\begin{aligned} W_f = &\frac{\alpha\alpha'}{M_\Theta}(f_{10})_{ik}(f_{10})_{ne}\Sigma_{ms}\overline{h}^s\epsilon^{iknem} + \frac{\beta\beta'}{M_F}(f_{10})_{ik}(\overline{f}_{\overline{5}})^i\overline{\Sigma}^{km}h_m \\ &+ \frac{\gamma\gamma'}{M_Y}(\overline{f}_{\overline{5}})^i e^c\Sigma_{ik}\overline{h}^k \end{aligned} \ . \qquad (21)$$

Substituting the VEVs (14) of $\Sigma, \overline{\Sigma}$ in the above operator and decomposing them into G_W–invariant pieces one easily finds that the coupling of doublets $h_i\overline{h}^i$, $(i = 4, 5)$ is reduced to a usual G_W–invariant *Yukawa* interaction, with the effective coupling constant of order $\alpha\alpha'\frac{V}{M_G}$. At the same time, triplets $h_i\overline{h}^i$, $(i = 1, 2, 3)$ are decoupled since there is no VEV capable of coupling them to light fermions. As a result, there is no baryon number violating $d = 5$ and $d = 6$ operators at the tree level.

Let us now discuss the question of whether such operators can be generated after the supersymmetry breaking. As we have seen in our $SO(10)$) example, this in general might happen. The reason was that after SUSY breaking, the45–plet Higgs can acquire a small ($\sim m_W$) projection of its VEV on another G_W–singlet direction living in $(1, 1, 15)_{45}$. This VEV couples the colour triplet Higgs with quarks and leptons in operator (6). However, there is a crucial difference between the $SO(10)$ and $SU(5) \otimes U(1)$ cases. This is provided by the fact that the ten–dimensional representation of $SU(5) \otimes U(1)$ (in contrast with 45 of $SO(10)$) includes just only one $SU(3)_c \otimes U(1)_{EM}$ (and G_W)–singlet component. Consequently the only allowed (by the requirement of the correct symmetry breaking) orientation of 10–plets VEV is (14) (of course the absolute value V in general will receive a small $\sim m_W$ correction after SUSY breaking). Above means, that in contrast with the $SO(10)$ case, the triplet remains decoupled from ordinary light fermions at any scale. Thus in the flipped $SU(5)$ model, the tree level proton decay mediating $d = 5$ and $d = 6$ operators via the triplet exchange are absent even after SUSY breaking.

Of course, in $SU(5) \otimes U(1)$ as well as in any other GUT such $d = 5$ operators can be induced radiatively but will be suppressed at least by factor $\sim \frac{m_W}{M_G}$. This can be easily understood on a pure dimensional ground. Since the only $\mathcal{D}$–component of the local product of chiral superfields can be generated in the perturbation theory [22], our $d = 5$ terms will be in general induced radiatively from an effective operator

$$\frac{g^K}{M_G^{n+2}}\left[QQQL\phi_1 \cdots \phi_n^+\right]_D \ . \qquad (22)$$

Here g^K stands for the coupling constants which in general will be presented in a given diagram and M_G is a typical mass of heavy particles propagating in the loop (e.g. in the flipped $SU(5)$ such will be the components of $\Sigma, F, \overline{Y}, Y, \Theta$ and $\overline{\Theta}$). All but one external leg Φ_i^+ must be a SUSY–breaking spurion insertion $\phi_i^+ = \overline{\theta}\,\overline{\theta} m_{\frac{3}{2}} M$ (where θ denotes the usual superspace coordinate, $m_{\frac{3}{2}} \sim m_W$ and M could be of order GUT or m_W) since each of the two fermion legs already carries one θ

with it. All other $n = 1$ external legs are scalars with VEVs $\sim M_G$ (or m_W). The above readily provides the suppression factor of order $\frac{m_W}{M_G^2}$.

DOUBLE SPLITTING MECHANISM

Our mechanism does not exclude in principle that the decoupled triplet Higgs at the same time can acquire a large $\sim M_G$ mass in the usual doublet–triplet splitting manner. Most elegantly, this can be achieved in the flipped $SU(5)$ model. For this reason, one has to introduce an additional pair of multiplets $H = (10, -4)$ and $(\overline{H} = (\overline{10}, 4)$ with large $M_H \sim M_G$ tree level masses and the zero VEVs. Then the following $SU(5) \otimes U(1)$–invariant couplings between $\Sigma, \overline{\Sigma}, H\overline{H}$ and $h, \overline{h}$ are possible in the superpotential

$$W_H = \lambda \Sigma H h + \lambda' \overline{\Sigma}\, \overline{H}\, \overline{h} + M_H \overline{H} H \quad . \tag{23}$$

Substituting the VEVs of Σ and $\overline{\Sigma}$ (14) in the above superpotential one obtains the following matrices for the colour triplet fragments from $H, \overline{H}$ and $h, \overline{h}$

$$\begin{array}{c} \\ \overline{3}_{\overline{h}} \\ \\ \overline{3}_H \end{array} \begin{array}{c} \begin{array}{cc} 3_h & 3_{\overline{H}} \end{array} \\ \begin{pmatrix} 0 & \lambda' V \\ & \\ \lambda V & M_H \end{pmatrix} \end{array} \tag{24}$$

Thus all triplets acquire masses of order M_G, while doublets from h and $\overline{h}$ remain massless. In such a case, there will be an additional source for the suppression of $d = 5, d = 6$ operators.

In summary, the essential feature of our mechanism is the existence of a pair of light ($\sim M_W$) supermultiplets with quantum numbers of right–handed down quarks. Since they carry both colour and electric charge they will easily beproduced and identified at future colliders. In the simpletst $N = 1$ supergravity scheme, their masses are in principle calculable in terms of the doublet Higgs or/and squarks masses. It should also be mentioned that they will modify the usual renomalization group analysis of the unification scale and $sin\,\Theta_W$. These important questions will be discussed in a future publication.

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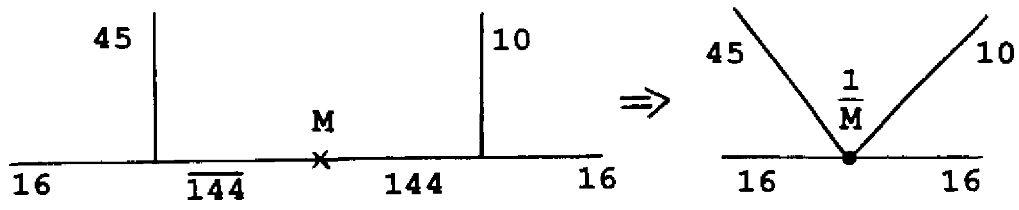

Fig.1
The tree supergraph which gives the effective operator of Eq.(6)

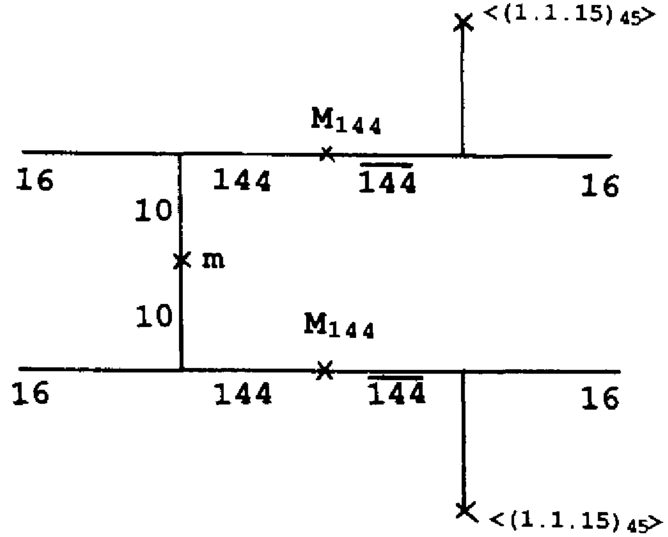

Fig.2
Origin of the baryon–number violating the tree level operator in the $SO(10)$ model