SUSY GUTS: 4 – GUTS: 3

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We construct a supersymmetric SU(5) model with the following properties: (1) $\sin^2\theta_W$, m_b/m_τ in accordance with experiment; (2) natural monopole suppression and universal baryon asymmetry generation; (3) proton decay at a rate 10^{31} yr with characteristic decay modes according to $\Gamma(\bar{\nu}_\mu K^+, \mu^+ K^0):\Gamma(\bar{\nu}_e K^+, e^+K^0, \mu^+\text{“}\pi^0\text{”}):\Gamma(e^+\pi^0, \bar{\nu}_e\pi^+) \simeq 1:\sin^2\theta_C:(\sin^2\theta_C)^2$, in sharp contrast with ordinary GUTs or other supersymmetric GUTs.

1. Motivation. Despite much success, grand unified theories (GUTs) [1] have been unable to explain the enormous difference between the grand unification mass scale and the scale of the electroweak breaking. This problem, called the gauge hierarchy problem [2], also has a technical aspect to it. At every order of perturbation theory new adjustments of extreme accuracy are needed among the various parameters in order to keep the masses of the "light" particles small. This aspect of the hierarchy problem is solved by invoking global supersymmetry [3]. Nonrenormalization theorems [4], valid for supersymmetric theories to all orders in perturbation theory, ensure that any fine adjustments done at the tree level will not be upset by radiative corrections as long as supersymmetry is unbroken. In globally supersymmetric GUTs, supersymmetry is assumed to remain unbroken down to "low" energies of order M_W (or at most a few TeV) [5].

The proliferation of fundamental particles in supersymmetric GUTs has led to some changes in the standard phenomenological predictions which have been analyzed by various authors [6,7]. In particular, the electroweak mixing angle $\sin^2\theta_W$ was found, in the minimal supersymmetric SU(5), to be a bit too large. The b-quark to τ-lepton mass ratio comes out to be essentially unchanged [7] from its standard GUT value [8]. Although gauge bosons become less important in nucleon decay due to the increase of the unification scale, Higgs-mediated proton decay occurs at a rate compatible with the experimental limit. In the particular case of softly broken supersymmetry, the dominant decay mode of the proton is [7] $\bar{\nu}_\tau K^+$, a signature probably hard to identify. On the other hand, an analysis of the cosmological implications of supersymmetric GUTs [9] has led us to a scenario in which monopoles are naturally suppressed and the universal baryon asymmetry is explained provided colour triplet Higgses are kept as "light" as 10^{10} GeV. Motivated by the natural appearance of this scale (which coincides with the lower mass limit on colour triplet masses imposed by the stability of the proton [10]), we have reanalyzed the phenomenological predictions of supersymmetric GUTs endowed with such "low"-mass Higgs supermultiplets. We have restricted ourselves to a minimal supersymmetric SU(5) model but our conclusions are quite general. We find that: (1) the predicted values of $\sin^2\theta_W$ and m_b/m_τ are in accordance with experiment; (2) protons decay at a rate of 10^{31} yr, through exchange of colour triplet Higgses, with the characteristic hierarchy of decay modes:

$$\Gamma(\bar{\nu}_\mu K^+, \mu^+K^0):\Gamma(\bar{\nu}_e K^+, \mu^+\text{“}\pi^0\text{”}, e^+K^0):\Gamma(e^+\pi^0, \bar{\nu}_e\pi^+) \simeq 1:\sin^2\theta_C:(\sin^2\theta_C)^2\ .$$

It should be stressed that an observable proton decay through this mode would be a clear indication of supersymmetry and "light" Higgses at the same time. In an ordinary GUT we have no non-renormalization theorems to guarantee that the Higgs mass will stay small enough [‡1] to cause an appreciable decay rate. In addition, in an or-

‡1 Radiative corrections would tend to push it to M_X.

dinary GUT such a light Higgs would be disastrous for the baryon asymmetry.

2. The model. The minimal supersymmetric grand unified model that can be constructed in no obvious conflict with phenomenology is an SU(5) gauge theory which, except for the gauge supermultiplet, contains quark and lepton supermultiplets $Q_{\bar{5}}$ and Q_{10} as well as Higgs supermultiplets in the adjoint (Σ_{24}) and the vector representation (H_5, $H_{\bar{5}}$). As is well known, apart from the unexplained huge difference between the grand unification scale and the supersymmetry breaking scale (which for simplicity we identify with the electroweak breaking scale), about which we have nothing to say, there is another unnatural adjustment that needs to be done, i.e., we must fine-tune the doublet Higgs masses to zero. However, in this case we can bypass the problem by introducing an SU(5) singlet superfield ϕ coupled only linearly to H_5 and $H_{\bar{5}}$ [11]. The superspace potential of the model is

$$W = \tfrac{1}{3} a \,\mathrm{tr}(\Sigma^3) + \tfrac{1}{2} bm \,\mathrm{tr}(\Sigma^2) + c H_{\bar{5}} \Sigma H_5 + d\phi H_{\bar{5}} H_5 + \ldots . \tag{1}$$

The potential will be

$$V = \mathrm{tr}\,|mb\Sigma + a\Sigma^2 - \tfrac{1}{5} a\,\mathrm{tr}(\Sigma^2) + c H_{\bar{5}} \times H_5 - \tfrac{1}{5} c H_{\bar{5}} \cdot H_5|^2$$
$$+ |(c\Sigma_i{}^j + d\phi\delta_i{}^j) H_{5j}|^2 + |(c\Sigma^i_j + d\phi\delta^i_j) H_{\bar{5}}{}^j|^2 + d^2 |H_{\bar{5}} H_5|^2 + \ldots . \tag{2}$$

The following degenerate supersymmetric minima exist:

(i) $\langle\Sigma\rangle = \langle H_5\rangle = \langle H_{\bar{5}}\rangle = 0$ [SU(5)].

(ii) $\langle\Sigma\rangle = (bm/a)\,\mathrm{diag}(2,2,2,-3,-3)$, $\langle H_5\rangle = \langle H_{\bar{5}}\rangle = 0$ [SU(3) × SU(2) × U(1)].

(iii) $\langle\Sigma\rangle = (bm/3a)\,\mathrm{diag}(1,1,1,1,-4)$, $\langle H_5\rangle = \langle H_{\bar{5}}\rangle = 0$ [SU(4) × U(1)].

The expectation value of the singlet is arbitrary. However, in view of the fact that the doublets in H_5, $H_{\bar{5}}$ will acquire a small expectation value when we incorporate supersymmetry breaking in the model, minimization implies that

$$\phi = (3cb/da)m ,$$

which naturally keeps the doublets light and gives the triplets a large (mass)^2 $25(c^2b^2/a^2)m^2$. The superpotential would then effectively be, in the SU(3) × SU(2) × U(1) phase

$$W \simeq 0 \cdot H_2 H_{\bar{2}} + [(5cb/a)m] H_3 H_{\bar{3}} + \ldots . \tag{3}$$

Non-renormalization theorems ensure that as long as supersymmetry is not broken [which we assume, down to energies of $O(M_W)$] any adjustments made in (3) will be respected by radiative corrections. Thus, the coupling c can be adjusted to values of $O(10^{-5}-10^{-6})$ leading to a triplet mass of $O(10^{10}$ GeV). But before we commit ourselves to a particular adjustment let us turn to the renormalization group to examine the low-energy phenomenology of our model.

3. Renormalization group analysis. The renormalization group equations for the gauge couplings of the SU(3) × SU(2) × U(1) theory can easily be derived. They are

$$\alpha_3^{-1}(\mu) = \alpha_G^{-1} - (2\pi)^{-1}(9 - F - \tfrac{1}{2}T)\ln(M_X/\mu) ,$$
$$\sin^2\theta_W/\alpha(\mu) = \alpha_G^{-1} - (2\pi)^{-1}(6 - F - \tfrac{1}{2}H)\ln(M_X/\mu) ,$$
$$\tfrac{3}{5}\cos^2\theta_W/\alpha(\mu) = \alpha_G^{-1} + (2\pi)^{-1}(F + \tfrac{3}{10}H + \tfrac{1}{5}T)\ln(M_X/\mu) . \tag{4}$$

F is the number of flavours, T the number of colour triplets and H the number of SU(2) doublets. α_G is the coupling at the unification point M_X. An equation for the unification point can easily be derived from (4)

$$\alpha^{-1}(M_W) - \tfrac{8}{3}\alpha_3^{-1}(M_W) = (2\pi)^{-1}(18 + H - T)\ln(M_X/M_W) . \tag{5}$$

If we have some intermediate scale Λ, (5) is modified according to

$$\alpha^{-1}(M_W) - \tfrac{8}{3}\alpha_3^{-1}(M_W) = (2\pi)^{-1}(18 + H_2 - T_2)\ln(M_x/\Lambda) + (2\pi)^{-1}(18 + H_1 - T_1)\ln(\Lambda/M_W)\,, \quad (6)$$

where T_2 (H_2) are the triplets (doublets) that contribute in the interval $[M_x, \Lambda]$ and T_1 (H_1) are the triplets (doublets) that contribute in the interval $[\Lambda, M_W]$. Obviously $T_1 = 0$. Eq. (6) can be cast in the form

$$\ln(M_x/M_W) = [2\pi/(18 + H_2 - T_2)]\,[\alpha^{-1}(M_W) - \tfrac{8}{3}\alpha_3^{-1}(M_W) + (2\pi)^{-1}(H_2 - T_2 - H_1)\ln(\Lambda/M_W)]\,. \quad (7)$$

Similarly we can obtain an analogous equation for the coupling at the unification point (again for the simple case of one intermediate scale Λ)

$$\frac{1}{\alpha_G} = \frac{1}{\alpha_3(M_W)}\left(1 - \frac{\tfrac{8}{3}(9 - F - \tfrac{1}{2}T_2)}{18 + H_2 - T_2}\right) + \frac{1}{\alpha(M_W)}\,\frac{9 - F - \tfrac{1}{2}T_2}{18 + H_2 - T_2}$$
$$+ \frac{1}{2\pi}\,\frac{\ln(\Lambda/M_W)}{18 + H_2 - T_2}\det\begin{pmatrix} 9 - F - \tfrac{1}{2}T_1 & 18 + H_1 - T_1 \\ 9 - F - \tfrac{1}{2}T_2 & 18 + H_2 - T_2 \end{pmatrix}. \quad (8)$$

Finally, an equation for the mixing angle can be obtained

$$\sin^2\theta_W(M_W) = (18 + H_2 - T_2)^{-1}$$
$$\times \{3 + [\alpha(M_W)/\alpha_3(M_W)]\,[10 + \tfrac{1}{3}(T_2 - H_2)] + [3\alpha(M_W)/\pi]\,[H_1 - (H_2 - T_2)]\ln(\Lambda/M_W)\}\,. \quad (9)$$

It is easy to observe that the unification point and the mixing angle depend only on the difference $H_2 - T_2$ and not on the absolute number of triplets and doublets that contribute above Λ. For complete SU(5) pentaplets $H_2 - T_2 = 0$. In that case, our equations become (for $F = 6$)

$$\ln(M_x/M_W) = \tfrac{1}{9}\pi\,[\alpha^{-1}(M_W) - \tfrac{8}{3}\alpha_3^{-1}(M_W) - (H_1/2\pi)\ln(\Lambda/M_W)]\,,$$

$$\alpha_G^{-1} = \alpha_3^{-1}(M_W)(\tfrac{5}{9} + \tfrac{2}{27}T_2) + \alpha^{-1}(M_W)(\tfrac{1}{6} - \tfrac{1}{36}T_2) + (36\pi)^{-1}(-3H_1 + 9T_2 + \tfrac{1}{2}H_1T_2)\ln(\Lambda/M_W)\,,$$

$$\sin^2\theta_W(M_W) = \tfrac{1}{6} + \tfrac{5}{9}[\alpha(M_W)/\alpha_3(M_W)] + [H_1\alpha(M_W)/6\pi]\ln(\Lambda/M_W)\,. \quad (10)$$

As long as $\Lambda < M_x$, the light doublets H_1 do not contribute all the way to M_x. Their contribution in the interval $[\Lambda, M_x]$ is cancelled by their associated triplets. Only the value of α_G depends on the absolute number of Higgses that contribute above Λ, as well as on the number of flavours. Setting $\Lambda = M_x$ we obtain, for $H_1 = 2$ and $\Lambda_{\overline{MS}} =$ 0.1 GeV [corresponding to $\alpha_3(M_W) = 0.101$ and $\alpha(M_W)^{-1} \simeq 127.56$],

$$\sin^2\theta_W \simeq 0.236\,.$$

This value seems too large compared with the current experimental value. For $H_1 = 4$ one gets $\sin^2\theta_W \simeq 0.259$ in clear disagreement with experiment. In contrast to the above situation if we set $(\Lambda/M_W) = 10^8$ we obtain (for $\Lambda_{\overline{MS}} = 0.1$ GeV) for $H_1 = 2$

$$\sin^2\theta_W \simeq 0.225\,,$$

and for $\Lambda_{\overline{MS}} = 0.2$ GeV

$$\sin^2\theta_W \simeq 0.221\,.$$

These values are definitely more comfortable to live with. Even the corresponding value for $H_1 = 4$, $\sin^2\theta_W(M_W) \simeq$ 0.236 (for $\Lambda_{\overline{MS}} = 0.2$ GeV) is not clearly incompatible with experiment. The values improve with increasing $\Lambda_{\overline{MS}}$. We have displayed the mixing angle as a function of H_1 and Λ/M_W in tables 1 and 2 and in fig. 1. The unification scale as a function of Λ/M_W has been tabulated in tables 3 and 4. The unification point increases with decreasing intermediate scale Λ. Finally, we have calculated the value of the SU(5) coupling constant for six flavours as a function of the number of colour triplets and as a function of the intermediate scale Λ/M_W (see tables 5 and 6).

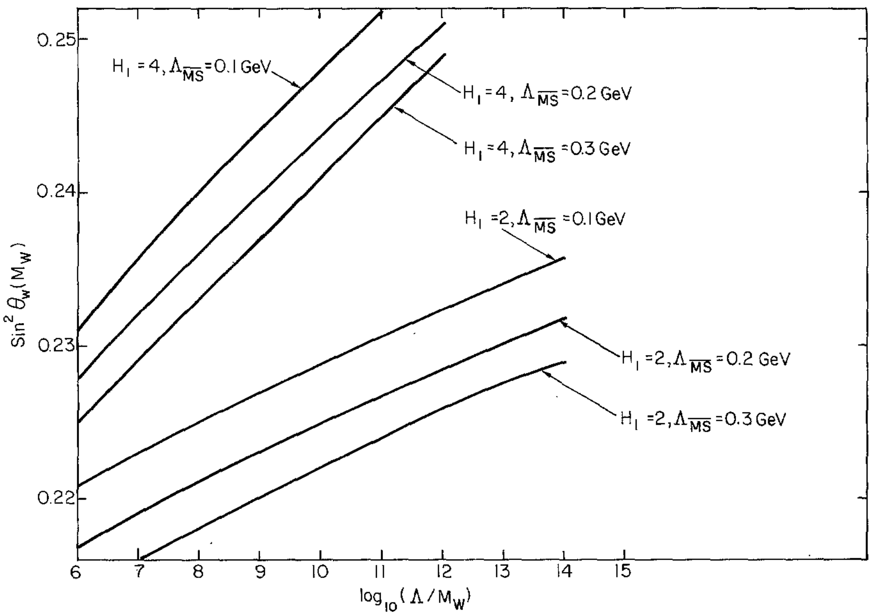

Fig. 1. $\sin^2\theta_W$ as a function of Λ/M_W and of the number of light doublets H_1.

α_G increases with decreasing intermediate scale Λ. It is also an increasing function of the number of Higgs supermultiplets that contribute above Λ.

Another successful prediction of ordinary GUTs is the ratio of the b-quark mass over the τ-lepton mass [8]. In our case of an intermediate threshold Λ, it is given by the formula (for six flavours)

$$(m_b/m_T)_{SUSY}/(m_b/m_T)_{ord} \simeq [\alpha_3(M_W)/(\alpha_G)_{ord}]^{-4/7}\,[\alpha_3(M_W)/\alpha_3(\Lambda)]^{8/9}\,[\alpha_3(\Lambda)/\alpha_G]^{8/3b}\,, \tag{11}$$

where $b = 3 - \frac{1}{2}T_2$ (T_2 is the number of coloured triplets contributing above Λ). We have neglected the small contribution of the U(1) coupling constant. Setting $\alpha_3(M_W) = 0.1015$ and $(1/\alpha_G)_{ord} \simeq 41.22$ (this corresponds to $\Lambda_{\overline{MS}} = 0.1$ GeV), we obtain for $\Lambda/M_W \simeq 10^8$,

Table 1
$\sin^2\theta_W$ as a function of Λ/M_W, $H_1 = 2$.

Λ/M_W	$\sin^2\theta_W$		
	$\Lambda_{\overline{MS}} = 0.1$ GeV	$\Lambda_{\overline{MS}} = 0.2$ GeV	$\Lambda_{\overline{MS}} = 0.3$ GeV
10^6	0.221	0.217	0.214
10^7	0.223	0.219	0.216
10^8	0.225	0.221	0.218
10^9	0.227	0.222	0.220
10^{10}	0.229	0.224	0.222
10^{11}	0.231	0.226	0.224
10^{12}	0.232	0.228	0.226
10^{13}	0.234	0.230	0.228
10^{14}	0.236	0.232	0.229

Table 2
$\sin^2\theta_W$ as a function of Λ/M_W, $H_1 = 4$.

Λ/M_W	$\sin^2\theta_W$		
	$\Lambda_{\overline{MS}} = 0.1$ GeV	$\Lambda_{\overline{MS}} = 0.2$ GeV	$\Lambda_{\overline{MS}} = 0.3$ GeV
10^6	0.231	0.228	0.226
10^7	0.236	0.232	0.229
10^8	0.240	0.236	0.233
10^9	0.244	0.240	0.237
10^{10}	0.248	0.244	0.241
10^{11}	0.252	0.247	0.245
10^{12}	0.255	0.251	0.249
10^{13}	0.259	0.255	0.252
10^{14}	0.263	0.259	0.256

Table 3
M_X/M_W as a function of Λ/M_W, $H_1 = 2$.

Λ/M_W	M_X/M_W		
	$\Lambda_{\overline{MS}} = 0.1$ GeV	$\Lambda_{\overline{MS}} = 0.2$ GeV	$\Lambda_{\overline{MS}} = 0.3$ GeV
10^6	4.9×10^{14}	1.2×10^{15}	2.1×10^{15}
10^8	2.9×10^{14}	7.2×10^{14}	1.2×10^{15}
10^{10}	1.7×10^{14}	4.3×10^{14}	7.4×10^{14}
10^{12}	1.0×10^{14}	2.6×10^{14}	4.4×10^{14}

Table 4
M_X/M_W as a function of Λ/M_W, $H_1 = 4$.

Λ/M_W	M_X/M_W		
	$\Lambda_{\overline{MS}} = 0.1$ GeV	$\Lambda_{\overline{MS}} = 0.2$ GeV	$\Lambda_{\overline{MS}} = 0.3$ GeV
10^6	1.0×10^{14}	2.6×10^{14}	4.4×10^{14}
10^8	3.8×10^{13}	9.3×10^{13}	1.6×10^{14}
10^{10}	1.4×10^{13}	3.3×10^{13}	5.7×10^{13}
10^{12}	4.9×10^{12}	1.2×10^{13}	2.1×10^{13}

Table 5
$1/\alpha_G$ as a function of Λ/M_W. $H_1 = T_2 = 2$, $F = 6$, $\Lambda_{\overline{MS}} = 0.1$ GeV.

Λ/M_W	$1/\alpha_G$
10^6	22.82
10^8	23.39
10^{10}	23.96
10^{12}	24.53

Table 6
$1/\alpha_G$ as a function of the number of coloured triplets T_2 contributing above Λ. $H_1 = 2$, $\Lambda/M_W = 10^8$, $F = 6$, $\Lambda_{\overline{MS}} = 0.1$ GeV.

T_2	$1/\alpha_G$
2	23.39
4	21.02
6	18.65
8	16.28
10	13.91

$$\eta \equiv (m_b/m_T)_{SUSY}/(m_b/m_T)_{ord} \simeq 1.05$$

for $H_1 = T_2 = 2$; $\eta \simeq 1.07$ for $H_1 = 2$, $T_2 = 4$; and $\eta \simeq 1.02$ for $H_1 = T_2 = 4$. The value of the ratio approaches unity when we increase Λ/M_W, as can be seen from table 7. Thus, the b–τ mass ratio remains virtually unaffected by the intermediate threshold.

4. *Nucleon decay*. Before embarking on an analysis of the various Higgs mediated baryon-number violating interactions we should stress that baryon-number violating operators of dimension five [7,12], like the ones appearing in the softly broken version of supersymmetric SU(5), would cause an unacceptably large proton decay rate if we insist on keeping colour triplet Higgses as light as 10^{10} GeV ‡2. However, operators of that sort can be avoided by imposing extra symmetries. In that case, on which we shall concentrate, nucleon decay is dominated by the exchange of "light" Higgs triplets. Gauge bosons or heavy Higgses with masses of order M_X are unimportant since their contributions are suppressed by the large value of the unification mass M_X. The unimportance of gauge inter-

‡2 This is the lower mass limit for Higgs triplets imposed from proton decay [10].

Table 7
$(m_b/m_\tau)_{SUSY}/(m_b/m_\tau)_{ord}$ as a function of Λ/M_W. $H_1 = T_2 = 2$, $F = 6$, $\Lambda_{\overline{MS}} = 0.1$ GeV.

Λ/M_W	$\left(\frac{m_b}{m_\tau}\right)_S \Big/ \left(\frac{m_b}{m_\tau}\right)_o$
10^6	1.08
10^8	1.05
10^{10}	1.04
10^{12}	1.02

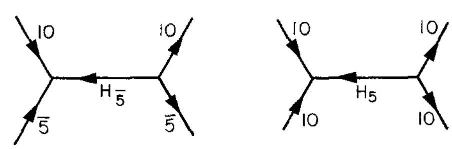

Fig. 2. Baryon-number violating processes.

actions in nucleon decay, due to the large value of M_X, is a characteristic feature of supersymmetric GUTs and should be stressed. In ordinary GUTs, even if we were to keep Higgs triplets light enough to dominate nucleon decay, radiative corrections would renormalize their mass to M_X, thus restoring the dominance of gauge interactions in nucleon decay. In supersymmetric GUTs this is clearly not the case due to non-renormalization theorems. Independently of the above there is another argument that such a situation is improbable in ordinary GUTs. In order to obtain a non-vanishing baryon asymmetry, two different Higgs multiplets are needed. Their masses should not be very different otherwise the baryon asymmetry would be suppressed proportionally to their (mass)^2 ratio [13]. At least one of them should satisfy the out-of-equilibrium condition $M_H > \alpha_H M_{Pl}$. But this constraint implies that at least one of the Higgses should couple to all light fermions with Yukawa couplings $\alpha_H \sim 10^{-9}$. It is doubtful whether radiative corrections could respect that, but even if this could be arranged it would certainly be an unnatural and bizarre situation. In the case of our supersymmetric SU(5), as we have explained elsewhere [9], when baryon creation occurs (roughly at 10^{10} GeV) we are off-equilibrium anyhow and no constraint needs to be satisfied.

In ordinary supersymmetric GUTs, on the other hand, in order to obtain baryon asymmetry four Higgs supermultiplets are needed and if they all contain light doublets $\sin^2\theta_W$ would come out 0.26, which is too large. This can be avoided [14] by arranging it so that two of the Higgs multiplets are fully superheavy (in that case they would get no expectation value) and only two light doublets would contribute to $\sin^2\theta_W$. This would be quite a trick and certainly in our case we do not have to resort to it. [For $H_2 = T_2 = 4$ we obtain with $(\Lambda/M_W) = 10^8$ $\sin^2\theta_W = 0.240$ and $(m_b/m_\tau) \simeq 1.02$, which are not in disagreement with experiment.]

Let us now examine in some detail nucleon decay in our model. The only dimension six operators that can mediate nucleon decay through Higgs exchange in our SU(5) model arise from the diagrams of fig. 2. They give rise to an effective lagrangian [15] for nucleon decay of the form

$$\mathcal{L}_{\mathrm{eff}} \simeq m_{\tilde{H}}^{-2} [(Q_L)_{\alpha\beta} \mathcal{M}_d (Q_L)^{\beta}] [(Q_L)_{\alpha\gamma} \mathcal{M}_d (Q_L)^{\gamma}]^* + m_{\tilde{H}}^{-2} [(Q_L)_{\beta\gamma} \epsilon^{\beta\gamma\alpha\delta\epsilon} \mathcal{M}_u (Q_L)_{\delta\epsilon}] [(Q_L)_{\zeta\eta} \epsilon^{\zeta\eta\alpha\vartheta\iota} \mathcal{M}_u (Q_L)_{\vartheta\iota}]^* , \qquad (12)$$

where $(Q_L)_{\beta\gamma}$ and $(Q_L)^{\delta}$ stand for the **10** and $\overline{\mathbf{5}}$ of fermions, $\mathcal{M}_d$ and $\mathcal{M}_u$ are the Yukawa couplings in generation space and the index α is coloured. Next, we inverse-mix the up quarks in the first part of the lagrangian and mix the down quarks and leptons in the second part. In other words we write (12) in terms of diagonal mass matrices

$$\mathcal{M}_d = V_1^{-1}\,\mathrm{diag}(m_d, m_s, m_b), \quad \mathcal{M}_u = V_2^{-1}\,\mathrm{diag}(m_u, m_c, m_t) , \qquad (13)$$

where $V_1^2 + V_2^2 = 1/\sqrt{2}G_F$. Then our effective lagrangian reduces to [‡3]

$$\mathcal{L}_{\mathrm{eff}} \simeq m_{\tilde{H}}^{-2} (\mathcal{U}^{-1} U_L \mathcal{M}\, \&_L^-)(\mathcal{U} U_L^c\, \mathcal{M}_d D_L^c)^* - m_{\bar{H}}^{-2} (D_L \mathcal{M}\, \aleph_L)(\mathcal{U} U_L^c\, \mathcal{M}_d D_L^c)^* + m_{\tilde{H}}^{-2} (U_L \mathcal{M}_u \mathcal{U} D_L)(U_L^c \mathcal{M}_u \mathcal{U} \&_L^+)^* , \qquad (14)$$

where the matrix $\mathcal{U}$ is taken to be

$$\mathcal{U} \simeq \begin{bmatrix} 1 & \epsilon & \epsilon^2 \\ \epsilon & 1 & \epsilon \\ \epsilon^2 & \epsilon & 1 \end{bmatrix} , \qquad (15)$$

with $\epsilon \simeq O(\sin\theta_C)$, i.e., $|\epsilon|^2 \simeq O(1/20)$. It is already evident that no ν_τ emission can occur since, as can be seen in the second term, ν_τ is always accompanied by a b-quark. Thus, it is clear that new characteristic nucleon decay modes should be expected.

‡3 In the case of ordinary GUTs the masses m_H and $m_{\tilde{H}}$ need not be the same. In such a case the hierarchy of decay modes would be affected. This cannot happen in our case since the dominant contribution comes from the first two terms in (14), and $m_H \simeq m_{\tilde{H}}$.

Excluding from (14) all kinematically irrelevant to nucleon decay terms, we end up with

$$\begin{aligned}\mathcal{L}_{\text{eff}} \simeq m_{\text{H}}^{-2}\{ & m_{\text{d}}^2(\text{u}_\text{L}\,\text{e}_\text{L}\,\overline{\text{d}_\text{L}^\text{c}}\,\overline{\text{u}_\text{L}^\text{c}}) + \epsilon m_\text{d} m_\text{s}(\text{u}_\text{L}\,\text{e}_\text{L}\,\overline{\text{s}_\text{L}^\text{c}}\,\overline{\text{u}_\text{L}^\text{c}}) + \epsilon m_\text{s} m_\text{d}(\text{u}_\text{L}\,\mu_\text{L}\,\overline{\text{d}_\text{L}^\text{c}}\,\overline{\text{u}_\text{L}^\text{c}}) + \epsilon^2 m_\text{s}^2(\text{u}_\text{L}\,\mu_\text{L}\,\overline{\text{s}_\text{L}^\text{c}}\,\overline{\text{u}_\text{L}^\text{c}}) \\ & - m_\text{d}^2[\text{d}_\text{L}(\nu_\text{e})_\text{L}\,\overline{\text{u}_\text{L}^\text{c}}\,\overline{\text{d}_\text{L}^\text{c}}] - \epsilon m_\text{d} m_\text{s}[\text{d}_\text{L}(\nu_\text{e})_\text{L}\,\overline{\text{u}_\text{L}^\text{c}}\,\overline{\text{s}_\text{L}^\text{c}}] - m_\text{d} m_\text{s}[\text{s}_\text{L}(\nu_\mu)_\text{L}\,\overline{\text{u}_\text{L}^\text{c}}\,\overline{\text{d}_\text{L}^\text{c}}] + m_\text{u}^2(\text{u}_\text{L}\,\text{d}_\text{L}\,\overline{\text{u}_\text{L}^\text{c}}\,\overline{\text{e}_\text{L}^+}) \\ & + \epsilon m_\text{u}^2(\text{d}_\text{L}\,\text{u}_\text{L}\,\overline{\text{u}_\text{L}^\text{c}}\,\overline{\mu_\text{L}^+}) + \epsilon m_\text{u}^2(\text{u}_\text{L}\,\text{s}_\text{L}\,\overline{\text{u}_\text{L}^\text{c}}\,\overline{\text{e}_\text{L}^+}) + m_\text{u}^2\epsilon^2(\text{u}_\text{L}\,\text{s}_\text{L}\,\overline{\text{u}_\text{L}^\text{c}}\,\overline{\mu_\text{L}^+})\}\end{aligned} \tag{16}$$

$m_\text{d}, m_\text{s}, m_\text{u}$ are normalized d, s and u quark masses. It is evident in (16) that the dominant proton decay modes are $\bar{\nu}_\mu \text{K}^+$ and $\mu^+\text{K}^0$. More specifically, the hierarchy of decay modes predicted by (16) is

$$\Gamma(\bar{\nu}_\mu\text{K}^+, \mu^+\text{K}^0)/\Gamma(\mu^+\text{“}\pi^0\text{”}, \text{e}^+\text{K}^0, \bar{\nu}_\text{e}\text{K}^+) \simeq (\sin^2\theta_\text{C})^{-1}\ ,$$

and

$$\Gamma(\mu^+\text{“}\pi^0\text{”}, \text{e}^+\text{K}^0, \bar{\nu}_\text{e}\text{K}^+)/\Gamma(\text{e}^+\pi^0, \bar{\nu}_\text{e}\pi^+) \simeq (\sin^2\theta_\text{C})^{-1}\ .$$

Although the above naive analysis does not take into account hadron wave function effects it is hard to believe that the above hierarchical structure can be totally masked by these effects and elude detection. Thus, Higgs mediated proton decay in supersymmetric SU(5), in contrast with ordinary GUTs or softly broken SUSY GUTS where either $\text{e}^+\pi^0$ or $\bar{\nu}_\tau\text{K}^+$ dominate, predicts the following hierarchy of proton decay modes

$$\Gamma(\bar{\nu}_\mu\text{K}^+, \mu^+\text{K}^0) : \Gamma(\mu^+\text{“}\pi^0\text{”}, \text{e}^+\text{K}^0, \bar{\nu}_\text{e}\text{K}^+) : \Gamma(\text{e}^+\pi^0, \bar{\nu}_\text{e}\pi^+) \simeq 1 : \sin^2\theta_\text{C} : (\sin^2\theta_\text{C})^2\ . \tag{17}$$

5. Conclusions. Motivated by the necessity of Higgs triplets of mass 10^{10} GeV for cosmological baryon production in the framework of supersymmetric theories with natural monopole suppression, we embarked on an overall study of SUSY GUTs endowed with such “light” Higgses. We restricted ourselves to a minimal SU(5) model but our conclusions are quite general. Our results can be summarized as follows:

(1) The mixing angle (θ_W) is in comfortable agreement with experiment if we keep coloured triplets “light”.

(2) The mass ratio m_b/m_τ is virtually unaffected, being of the same value as in ordinary GUTs.

(3) Protons decay at a rate of 10^{31} yr with the characteristic hierarchy of decay modes

$$\Gamma(\bar{\nu}_\mu\text{K}^+, \mu^+\text{K}^0) : \Gamma(\mu^+\text{“}\pi^0\text{”}, \text{e}^+\text{K}^0, \bar{\nu}_\text{e}\text{K}^+) : \Gamma(\text{e}^+\pi^0, \bar{\nu}_\text{e}\pi^+) \simeq 1 : \sin^2\theta_\text{C} : (\sin^2\theta_\text{C})^2\ ,$$

in sharp contrast with ordinary GUTs or other varieties of SUSY GUTs.

(4) In view of the fact that supersymmetric GUTs also solve the worse aspect of the hierarchy problem and provide us with a plausible scenario for monopole suppression and the generation of a universal baryon asymmetry, we feel justified in declaring the score 4 : 3 [‡4].

[‡4] For the previous score, see the title of ref. [7].

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