ORDINARY SU(5) PREDICTIONS FROM A SUPERSYMMETRIC SU(5) MODEL

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We show that with a minimal enlargement of the Higgs supermultiplet structure of the supersymmetric SU(5) model it is possible to get a theory where: (i) m_b/m_τ is in accordance with experiment; (ii) $\sin^2\theta_W = 0.22$ and (iii) the dominant proton decay mode is through the gauge-mediated channel $p \to \pi^0 e^+$ at a rate (10^{-31} yr^{-1}) compatible with the present experimental limit. This is possible since the grand unification scale is predicted to get exactly the same value as in the ordinary SU(5) model.

The ambitious perspective of embedding gravity into a truly grand unified theory together with the possibility of solving the gauge hierarchy problem have attracted much interest recently to supersymmetrical grand unified theories (SUSY GUTs) [1]. The phenomenology of the minimal supersymmetric SU(5) theory [2] has been carefully investigated [3]: $\sin^2\theta_W$ appears to be a bit too large ($\sin^2\theta_W = 0.236 \pm 0.002$), m_b/m_τ is unchanged with respect to the successful standard SU(5) prediction (i.e., $m_b/m_\tau \sim 2.8$) and Higgs-mediated nucleon decay occurs at a rate compatible with the experimental limit. In particular the prediction of the minimal SUSY SU(5) for the dominant p-decay mode strikingly (and worryingly) differs from the SU(5) prediction: proton should decay dominantly into $\bar{\nu}_\tau K^+$, a signature which is much harder to identify than the standard $\pi^0 e^+$ decay mode.

On the other hand, these phenomenological predictions are tightly tied up to the Higgs supermultiplet structure of the model. Already in the non-supersymmetrical version of SU(5) an *enlargement of the minimal Higgs structure* (i.e., only a **24** and one **5** of Higgs) has been repeatedly advocated for several reasons. In particular, it was shown that such an enlargement, with the presence of Higgs which do not develop a vacuum expectation value, was compulsory if fermion masses are to be produced *radiatively* [4]. In this scheme, in analogy with the $\bar{\mathbf{5}} + \mathbf{10}$ representations of fermions *also a* **10** *of Higgs was introduced* [4]. A **10** of Higgs may play also an important role in the generation of the cosmological baryon asymmetry if this has to happen at a scale lower than the grand unified mass scale [5]. In the SUSY SU(5) we are particularly interested in this **10** supermultiplet of Higgs also for a *broad sense of boson–fermion symmetry*. Fermions appear in the reducible $\bar{\mathbf{5}} + \mathbf{10}$ representation. In view of a possible enlargement of the minimal SUSY SU(5), it appears conceivable to address ourselves first to the possibility of the $\bar{\mathbf{5}} + \mathbf{10}$ of *Higgs supermultiplets.*

In this note we show that this minimal and plausible enlargement of the Higgs supermultiplet structure of SUSY SU(5) can lead to exciting phenomenological consequences: $\sin^2\theta_W$ is *lowered* to 0.221 and, even more interestingly, *the grand unification mass is predicted to be exactly the same as in the standard minimal SU(5) model.* Clearly, this latter consequence im-

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plies that proton has a dominant decay mode through the *usual gauge boson-mediated $\pi^0 e^+$ channel*, at a rate at the border with the present experimental limit (i.e., 10^{-31} yr^{-1}).

Obviously if all the components of $\mathbf{10}_{\mathrm{H}} + \overline{\mathbf{10}}'_{\mathrm{H}}$ [‡1] get superheavy, then no novelty is brought about by the presence of $\mathbf{10}_{\mathrm{H}}$. However, we know that in the case of $\mathbf{5}_{\mathrm{H}}$, two components do not get mass at the superheavy breaking SU(5) → SU(3) × SU(2) × U(1). They are colour singlets and form an SU(2) doublet. In exact analogy, we shall suppose the *colour triplet* components of the **10** to get *superheavy*, while the *isosinglet* and *colour singlet* component with electric charge +1 is assumed to remain *massless* at the first stage of symmetry breaking. Technically, in the minimal SUSY SU(5) model [2] the lightness of the isodoublet contained in $\mathbf{5}_{\mathrm{H}}$ is enforced by the equality of two parameters of the Higgs potential. This same strategy can be applied to keep light the (1, 1) component under $\mathrm{SU(3)_C} \times \mathrm{SU(2)_L}$ of $\mathbf{10}_{\mathrm{H}}$.

In order to prove our result, let us write the evolution equation of the $\mathrm{U(1)}_Y$, $\mathrm{SU(2)_L}$ and $\mathrm{SU(3)_C}$ gauge coupling constants from μ to the grand unification mass M_{X}:

$$\alpha_1^{-1}(\mu) = \alpha_{\mathrm{G}}^{-1} + (1/2\pi)(2N_{\mathrm{g}} + \tfrac{3}{10}N_2 + \tfrac{3}{5}N_1)\ln(M_{\mathrm{X}}/\mu), \tag{1a}$$

$$\alpha_2^{-1}(\mu) = \alpha_{\mathrm{G}}^{-1} + (1/2\pi)(-6 + 2N_{\mathrm{g}} + \tfrac{1}{2}N_2)\ln(M_{\mathrm{X}}/\mu), \tag{1b}$$

$$\alpha_3^{-1}(\mu) = \alpha_{\mathrm{G}}^{-1} + (1/2\pi)(-9 + 2N_{\mathrm{g}})\ln(M_{\mathrm{X}}/\mu), \tag{1c}$$

where α_{G} is the coupling at the unification scale M_{X} and N_{g}, N_2, N_1 denote the number of fermion generations, isodoublets, isosinglets (with $Y \neq 0$), respectively. Only eq. (1a) differs from the renormalization group equations for the gauge couplings of SU(3) × SU(2) × U(1) in the minimal SUSY SU(5) model [3], since the component (1, 1) of $\mathbf{10}_{\mathrm{H}}$ contributes only to the renormalization of α_1. From eqs. (1) we get:

$$\ln(M_{\mathrm{X}}/M_{\mathrm{W}}) = [2\pi/\alpha(M_{\mathrm{W}})]\,[1 - \tfrac{8}{3}\alpha(M_{\mathrm{W}})/\alpha_3(M_{\mathrm{W}})]\,/\,(18 + N_2 + N_1), \tag{2}$$

and

$$\sin^2\theta_{\mathrm{W}}(M_{\mathrm{W}}) = \{3 + \tfrac{1}{2}N_2 + [\alpha(M_{\mathrm{W}})/\alpha_3(M_{\mathrm{W}})] \times (10 - \tfrac{1}{3}N_2 + N_1)\}/(18 + N_2 + N_1). \tag{3}$$

In the minimal SUSY SU(5), $N_2 = 2$. In our minimal enlargement we have added a $\mathbf{10}_{\mathrm{H}} + \overline{\mathbf{10}}'_{\mathrm{H}}$ [‡1], so that $N_1 = 2$. Then: (in this case $\alpha_{\mathrm{G}}^{-1} = 23.6$)

$$\ln(M_{\mathrm{X}}/M_{\mathrm{W}}) = [\pi/11\alpha(M_{\mathrm{W}})]\,[1 - \tfrac{8}{3}\alpha(M_{\mathrm{W}})/\alpha_3(M_{\mathrm{W}})], \tag{4}$$

and

$$\sin^2\theta_{\mathrm{W}}(M_{\mathrm{W}}) = \tfrac{1}{22}[4 + \tfrac{34}{3}\alpha(M_{\mathrm{W}})/\alpha_3(M_{\mathrm{W}})]. \tag{5}$$

A quick look at the good old minimal SU(5) model [6] and, strikingly enough, one discovers that eq. (4) is *exactly the same* as the expression for $\ln(M_{\mathrm{X}}/M_{\mathrm{W}})$ in that model. This entails two major consequences:

(i) Operators of *dimension five* allowing for proton decay must be *prohibited* [‡2]. This can be achieved by the imposition of the R symmetry [7] or of an extra gauge U(1) symmetry [8];

(ii) SU(5) *superheavy gauge bosons* recover their dominant role in the nucleon decays. Indeed, the situation now is *entirely analogous to the non-supersymmetrical SU(5) model* [6], where the dominant gauge boson-mediated p-decay mode is through the channel $\pi^0 e^+$, at a rate quite close to the experimental bound (10^{-31} yr^{-1}). Notice that since we have not introduced intermediate mass scales, p-decay respects the $B-L$ symmetry [‡3].

Let us now turn to eq. (5). The presence of the (1, 1) component of $\mathbf{10}_{\mathrm{H}}$ at low energy *lowers* the value of $\sin^2\theta_{\mathrm{W}}$ and, indeed, instead of the $\sin^2\theta_{\mathrm{W}} = 0.236$ as predicted by the minimal SUSY SU(5) model, eq. (5) gives $\sin^2\theta_{\mathrm{W}} = 0.221$, in *good agreement* with the experimental average $\sin^2\theta_{\mathrm{W}} = 0.215 \pm 0.012$. The aim of lowering the value of $\sin^2\theta_{\mathrm{W}}$ had already been achieved by two of the authors by requiring the presence of coloured Higgses at intermediate mass

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[‡1] We need the presence also of $\overline{10}'_{\mathrm{H}}$ in order to cancel the anomalies induced by the fermions contained in 10_{H}.

[‡2] The alert reader may notice that in the presence of a dimension-5 operator $\tau_{\mathrm{p}} \sim M_{\mathrm{X}}^2 m^2_{\text{SUSY-breaking}}$ and that an order of magnitude decrease in M_{X} may be easily compensated by an order of magnitude increase in $m_{\text{SUSY-breaking}}$. Then we would have the amusing situation of having proton decay to $\bar{\nu}_\tau \mathrm{K}^+$ and $\mathrm{e}^+\pi^0$ at a comparable 10^{-31} yr^{-1} rate.

[‡3] The presence of the triplets of 10_{H} at some intermediate scale would change this conclusion [9].

scales [10]. However, the *simultaneous* effect of lowering $\sin^2\theta_W$ *and* M_X is a *peculiar property of the (1, 1) component*, since, being iso- and colour-singlet, it contributes only to β_1 speeding up the increase of α_1.

In conclusion, we have shown that a minimal and plausible enlargement of the SUSY SU(5) Higgs supermultiplet structure radically changes the prediction of the model for proton decay. Instead of the obsolete $\bar{\nu}_\tau K^+$ channel, the usual decay mode $p \to \pi^0 e^+$ is predicted at the same rate as in the minimal SU(5) model. Moreover, $\sin^2\theta_W$ is lowered to 0.221, in good agreement with the present experimental results. Taking into account that m_b/m_τ is predicted also here to be the same as in the usual SU(5) model [6], we can conclude that this model does not offer any change with respect to the predictions of the standard SU(5) model as far as m_b/m_τ, $\sin^2\theta_W$ and p-decay are concerned. Needless to say, the presence of new fundamental particles possibly at low energy may lead to exciting discoveries at LEP (or somewhere else ...) which can discriminate the SUSY SU(5) version we have presented here from the non-supersymmetrical one.

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