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Higgs sector and proton decay in SU(15) grand unification

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For a recently proposed symmetry-breaking pattern of SU(15) grand unification, we fully analyze the Higgs sector and examine the consistency of the mass scales with the observed proton lifetime.

From the viewpoint of a typical particle theorist, because of the lack of supporting evidence in the form of the most obvious experimental predictions such as proton decay, neutrino masses, and superheavy magnetic monopoles, the interest and activity in grand unified theories (GUT's) has waned in the last couple of years. The general idea of GUT's seems too appealing to drop altogether and it is important to seek other experimental predictions and alternative GUT models in order to find the best scheme.

Conventional GUT's have proton decay as a natural consequence. Since the lower limit on the proton decay lifetime has been successively raised by dedicated experiments, it prompts us to consider the possibility of a GUT where proton decay in particular, and baryon reconservation in general, is not a primary consequence. One such model[1] is the grand unification model proposed recently based on SU(15). In this theory, baryon number is conserved in the gauge sector but not in the Higgs sector,[2] meaning that the proton decay rate is not sharply determined by the gauge coupling but depends on Yukawa couplings and Higgs-boson self-couplings which are difficult if not impossible to estimate precisely. The symmetry-breaking scheme for SU(15) proposed in Ref. 1 is

$$\mathrm{SU}(15)\xrightarrow{M_G}\mathrm{SU}(12)_q\times\mathrm{SU}(3)_l\,, \tag{1a}$$

$$\xrightarrow{M_B}\mathrm{SU}(6)_L\times\mathrm{SU}(6)_R\times\mathrm{U}(1)'_h\times\mathrm{SU}(3)_l\,, \tag{1b}$$

$$\xrightarrow{M_A}\mathrm{SU}(3)_C\times\mathrm{SU}(2)_L\times\mathrm{U}(1)_Y\,, \tag{1c}$$

$$\xrightarrow{M_W}\mathrm{SU}(3)_C\times\mathrm{U}(1)_Q\,. \tag{1d}$$

This is the pattern which we shall analyze in detail in the present paper. We proceed in a step-by-step fashion, looking at the scales M_G, M_B, M_A, and M_W successively. Finally, we shall discuss the (complicated) question of proton decay.

It is worth recalling that, according to Ref. 1, the energy scales we are contemplating may be as low as $M_W=M_A=250$ GeV and $M_B=4\times10^6$ GeV, $M_G=6\times10^6$ GeV.

Before discussing the Higgs sector, we should stress that in the gauge sector each gauge boson of SU(15) has a well-defined B (baryon number) determined by to which two of the basic 15 fermions in

$$\mathbf{15}=(u_1u_2u_3d_1d_2d_3\bar{u}_1\bar{u}_2\bar{u}_3\bar{d}_1\bar{d}_2\bar{d}_3\nu_e e^- e^+) \tag{2}$$

the particular gauge boson couples. To illustrate this point, which can be subtle, note that one of the gauge bosons, the generator of $\mathrm{U}(1)'_h$ in Eq. (1b), is proportional to B. Consider the embedding $\mathrm{SU}(15)\supset\mathrm{SU}(5)$ where the 15 of SU(15) contains $(10+\bar{5})$ of SU(5). In the latter case proton decay is possible because while $(B-L)$ is conserved as in $p\to e^+\pi^0$ B and L separately are *not.* This is because the gauge bosons of the subgroup SU(5) are linear combinations of those of SU(15). The larger group has more symmetry and is able to conserve B. Note that L can be gauged too if we go to SU(16) (Ref. 3) although we shall not pursue this here.[4]

The advantage of avoiding such B nonconservation by gauge bosons is that one can envisage a unification scale well below the usual one, and hence envisage the likelihood of new gauge bosons and forces becoming manifest at energies accessible to the new generation of colliders. This can then test the conceptual basis of GUT's independent of the searches for rare events and tiny masses necessitated by usual GUT's.

Now we are prepared to summarize the technical details of our analysis at the different mass scales.

(i) At $M=M_G$. Here it is possible to postulate a nonzero vacuum expectation value (VEV) for one component of the $\mathbf{1}^3$ representation of Higgs fields. (Here the notation $\mathbf{1}^n$ means a totally antisymmetric nth-rank tensor.) The unique component is that in the noncolor sector with SU(15) indices 13–15. This complex Higgs multi-

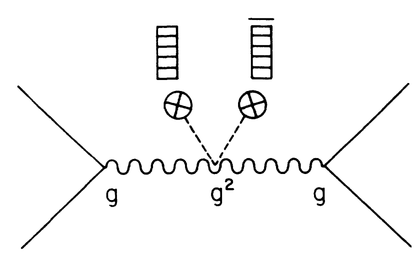

FIG. 1. Tree-level gauge-boson exchange. This has $\Delta B=0$.

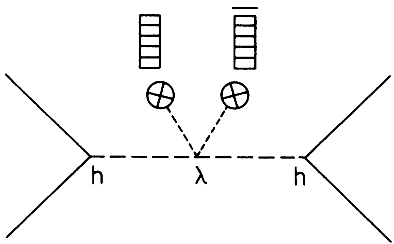

FIG. 2. Tree-level Higgs-boson exchange. This has $\Delta B = 0$.

plet is 455 dimensional.

(ii) At $M = M_B$. Here one needs a VEV for one component of the adjoint $\mathbf{1}^{14}\mathbf{1}$ of SU(15). The particular component is clearly that proportional to the generator of $U(1)'_h$; this adjoint is real and of dimension 224.

(iii) At $M = M_A$. This is complicated. The breaking of $SU(6)_L$ to the special maximal subalgebra $SU(3)_{CL} \times SU(2)'_L$ needs a VEV in the $(\mathbf{1}^5\mathbf{1}^5\mathbf{1}\mathbf{1})$ representation of $SU(6)_L$. At the SU(15) level this is contained in the fourth-rank tensor $\mathbf{1}^{14}\mathbf{1}^{14}\mathbf{1}\,\mathbf{1}$. This real Higgs multiplet has dimension 14,175. The adjoint (224) must have VEV's appropriate to break $SU(6)_R$ to $SU(3)_{CR} \times SU(3)'_{CR} \times U(1)_R$ to $SU(3)_R \times U(1)_R$ and $SU(3)_l$ to $SU(2)''_L \times U(1)'_y$. We now have an unbroken semisimple gauge group $SU(3)_{CL} \times SU(3)_{CR} \times SU(2)'_L \times SU(2)''_L$. The $\mathbf{1}^3$ contains a component transforming as $(3,\bar{3},2,2)$ under this group and if this component acquires a VEV it breaks the semisimple part to the desired $SU(3)_C \times SU(2)_L$. It also breaks one of the three U(1) groups: R, y', and h' leaving just B and Y. To break B we introduce a $\mathbf{1}^5$ of dimension 3003 (complex) and give a VEV to the $Y=0$ component labeled (10,11,12,13,14). This then leaves the standard gauge group $SU(3)_C \times SU(2)_L \times U(1)_Y$.

(iv) At $M = M_W$. We need one doublet VEV to break the electroweak group. It may be chosen to couple to the fermions, and be in either a $\mathbf{1}\,\mathbf{1}$ (dimension 120) or a $\mathbf{1}^2$ (dimension 105). The former gives a symmetric mass matrix, while the latter gives an antisymmetric one.

With this Higgs sector in hand, one can now analyze the phenomenological question of proton decay. In the gauge sector all gauge bosons at the SU(15) level have a well-defined B. After M_B breaking, the $U(1)'_h$ couples to the B which is still exactly conserved. At the level M_A breaking, all B violation must come from giving the single VEV to the **3003**, since without that B is still an exact gauge symmetry. The **3003**, together with the breaking at M_W, then leave just the standard model.

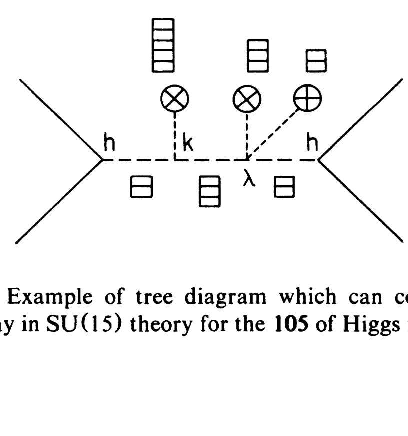

FIG. 3. Example of tree diagram which can contribute to proton decay in SU(15) theory for the **105** of Higgs fields.

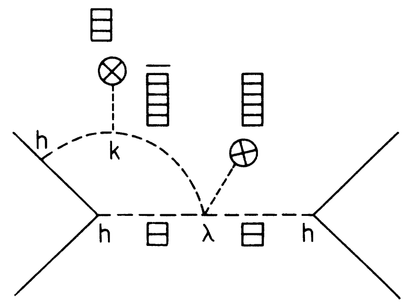

FIG. 4. Example of one-loop diagram contributing to proton decay in SU(15) GUT for **105** of Higgs fields.

Thus, B is broken in the Higgs sector but not in the gauge sector.

To estimate these effects, we first reconsider the gauge exchange (Fig. 1). Since the **3003** has a VEV for only one component it is easy to see that this diagram conserves B just as it would were the central vertex absent.

Consider now a Higgs-boson exchange of a similar kind (Fig. 2). In this diagram the Yukawa couplings involve either both **120** or both **105** of Higgs fields. By examining the indicial contractions at the λ vertex, one can confirm that this diagram has $\Delta B = 0$.

If there is a **105** coupling to the fermions, one can find a tree diagram (e.g., Fig. 3) which is nonvanishing. For consistency with a proton lifetime greater than 10^{32} yr, one can estimate that

$$h^2 k\lambda < 10^{-23} . \tag{3}$$

This may be met with Higgs-boson couplings $\lesssim 10^{-6}$. This is small for Yukawa and Higgs-boson couplings but cannot be ruled out.

Loop diagrams for proton decay, such as Fig. 4, give less restrictive bounds since they give (again this diagram vanishes for the **120** of Higgs fields)

$$h^3 \lambda k < 10^{-14} . \tag{4}$$

If there is only the **120** of Higgs fields coupling to the fundamental fermions, the lowest-order leading diagram to proton decay is more complicated. For example, Fig. 5

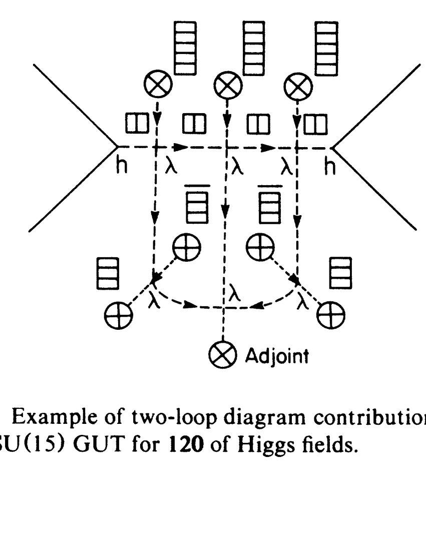

FIG. 5. Example of two-loop diagram contributions to proton decay in SU(15) GUT for **120** of Higgs fields.

(a two-loop diagram) gives a restriction of

$$\lambda^6 h^2 < 10^{-1}, \tag{5}$$

thus allowing any reasonable Yukawa and Higgs-boson self-couplings. Although there may be a complicated tree diagram or one-loop diagram for proton decay with the **120** of Higgs fields, it is challenging to find it. In any case, in the SU(15) model, especially with only the **120** of Higgs fields coupling to quarks and leptons, the proton lifetime is comfortably consistent with the experimental limit.

In conclusion, we have analyzed the Higgs sector of the SU(15) GUT to give the symmetry-breaking pattern of Ref. 1. There is no phenomenological difficulty with proton decay and this makes it even more exciting to await discovery of the low-energy gauge bosons of this theory at the Superconducting Super Collider when it is running.

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[1]P. H. Frampton and B. H. Lee, Phys. Rev. Lett. **64**, 619 (1990).

[2]In Ref. 1, the Higgs sector suggested was not adequate to break the symmetry completely and it was incorrectly stated that the baryon number is conserved in the Higgs sector. This has been pointed out by several authors, including P. Pal, Oregon Report No. OITS-438, 1990 (unpublished); U. Sarkar, R. B. Mann, and T. G. Steele, University of Waterloo, Report No. WATPHS TH-90/03 1990 (unpublished).

[3]J. C. Pati, A. Salam, and J. Strathdee, Nucl. Phys. **B185**, 445 (1981).

[4]Other authors who have looked at similar types of models include H. Fritzsch and P. Minkowski, Ann. Phys. (N.Y.) **93**, 193 (1975); M. Gell-Mann, P. Ramond, and R. Slansky, Rev. Mod. Phys. **50**, 721 (1978); S. L. Adler, Phys. Lett. B **225**, 143 (1989).