$B - L$ NON-CONSERVING PROTON DECAY IN GUTS

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It is shown that $B - L$ non-conserving proton decay ($p \to e^- \pi^+ \pi^+$ etc.) is allowed through gauge boson mixing in both SO(10) and E(6) GUTs, but not in the SU(5) GUT. The lifetime for this decay mode is estimated.

One of the most illuminating features of grand unified theories is the prediction of proton decay. At present it is believed that GUTs with unifying gauge groups SU(5), SO(10) or E(6) allow only $\Delta(B-L) = 0$ proton decay [1], although $B - L$ non-conserving proton decay modes are allowed within the SU(16) GUT [2]. In this paper, the group theoretic structure of the gauge bosons for SU(5), SO(10) and E(6) GUTs are discussed. Particular emphasis is given to the gauge particles mediating proton decay. It is shown that, in contrast to the present belief, $B - L$ non-conserving proton decay is allowed by SO(10) and E(6) GUTs. However, the SU(5) GUT does not allow $B - L$ non-conserving proton decay due to the absence of the appropriate gauge bosons. Finally, the lifetime for this decay mode is estimated.

The SO(10) group is the lowest rank simple group which contains all the features of the SU(5) GUT and in addition allows left–right symmetry, N–$\bar{\text{N}}$ oscillation and intermediate mass scales in the grand plateau region (10^2–10^{15} GeV). So, I shall first discuss this group in detail and then extend my result to other unifying groups.

The transformation property of the **45** gauge bosons of the SO(10) group under $SU(4)_c \times SU(2)_L \times SU(2)_R$ are

$$\mathbf{45} = (15, 1, 1) + (1, 3, 1) + (1, 1, 3) + (6, 2, 2) .$$

The first three terms represent the generators of the groups $SU(4)_c$, $SU(2)_L$ and $SU(2)_R$, respectively. These **45** gauge bosons further transform under $SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ as

$$(15, 1, 1) = (8, 1, 1, 0) + (1, 1, 1, 0) + (3, 1, 1, 4/3) + (\bar{3}, 1, 1, -4/3)$$

$$(1, 3, 1) = (1, 3, 1, 0) ,$$

$$(1, 1, 3) = (1, 1, 3, 0) ,$$

$$(6, 2, 2) = (3, 2, 2, -2/3) + (\bar{3}, 2, 2, 2/3) .$$

We exhibit the $B - L$ values here. The quantum number corresponding to the normalised generator is $\sqrt{\frac{3}{8}}(B - L)$. (8, 1, 1, 0), (1, 3, 1, 0), (1, 1, 3, 0) and (1, 1, 1, 0) correspond to the generators of the $SU(3)_c$ group (gluons), $SU(2)_L$ group ($W_L^{\pm,0}$), $SU(2)_R$ group ($W_R^{\pm,0}$) and $U(1)_{B-L}$ group (couples to the $B - L$ quantum-number conserving current), respectively. The gauge particles $X \sim (\bar{3}, 1, 1, -4/3)$ correspond to the lepto-quarks ($\bar{q}_L \gamma_\mu \ell_L$) and $Y_s \sim (\bar{3}, 2, 2, 2/3)$ correspond to the diquarks ($\bar{q}_L^c \gamma_\mu q_L$) and lepto-antiquarks ($\bar{q}_L \gamma_\mu \ell_L^c$) and (3, 1, 1, 4/3) and (3, 2, 2, −2/3) are, respectively, their hermitian conjugates. These gauge bosons are represented in fig.1.

The nature of the gauge particles clearly indicate the possible proton decay processes. The $B - L$ conserving proton decay can be mediated by the gauge boson Y_s alone as indicated in fig. 2a. However, the $B - L$ non-conserving proton decay (fig. 2b) can be mediated by certain choices of the Higgses (Γ_1 and Γ_2) which allow mixing between the gauge particles X and Y_s.

The amplitudes of the two processes are,

$$A(\Delta(B - L) = -2) \approx g^2/M_{Y_s}^2 , \quad (1a)$$

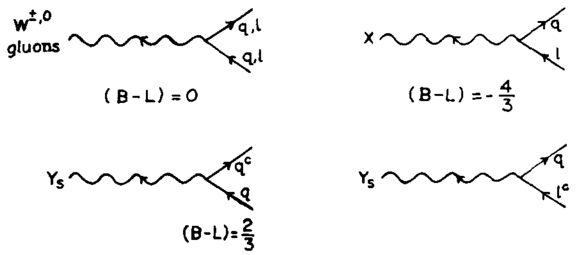

Fig. 1. Gauge particles of the SO(10) GUT.

$$A(\Delta(B-L)=-2) \approx g^2 \langle\Gamma_1\rangle\langle\Gamma_2\rangle / M_{Y_s}^2 M_X^2 . \qquad (1b)$$

Now, I shall show that the appropriate Higgses Γ_1 and Γ_2 which acn allow mixing between the gauge particles Y_s and X are present among the Higgses necesary to break the symmetry group SO(10) down to $SU(3)_c \times U(1)_{EM}$ through the following chain,

$$SO(10) \xrightarrow{M_u} SU(4)_c \times SU(2)_L \times SU(2)_R$$
$$\xrightarrow{M_c} SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$$
$$\xrightarrow{M_R} SU(3)_c \times SU(2)_L \times U(1)_Y$$
$$\xrightarrow{M_L} SU(3)_c \times U(1)_{EM} ,$$

and hence I shall find the mass scales included in expressions (1a) and (1b).

The Higgs (1, 1, 1) under $SU(4)_c \times SU(2)_L \times SU(2)_R$ included in a **54** dimensional representation of SO(10) acquires mass of the order of M_u and causes the first stage symmetry breaking in the above chain. The gauge particles (6, 2, 2) which contain Y_s and $\bar{Y}_s$ and mediates proton decay, must also acquire mass of the order of M_u. The next stage symmetry

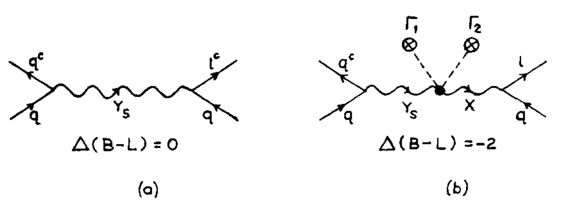

Fig. 2. (a) The $B-L$ conserving proton decay process mediated by the gauge boson Y_S. (b) $B-L$ non-conserving proton decay induced by the mixing of gauge bosons. Γ_1 and Γ_2 are Higgs fields which allow mixing between the gauge particles Y_s and X.

breaking occurs at a mass scale M_c by the Higgs

$$(1,1,1,0) \text{ [under } SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-l}$$
$$\subset (15,1,1) \text{ [under } SU(4)_c \times SU(2)_L \times SU(2)_R]$$
$$\subset 210 \quad \text{of } SO(10) .$$

The mass of the lepto-quark gauge particles X are of this order (i.e. M_c). The Higgs

$$(1,1,0) \text{ [under } SU(3)_c \times SU(2)_L \times U(1)_Y]$$
$$\subset (1,1,3,-2)$$
$$\text{[under } SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}]$$
$$\subset (10,1,3) \text{ [under } SU(4)_c \times SU(2)_L \times SU(2)_R]$$
$$\subset \overline{126} \quad \text{of } SO(10) ,$$

breaks the symmetry at a mass scale M_R. The value of Y given in the expression, satisfies the charge relation $Q = T_{3L} + Y$ and differs by a constant factor $(5/3)^{1/2}$ from the quantum number corresponding to the normalised generator. Finally the Weinberg–Salam symmetry breaking takes place at a mass scale M_L, by the Higgses

$$(1,0) \text{ [under } SU(3)_c \times U(1)_{EM}]$$
$$\subset (1,2,\pm\tfrac{1}{2}) \text{ and } (1,3,-1)$$
$$\text{[under } SU(3)_c \times SU(2)_L \times U(1)_Y]$$
$$\subset (1,2,2,0) \text{ and } (1,3,1,-2), \text{ respectively}$$
$$\text{[under } SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}]$$
$$\subset (15,2,2) \text{ and } (10,3,1), \text{ respectively}$$
$$\text{[under } SU(4)_c \times SU(2)_L \times SU(2)_R]$$
$$\subset 126 \quad \text{of } SO(10) .$$

The structure of the Higgses suggest that one can choose the last two Higgses for Γ_1 and Γ_2 which can mix the gauge particles Y_s and X. Then, $\langle\Gamma_1\rangle = \langle\Gamma_2\rangle \sim M_L$ and

$$A(\Delta(B-L)=0) \approx g^2/M_u^2 , \qquad (2a)$$

$$A(\Delta(B-L)=-2) \approx g^2 M_L^2 / M_u^2 M_c^2 . \qquad (2b)$$

An appropriate choiee of Higgses gives a similar result for the SU(16) GUT [3].

Now consider the gauge group E(6). This group can descend down to $SU(3)_c \times U(1)_{EM}$ via two symmetry breaking modes, which will allow $B-L$ non-conserving proton decay.

Mode A:

$$E(6) \xrightarrow{M_u} SO(10) \times U(1)$$
$$\xrightarrow{M_V} SU(4)_c \times SU(2)_L \times SU(2)_R$$
$$\xrightarrow{M_c} SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$$
$$\xrightarrow{M_R} SU(3)_c \times SU(2)_L \times U(1)_Y$$
$$\xrightarrow{M_L} SU(3)_c \times U(1)_{EM} .$$

Mode B:

$$E(6) \xrightarrow{M_u} SU(3)_c \times SU(3)_L \times SU(3)_R$$
$$\xrightarrow{M_c} SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$$
$$\xrightarrow{M_R} SU(3)_c \times SU(2)_L \times U(1)_Y$$
$$\xrightarrow{M_L} SU(3)_c \times U(1)_{EM} .$$

Since in mode A, the unifying group E(6) breaks first to $SO(10) \times U(1)$ and then to other subgroups, it is obvious that the Higgses that break the E(6) group down to $SU(3)_c \times U(1)_{EM}$ group will be the same as those, which breaks SO(10) down to $SU(3)_c \times U(1)_{EM}$. The only difference from the previous case is that the particular SO(10) representations will be further contained in some E(6) representations. Hence this mode of symmetry breaking will allow both $B-L$ conserving and $B-L$ non-conserving proton decays. However, this is not obvious in mode B.

The 78 gauge boson of the E(6) GUT has the transformation property under the group $SU(3)_c \times SU(3)_L \times SU(3)_R$

$$78 = (8,1,1) + (1,8,1) + (1,1,8) + (3,\bar{3},\bar{3}) + (\bar{3},3,3).$$

The first three terms correspond to the gauge particles, which remain massless as long as the symmetries $SU(3)_c$, $SU(3)_L$ and $SU(3)_R$ remain unbroken. The gauge particles $(\bar{3},3,3)$ acquire a mass $\sim M_u$ and are responsible for proton decays and $(3,\bar{3},\bar{3})$ is the hermitian conjugate of (3,3,3). Now, for a better understanding of proton decay consider the components of $(\bar{3},3,3)$ under $SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$

$$(\bar{3},3,3) = (\bar{3},2,2,2/3) + (\bar{3},1,1,-4/3) + (\bar{3},2,1,-1/3) + (\bar{3},1,2,-1/3) .$$

This shows that $(\bar{3},3,3)$ contains the gauge bosons Y_s and X (discussed previously) which can mediate both $B-L$ conserving and $B-L$ non-conserving proton decays if appropriate Higgses are present. Now the Higgses

$$(1,0) \text{ [under } SU(3)_c \times U(1)_{EM}]$$
$$\subset (1,2,\pm\tfrac{1}{2}) \text{ and } (1,3,-1) \text{ [under } SU(3)_c \times SU(2)_L \times U(1)_Y]$$
$$\subset (1,2,2,0) \text{ and } (1,3,1,-2), \text{ respectively [under } SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}]$$
$$\subset (1,8,8) \text{ and } (1,\overline{10},10), \text{ respectively [under } SU(3)_c \times SU(3)_L \times SU(3)_R]$$
$$\subset \overline{3003} \text{ of } E(6) ,$$

break the $SU(2)_L$ symmetry and give masses to the fermions. These Higgses can, as before, play the role of Γ_1 and Γ_2 to mix the gauge particles Y_s and X and hence allow $B-L$ non-conserving proton decay. The amplitudes for these processes, however, are given by

$$A(\Delta(B-L)=0) \approx g^2/M_u^2 , \qquad (3a)$$

$$A(\Delta(B-L)=-2) \approx g^2 M_L^2/M_u^4 . \qquad (3b)$$

These expressions becomes similar to the SO(10) situation, if in the SO(10) GUT one chooses $M_c = M_u$.

Before proceeding further to discuss the SU(5) GUT, it will be convenient to check the structure of the gauge particles Y_s and X under the subgroup $SU(3)_c \times SU(2)_L \times U(1)_Y$

$$Y_s = (\bar{3},2,2,2/3) \text{ [under } SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}]$$
$$= (\bar{3},2,-1/6) + (\bar{3},2,5/6) \text{ [under } SU(3)_c \times SU(2)_L \times U(1)_Y]$$

$$X = (\bar{3},1,1,-4/3) \text{ [under } SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}]$$
$$= (3,1,-2/3) \text{ [under } SU(3)_c \times SU(2)_L \times U(1)_Y] .$$

The **24** gauge bosons of the SU(5) GUT transform under $SU(3)_c \times SU(2)_L \times U(1)_Y$ as

$$24 = (8,1,0) + (1,3,0) + (1,1,0) + (\bar{3},2,5/6) + (3,2,-5/6) .$$

The first three terms generate the groups $SU(3)_c$, $SU(2)_L$ and $U(1)_Y$ and the fourth term, which is contained in Y_s, mediates proton decay conserving $B - L$ quantum number and the last term is its hermitian conjugate. The absence of any gauge particles with $Y = \pm 2/3$ makes $B - L$ non-conserving proton decay impossible. This is in contrast to the case of the SU(16) GUT, where an appropriate choice of Higgses can suppress the $B - L$ conserving proton decay, although the gauge bosons are present [3].

Finally it is concluded that although the SU(5) GUT prohibits $B - L$ non-conserving proton decay, such modes are allowed by both SO(10) and E(6) GUTs through mixing of gauge bosons.

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