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THE MASS MATRIX FOR A LEPTONIC U(3) MODEL *

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ABSTRACT

In the approximation that electron and muon masses are small compared with the newly postulated lepton masses, a mass matrix is constructed for the U(3) nonet scheme of lepton interactions.

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I. INTRODUCTION

In a recent note [1], a nonet model of leptons was proposed which introduced six new heavy leptons and was designed to give a unified gauge treatment of weak and electromagnetic interactions. This note is concerned with the construction of a mass matrix through the mechanism of spontaneous symmetry breaking. It appears that the requirement of U(3) symmetry, together with the restrictions on unwanted processes, places extraordinarily tight constraints on the form of the mass matrix. The simplest and most attractive model we have been able to construct uses two sets of $8 + 10 + \overline{10}$ multiplets and appears to indicate an underlying $O(9)_L \otimes O(9)_R$ gauge structure. The surprise is that even with this large number of scalar particles there are strong constraining relations among the leptonic masses which we exhibit below.

II. THE U(3) CLASSIFICATION AND THE GAUGE INTERACTIONS

The three known leptons $(\mu^+, \nu_e + \overline{\nu}_\mu, e^-)$ and the six postulated heavy leptons $(\mu^0, M^0, M^-, E^+, E^0, e^0)$ are grouped into two nonets:

$$\psi_L = \begin{pmatrix} E_1 & E^+ & \mu^+ \\ e^- & E_2 & \mu^0 \\ M^- & M^0 & E_3 \end{pmatrix}_L , \qquad \psi_R = \begin{pmatrix} M_1 & \mu^+ & E^+ \\ M^- & M_2 & E^0 \\ e^- & e^0 & M_3 \end{pmatrix}_R$$

where $(E_1, E_2, E_3)_L$ and $(M_1, M_2, M_3)_R$ are orthogonal combinations of $(E^0, e^0, \nu_e)_L$ and $(\mu^0, M^0, \overline{\nu}_\mu)_R$, respectively [2]. In forming an SU(3) gauge model of intermediate bosons (among which is included the photon) one must impose at least three conditions. We list these:

a) The photon being the usual U-spin scalar,

$$A = -\tfrac{1}{2}(\sqrt{3}\,W^3 + W^8) \quad ,$$

the other $\Delta S = 0$ neutral gauge boson must be the U-spin triplet

$$Z = -\tfrac{1}{2}(W^3 - \sqrt{3}\, W^8) \quad .$$

This corresponds to a mixing angle of 60° with reference to the $SU(2)_I \otimes U(1)_Y$ gauge subgroup.

b) In view of its experimental suppression, we shall require that there be no $Z\bar{\nu}\nu$ interactions. Because gauge couplings of octets are always F-type, this is automatic in the nonet model if the ν occurs only in the diagonal elements $(E_1, E_2, E_3)_L$ and $(M_1, M_2, M_3)_R$.

c) The charged "strange" vector bosons $X^\pm$ will, in general, couple to "wrong" neutrinos with interactions of the type $X^+(\nu_\mu e^-)_R$ and $X^+(\overline{\mu^+}\nu_e)_L$.

Since there is no experimental evidence for such couplings, we must either arrange that the F-couplings of $X^\pm$ with $\left[(\bar{M}_3 - \bar{M}_1)\, e^-\right]_R$ and $\left[\overline{\mu^+}(E_1 - E_3)\right]_L$ do not feature neutrinos, or else that the $X^\pm$ are extremely heavy. We find that the latter is difficult to accomplish with an acceptable mass matrix incorporating spontaneous symmetry breaking; we choose to secure the absence of undesirable charged currents by requiring the neutrinos to be V-spin singlets, i.e. a mixture of the combinations $E_1 + E_2 + E_3$ and $E_1 - 2E_2 + E_3$. This then leads to the general mixing scheme:

$$E_1 + E_2 + E_3 = \sqrt{3}\left[-\nu_e \sin\gamma + (E^0 \cos\beta + e^0 \sin\beta)\cos\gamma\right]$$

$$E_1 - 2E_2 + E_3 = \sqrt{6}\left[\nu_e \cos\gamma + (E^0 \cos\beta + e^0 \sin\beta)\sin\gamma\right]$$

$$E_1 - E_3 = \sqrt{2}\left[-E^0 \sin\beta + e^0 \cos\beta\right]$$

and likewise for M_1, M_2, M_3 with $\bar{\nu}_\mu, \mu^0, M^0, \gamma', \beta'$ replacing $\nu_e, E^0, e^0, \gamma, \beta$, respectively. The $\mu \leftrightarrow e$ universality requires $\gamma = \gamma'$ and we can at this point remark on the symmetry between ψ_L and ψ_R which takes $\mu \leftrightarrow E$, $e \leftrightarrow M$, $\nu_e \leftrightarrow \bar{\nu}_\mu$, $\beta \leftrightarrow \beta'$. Salam and Pati specialized[3] to $\gamma = \gamma' = 0$. We shall do the same and, further, we shall set $\beta = 90^\circ$, $\beta' = 0$, thereby identifying e^0_L, μ^0_R with the SU(3) scalars and E^0_L, M^0_R with the V-spin triplets. (These choices of angles $\gamma, \gamma', \beta, \beta'$ could be relaxed.)

The gauge bosons are described by the octet matrix:

$$W = \begin{pmatrix} -\frac{2A}{\sqrt{6}} & W^{+} & X^{+} \\ W^{-} & \frac{Z}{\sqrt{2}} + \frac{A}{\sqrt{6}} & X^{0} \\ X^{-} & \bar{X}^{0} & -\frac{Z}{2} + \frac{A}{\sqrt{6}} \end{pmatrix}$$

and for reference we set down the F-couplings to the leptons:

$$\mathcal{L}(W,\psi) = -\sqrt{2/3}\ e\ \mathrm{Tr}(W[\bar{\psi},\psi])$$

$$= eA\left[\overline{\mu^{+}}\gamma\mu^{+} + \overline{E^{+}}\gamma E^{+} - \overline{e^{-}}\gamma e^{-} - \overline{M^{-}}\gamma M^{-}\right]$$

$$+\frac{eZ^{0}}{\sqrt{3}}\begin{bmatrix} \overline{\mu^{+}}\, i\gamma\gamma_5\, \mu^{+} - \overline{\mu^{0}}\,\gamma\,(1-i\gamma_5)\,\mu^{0} - \overline{M^{-}}\, i\gamma\gamma_5 M^{-} + \overline{M^{0}}\gamma(1-i\gamma_5)M^{0} \\ -\overline{E^{+}}\, i\gamma\gamma_5 E^{+} - \overline{E^{0}}\gamma(1+i\gamma_5)\,E^{0} + \overline{e^{-}}\, i\gamma\gamma_5\, e^{-} + \overline{e^{0}}\,\gamma\,(1+i\gamma_5)e^{0} \end{bmatrix}$$

$$-\frac{eW^{+}}{\sqrt{3}}\begin{bmatrix} \left(\sqrt{2}\ \overline{\mu^{+}}\,\mu^{0} - (\overline{E^{0}} - \sqrt{3}\ \overline{\nu_e})\ e^{-} + \overline{E^{+}}(E^{0} - \sqrt{3}\,\nu_e) - \sqrt{2}\ \overline{M^{0}}\,M^{-}\right)_L \\ +\left(\sqrt{2}\ \overline{E^{+}}\ E^{0} - (\overline{\mu^{0}} - \sqrt{3}\,\nu_\mu)\ M^{-} + \overline{\mu^{+}}\,(\mu^{0} - \sqrt{3}\ \bar{\nu}_\mu) - \sqrt{2}\ \overline{e^{0}}\,e^{-}\right)_R \end{bmatrix} + \text{h.c.}$$

$$-\frac{eX^{+}}{\sqrt{3}}\begin{bmatrix} (2\overline{\mu^{+}}\ E^{0} - \sqrt{2}\ \overline{\mu^{0}}\ e^{-} - 2\overline{E^{0}}\ M^{-} + \sqrt{2}\ \overline{E^{+}}\ M^{0})_L \\ +(2\overline{E^{+}}\,\mu^{0} - \sqrt{2}\ \overline{E^{0}}\ M^{-} - 2\overline{\mu^{0}}\ e^{-} + \sqrt{2}\ \overline{\mu^{+}}\ e^{0})_R \end{bmatrix} + \text{h.c.}$$

$$-\frac{eX^{0}}{\sqrt{3}}\begin{bmatrix} (\overline{\mu^{0}}\,(E^{0} + \sqrt{3}\ \nu_e) - \sqrt{2}\ \overline{\mu^{+}}\ E^{+} - (\overline{E^{0}} + \sqrt{3}\ \overline{\nu_e})\,M^{0} + \sqrt{2}\ \overline{e^{-}}\ M^{-})_L \\ +(\overline{E^{0}}\,(\mu^{0} + \sqrt{3}\ \bar{\nu}_\mu) - \sqrt{2}\ \overline{E^{+}}\,\mu^{+} - (\overline{\mu^{0}} + \sqrt{3}\,\nu_\mu)\,e^{0} + \sqrt{2}\ \overline{M^{-}}\,e^{-})_R \end{bmatrix} + \text{h.c.}$$

Note that the light particle combinations $(\overline{\mu^{+}}\nu)$, $(\overline{e^{-}}\nu)$, $\overline{\mu^{+}}\mu^{+}$, $\overline{e^{-}}e^{-}$ occur only for $W^{\pm}$, A^{0} and Z^{0} currents. The X-currents involve at least one heavy lepton among the bilinear Fermi field products.

III. THE MASS MATRIX

If the new leptons do exist they must be quite heavy ($\gg 1$ GeV) and one may even speculate with Pakvasa and Tennakone[4] that their masses are α^{-1} times larger than m_μ. We shall construct the mass matrix for leptons with a first restriction $(m_e, m_\mu)/m_{\text{new leptons}} \approx 0$. Since $(e^0, e^-)_R$, for example, is an isospin doublet our problem will be to ensure that e^0 does not remain massless. What will save this particle from this catastrophe will be the arrangement by which e^0_L belongs to the SU(3) singlet, even though its helicity conjugate e^0_R is a member of a doublet.

To construct the mass matrix we shall use spin-zero self-conjugate multiplets of 8's and $(10 + \overline{10})$'s , and, as stated in Ref.1, we shall need to stipulate that $\langle K^0 \rangle \neq 0$. We shall also require CP conservation, though this could be relaxed. Even with CP conservation, however, one may distinguish two types of scalar multiplets under the CP operation on the K^0-like particles contained in the 8, 10 and $\overline{10}$.

Consider the octet first. If K^0 and $\overline{K^0}$ are hermitian-conjugate fields, the two cases to be distinguished are

$$(A) \qquad (CP)\, K^0\, (CP)^{-1} = \overline{K^0} \qquad \text{so that } \langle K_1 \rangle \neq 0$$

$$(B) \qquad (CP)\, K^{0\prime} (CP)^{-1} = -\overline{K^{0\prime}} \qquad \text{so that } \langle K_2' \rangle \neq 0$$

(we attach a prime to all fields of class B to distinguish them from fields of class A). Next, consider the decuplet with its four K-like fields[2] Ξ^0, $\overline{\Xi^0}$, Δ^0 and $\overline{\Delta^0}$, where we can again distinguish between types A and B according as

$$(A) \qquad (CP)\, (\Xi^0, \Delta^0)\, (CP)^{-1} = (\overline{\Xi^0}, \overline{\Delta^0})$$

$$(B) \qquad (CP)\, (\Xi^{0\prime}, \Delta^{0\prime}) (CP)^{-1} = -(\overline{\Xi^{0\prime}}, \overline{\Delta^{0\prime}}) .$$

With this preparation we are ready to write down the mass matrices. In general, a spin-zero octet can be coupled in four ways to the nonets ψ_L and ψ_R. These are the F and D couplings plus two singlet couplings (see Appendix). For a $10 + \overline{10}$, only one CP-conserving coupling is possible. However, since there are two distinct non-zero expectation values possible, $\langle \Xi^0 \rangle \neq 0$ and $\langle \Delta^0 \rangle \neq 0$ (as against just $\langle K^0 \rangle \neq 0$ for the octet case), the CP-conserving leptonic mass matrix can admit of a total of six arbitrary constants from the $8 + 10 + \overline{10}$ scalar particles. This count is for class A multiplets and would be doubled if additional class B multiplets are also permitted.

In the Appendix we have set down all the twelve possible contributions to the leptonic mass matrix from which it should be possible to construct a mass matrix with arbitrary masses for all the particles. In the text, we wish to solve the restricted and surprisingly difficult problem of ensuring zero masses for e^-, ν, μ^+ and large masses for the remaining six leptons. It appears that this is impossible to accomplish (see Appendix) if we confine ourselves only to $8 + 8'$ scalar mesons. The simplest choice appears to be to work with one octet (A or B type) plus one $(10 + \overline{10})$ multiplet of type A and a second $(10 + \overline{10})'$ of type B. Rather than exhibit the mass matrix for this case, we choose to take two symmetrical sets of A and B type multiplets $(8 + 10 + \overline{10})$ plus $(8 + 10 + \overline{10})'$. Provided that the 8's do not couple via F or D with leptons and provided that $\langle \Delta^0 \rangle \equiv 0$, we obtain for the mass matrix:

$$\mathcal{L}_8 = S_\mu \left[\tfrac{1}{2}(\overline{M^0} + \overline{\mu^0})(1 + i\gamma_5)(M_1 + M_2 + M_3) + h.c.\right]$$
$$+ S_e \left[\tfrac{1}{2}(\overline{e^0} + \overline{E^0})(1 - i\gamma_5)(E_1 + E_2 + E_3) + h.c.\right]$$

$$\mathcal{L}_{8'} = S'_\mu \left[\tfrac{1}{2}(\overline{M^0} - \overline{\mu^0})(1 + i\gamma_5)(M_1 + M_2 + M_3) + h.c.\right]$$
$$+ S'_e \left[\tfrac{1}{2}(\overline{e^0} - \overline{E^0})(1 - i\gamma_5)(E_1 + E_2 + E_3) + h.c.\right]$$

$$\mathcal{L}_{(10 + \overline{10})} = G\Big[\overline{e^-}e^- - \overline{\mu^+}\mu^+ - \overline{E^+}E^+ + \overline{M^-}M^- +$$
$$+ \tfrac{1}{2}(\overline{e^0} - \overline{E^0})(1 - i\gamma_5)(E_3 - E_1) + h.c. +$$
$$+ \tfrac{1}{2}(\overline{M^0} - \overline{\mu^0})(1 + i\gamma_5)(M_3 - M_1) + h.c.\Big]$$

$$\mathcal{L}_{(10+\overline{10})'} = G' \Big[\overline{e^-} e^- - \overline{\mu^+} \mu^+ + \overline{E^+} E^+ - \overline{M^-} M^- + \tfrac{1}{2}(\overline{e^0} + \overline{E^0})(1 - i\gamma_5)(E_3 - E_1) + \text{h.c.} - \tfrac{1}{2}(\overline{M^0} + \overline{\mu^0})(1 + i\gamma_5)(M_3 - M_1) + \text{h.c.} \Big] .$$

To secure the masslessness of e^- and μ^+ we must clearly set $G + G' = 0$ (either by adjusting the intrinsic couplings g and g' of the $10 + \overline{10}$ and $(10 + \overline{10})'$ or by adjusting $\langle \Xi^0 \rangle$ and $\langle \Xi^{0\prime} \rangle$, or both, where $G = g\langle \Xi^0 \rangle$, $G' = g'\langle \Xi^0 \rangle$).

Note that since only the combinations $E_3 - E_1$ and $E_1 + E_2 + E_3$ (and similarly for M) appear in the neutral particle masses, this avoids the problem of ν_e mixing with e^0 or E^0.

Finally, we may diagonalize quite simply by taking $S_\mu = -S'_\mu$ and $S_e = S'_e$ to obtain the result [6]

$$M(\mu^0) = 2\sqrt{3}\, S_\mu \quad , \qquad m(e^0) = 2\sqrt{3}\, S_e \quad ,$$

$$m(M^0) = m(E^0) = 2\sqrt{2} G \quad , \qquad m(M^-) = m(E^+) = 2G \; .$$

For the W masses the spontaneous symmetry-breaking mechanism gives

$$\mathcal{L}_m(W) = M_8^2 \left[W^+W^- + X^+X^- + 2X_2^2 + 2Z^2 \right] + M_8'^2 \left[W^+W^- + X^+X^- + 2X_1^2 + 2Z^2 \right] + (M_{10}^2 + M_{10}'^2)\left[W^+W^- + 7X^+X^- + X_1^2 + X_2^2 + 2Z^2 \right] .$$

Note that the "strange" bosons $X^\pm$ are usefully, though not excessively, heavier than the "non-strange" $W^\pm$. Also note that Z mass is twice the $W^\pm$ mass which (on account of $W(e\nu)$, $(\mu\nu)W$ coupling constant being exactly equal to the electromagnetic) must equal 53 BeV, as remarked in Ref. 1, provided we specialize to $\gamma = \gamma' = 0$ ($\alpha = \alpha' = -30^\circ$ of Ref.1). Since there are only seven heavy W's in the theory, only seven combinations of the scalar particles can be gauged away. Thus for the purposes of the present model, one should assume that the masses of the scalar particles are very very large, in order to suppress undesirable transitions proceeding through these; $(m_W/m_\phi \ll 1)$. A better model can be constructed, using an $O_L(9) \times O_R(9)$ symmetry, where all the offending scalar particles introduced can be gauged away. We shall discuss this elsewhere.

APPENDIX

Here we list the couplings we have not used. These may be of value if one wishes to include arbitrary values of m_e and m_μ. In this paper we have taken the attitude with Weinberg [6] that these should be obtained from radiative corrections.

1. A-type octet mass terms

$$\begin{aligned}
\mathcal{L}_{m8}(\psi) = \; & F\Big[\overline{e^-}e^- + \overline{M^-}M^- - \overline{E^+}E^+ - \overline{\mu^+}\mu^+ + \\
& + \tfrac{1}{2}(\overline{M^0} - \overline{\mu^0})(1 + i\gamma_5)(M_2 - M_3) + \text{h.c.} \\
& + \tfrac{1}{2}(\overline{e^0} - \overline{E^0})(1 - i\gamma_5)(E_2 - E_3) + \text{h.c.}\Big] \\
& + D\Big[\overline{e^0}e^- + \overline{M^-}M^- + \overline{E^+}E^+ + \overline{\mu^+}\mu^+ + \\
& + \tfrac{1}{2}(\overline{M^0} + \overline{\mu^0})(1 + i\gamma_5)(M_2 + M_3) + \text{h.c.} \\
& + \tfrac{1}{2}(\overline{e^0} + \overline{E^0})(1 + i\gamma_5)(E_2 + E_3) + \text{h.c.}\Big]
\end{aligned}$$

+ S-terms given in text.

2. B-type octet mass terms

$$\begin{aligned}
\mathcal{L}'_{m8}(\psi) = \; & F'\Big[\overline{e^-}e^- - \overline{M^-}M^- + \overline{E^+}E^+ - \overline{\mu^+}\mu^+ - \\
& - \tfrac{1}{2}(\overline{M^0} + \overline{\mu^0})(1 + i\gamma_5^0)(M_2 - M_3) + \text{h.c.} \\
& + \tfrac{1}{2}(\overline{e^0} + \overline{E^0})(1 - i\gamma_5)(E_2 - E_3) + \text{h.c.}\Big] \\
& + D'\Big[\overline{e^-}e^- - \overline{M^-}M^- - \overline{E^+}E^+ + \overline{\mu^+}\mu^+ - \\
& - \tfrac{1}{2}(\overline{M^0} - \mu^0)(1 + i\gamma_5)(M_2 + M_3) + \text{h.c.} \\
& + \tfrac{1}{2}(\overline{e^0} - \overline{E^0})(1 + i\gamma_5)(E_2 + E_3) + \text{h.c.}\Big]
\end{aligned}$$

+ S'-terms given in text.

3. <u>A-type decuplet mass terms for $\langle\Delta^0\rangle \neq 0$</u>

$$\mathcal{L}_{m(10+\overline{10})}(\psi) = G_\Delta\Big[\overline{E^+}E^+ - \overline{M^-}M^- - \overline{e^-}e^- + \overline{\mu^+}\mu^+ + $$
$$+ \tfrac{1}{2}(\overline{E^0} - \overline{e^0})(1 + i\gamma_5)(E_1 - E_2) + \text{h.c.}$$
$$+ \tfrac{1}{2}(\overline{\mu^0} - \overline{M^0})(1 + i\gamma_5)(M_1 - M_2) + \text{h.c.}\Big]$$

+ G terms given in text.

4. <u>B-type decuplet mass terms for $\langle\Delta^0\rangle' \neq 0$</u>

$$\mathcal{L}'_{m(10+\overline{10})}(\psi) = G'_\Delta\Big[\overline{E^+}E^+ - \overline{M^-}M^- + \overline{e^-}e^- - \overline{\mu^+}\mu^+ + $$
$$+ \tfrac{1}{2}(\overline{E^0} + e^0)(1 + i\gamma_5)(E_1 - E_2) + \text{h.c.} -$$
$$- \tfrac{1}{2}(\overline{\mu^0} + M^0)(1 + i\gamma_5)(M_1 - M_2) + \text{h.c.}\Big]$$

+ G' terms given in text.

All of these contributions arise by giving appropriate K-like mesons non-zero expectation values in the couplings listed below:

$$\mathcal{L}(\psi,\phi) = f\,\mathrm{Tr}(\phi[\overline{\psi}_L, \psi_R] + \phi\,[\overline{\psi}_R, \psi_L])$$
$$+ d\,\mathrm{Tr}(\phi\{\overline{\psi}_L, \psi_R\} + \phi\,\{\overline{\psi}_R, \psi_L\})$$
$$+ s_\mu(\mathrm{Tr}\,\phi\,\overline{\psi}_L\,\mathrm{Tr}\,\psi_R + \mathrm{Tr}\,\overline{\psi}_R\,\mathrm{Tr}\,\psi_L\phi)$$
$$+ s_e(\mathrm{Tr}\,\phi\,\overline{\psi}_R\,\mathrm{Tr}\,\psi_L + \mathrm{Tr}\,\overline{\psi}_L\,\mathrm{Tr}\,\psi_R\phi)$$
$$+ if'\mathrm{Tr}(\phi'[\overline{\psi}_L, \psi_R] - \phi'[\overline{\psi}_R, \psi_L])$$
$$+ id'\mathrm{Tr}(\phi'\{\overline{\psi}_L, \psi_R\} - \phi'\{\overline{\psi}_R, \psi_L\})$$
$$+ is'_\mu(\mathrm{Tr}\,\phi'\,\overline{\psi}_L\,\mathrm{Tr}\,\psi_R - \mathrm{Tr}\,\overline{\psi}_R\,\mathrm{Tr}\,\psi_L\phi')$$

$$+ \; iS'_e(\mathrm{Tr}\,\phi'\,\overline{\psi}_R\;\mathrm{Tr}\,\psi_L \;-\; \mathrm{Tr}\,\overline{\psi}_L\;\mathrm{Tr}\,\psi_R\,\phi')$$

$$+ \; g\left(\Phi\,(\overline{\psi}_R\psi_L + \overline{\psi}_L\psi_R)\,\epsilon \;+\; \overline{\Phi}(\overline{\psi}_L\psi_R + \overline{\psi}_R\psi_L)\,\epsilon\right)$$

$$+ \; ig'\left(\Phi'(\overline{\psi}_R\psi_L - \overline{\psi}_L\psi_R)\,\epsilon \;-\; \overline{\Phi}'(\overline{\psi}_L\psi_R - \overline{\psi}_R\psi_L)\,\epsilon\right)$$

Here $\phi = \phi_a^b$ is octet and $\Phi = \Phi_{(abc)}$ is decuplet and ϵ stands for the symbol ϵ_{abc}. Note that $K^{\pm}$ do not couple F-wise to $\mu\nu$ and $e\nu$ combinations but that Δ^+ and Ξ^- do, like $\pi^{\pm}$ and $\Sigma^{\pm}$. These interactions can be suppressed by making the scalar meson masses enormous, and the same mechanism will be needed for neutral scalar interactions like $\Delta^0(\overline{\mu^+}\mu^+ - \overline{e^-}e^-)$, etc.

Note the following patterns:

1) For A-type couplings of 8's and 10 + $\overline{10}$'s the combinations ($\bar{e}e-\bar{\mu}\mu$) and ($\overline{M}M-\overline{E}E$) occur with the same sign, while for B-type couplings the relative sign of these combinations is reversed. Thus in order that ($\bar{e}e-\bar{\mu}\mu$) mass terms have a different coefficient from ($\overline{M}M-\overline{E}E$) mass terms it is essential to admit <u>both</u> A- and B-type couplings.

2) For the D-type couplings it is the ($\bar{e}e+\bar{\mu}\mu$) and ($\overline{M}M+\overline{E}E$) combinations which occur in $\mathcal{L}_m$. These couplings will then break the e-μ and M-E universality induced by F-type octet and 10 + $\overline{10}$ couplings. Since in the present paper we wished to preserve this universality, we discarded D-type couplings.

3) One's first instinct is to try to work with A and B type octet F,D and S couplings only and to desist from including 10 + $\overline{10}$'s. One can show quite generally that in this case masslessness of e^- and μ^+ necessarily entails masslessness of e^0 <u>or</u> μ^0.

REFERENCES AND FOOTNOTES

1. Abdus Salam and J.C. Pati, Phys. Letters (to appear).

2. Note a change of notation relative to Ref.1. The $E^0(M^0)$ and $e^0(\mu^0)$ of this paper are $E^0(M^{0\prime})$ and $E^{0\prime}(M^0)$ of Ref.1.

3. $\gamma = \gamma' = 0$ corresponds to $\alpha = \alpha' = -30^\circ$ of Ref.1.

4. S. Pakvasa and K. Tennakone, Phys. Rev. Letters 11, 757 (1971).

5. The reader is reminded that Ξ^0 and Δ^0 are generic symbols for the scalar particles, which are not to be confused with the corresponding baryonic states.

6. S. Weinberg, Phys. Rev. 5D, 1962 (1972).