INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS

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1.

After yesterday's talks about the new particles[1] (J/ψ) and the dimuon events[2], it is quite clear that new quantum numbers outside of the very successful SU(3)-symmetry have already begun to appear in physics. The set of possible candidates for such new quantum numbers include colour and charm. You have heard the interpretation[3] this morning that the new particles reflect charm-anticharm-composites. This afternoon you will hear that they may reflect colour[4].

Both colour and charm are needed in the quark-lepton-unification scheme[5,6] which we proposed sometime ago. We suggested that the basic set of fermions F should possess four valencies denoted by (p, n, λ, χ) and four colours denoted by (red, yellow, blue and lilac) = (a , b , c , d); the fourth colour lilac being lepton-number. There are several reasons why a 4 x 4-structure for the basic set of fermions F is desirable. The chief among them are that it allows putting quarks and leptons together within the same multiplet and that the underlying $SU(4) \times SU(4)'$-symmetry predicts uniquely the charges of the leptons to be (0 , -1 , -1 , 0) to match precisely the charges of the known leptons $(\nu_e, e^-, \mu^-, \nu_\mu)$.

We also had noted that this four-colour-four-valency-attribute for the basic set F admits a natural[7] unification of "all" forces (weak, electromagnetic and strong) in terms of a single coupling constant, only provided we postulate[8),9] a new heavy mirror-set of fermions F', the two sets F and F' being coupled with opposite chiral projections to the same set of gauge bosons. The gauge lagrangian, thus generated is invariant under the mirror-symmetry transformation $(F_L \leftrightarrow F'_R$ and $F_R \leftrightarrow F'_L)$. Normal low-lying baryons and mesons are still to be considered primarily as composites of the lighter F-type-quarks (and antiquarks).

There are several experimental consequences of our unification hypothesis combining colour, charm and mirror. In this talk, we discuss[10]:

(a) an interpretation of the J/ψ-particles in terms of the new quantum numbers in our scheme (colour, charm and mirror),

(b) an explanation of the $\bar{\nu}$-y-distribution-anomaly[11] through a mirror helicity-flip-coupling,

(c) some recent calculations[12] on decay-rates and selection-rules for decays of integer-charge coloured-quarks (within the quark-lepton-unification hypothesis) with the hope that these might be helpful in discovering the fundamental constituents - the quarks, and finally,

(d) the suggestion that quarks and leptons, themselves, are made out of pre-quarks and pre-bosons.

2. THE BASIC MODEL; A BRIEF REVIEW

To set the notations, we first present briefly the main features of the basic model built upon a sixteen-fold of four-component fermions $F_{L,R}$:

$$F_{L,R} = \begin{bmatrix} p_a & p_b & p_c & p_d = \nu_e \\ n_a & n_b & n_c & n_d = e^- \\ \lambda_a & \lambda_b & \lambda_c & \lambda_d = \mu^- \\ \chi_a & \chi_b & \chi_c & \chi_d = \nu_\mu \\ \text{red} & \text{yellow} & \text{blue} & \text{lilac} \end{bmatrix}_{L,R} \qquad (1)$$

Here χ denotes charm. Note the necessity of colour and charm for putting baryonic and leptonic matter together. All "low-energy" phenomena may be described by gauging a minimal non-abelian local symmetry:

$$\mathcal{G} = SU(2)_L \times SU(2)_R \times SU(4)'_{L+R} \quad . \qquad (2)$$

where $SU(2)_{L,R}$ gauges valency-indices $\{(p\ ,\ n) + (\chi\ ,\ \lambda)\}_{L,R}$, while $SU(4)'$ gauges the four colours (red, yellow, blue and lilac = lepton number). This is the minimal symmetry capable of uniting baryons and leptons and providing a unified description of weak, electromagnetic and strong interactions. In addition, it is anomaly-free. The gauge fields[13] of the theory $W_{L,R}$ and V generated by $SU(2)_{L,R}$ and $SU(4)'$, respectively are:

$$W_{L,R} = 1/2 \begin{bmatrix} \tau . W & 0 \\ 0 & \tau_1(\tau . W)\tau_1 \end{bmatrix}_{L,R} \qquad V = \left[\begin{array}{ccc|c} V_{11} & V_\rho^- & V_{K^*}^- & \chi^0 \\ V_\rho^+ & V_{22} & V_{K^*}^0 & \chi^- \\ V_{K^*}^+ & V_{K^*}^0 & V_{33} & \chi'^- \\ \hline \chi^0 & \chi^- & \chi'^- & \sqrt{3}/4S^0 \end{array}\right] \qquad (3)$$

The associated coupling parameters[14] are:

$$g_L \simeq g_R \sim e \ ; \quad e^2/4\pi = \frac{1}{137} \ ; \quad \frac{f^2}{4\pi} = 1 \sim 10 \qquad (4)$$

The required masses for the gauge particles[5,6] are:

$$\begin{aligned} m(V(8)) &\simeq 3 \sim 5 \text{ GeV} \\ m(W_L) &\approx 100 \text{ GeV} \\ m(W_R) &\gtrsim 300 \text{ GeV} \\ m(S^0) &\gtrsim 1000 \text{ GeV} \\ m(X) &\gtrsim 10^5 \text{ GeV} \end{aligned} \qquad (5)$$

Here $V(8)$ denotes the colour-octet of gauge particles (gluons) coupled to red, yellow and blue colours only (these appear in the top-left 3×3-block of V). They, being "light", generate the effective strong-interactions between qq and $q\bar{q}$-pairs.

The scheme described above leads to two (notable) possibilities for quark-charges, with a unique prediction for the lepton-charges (0 , -1 , -1 , 0):

Baryon-lepton-symmetric integer charge quark model, or Baryon-lepton-asymmetric fractionally-charged quark-model

$$[Q_F] = \begin{bmatrix} 0 & +1 & +1 & 0 \\ -1 & 0 & 0 & -1 \\ -1 & 0 & 0 & -1 \\ 0 & +1 & +1 & 0 \end{bmatrix} \ , \text{ or } \begin{bmatrix} 2/3 & 2/3 & 2/3 & 0 \\ -1/3 & -1/3 & -1/3 & -1 \\ -1/3 & -1/3 & -1/3 & -1 \\ 2/3 & 2/3 & 2/3 & 0 \end{bmatrix} \qquad (6)$$

The electric-charge-formulae (in terms of generators of $SU(4) \times SU(4)'$) for the two cases are:

$$\begin{aligned} Q &= (F_3 + F_8/3 - \sqrt{2/3}\,F_{15}) + (F'_3 + F'_8/3 - \sqrt{2/3}\,F'_{15}) \quad \text{(Integer charge quarks)} \\ &= (F_3 + F_8/3 - \sqrt{2/3}\,F_{15}) - \sqrt{2/3}\,F'_{15} \quad \text{(Fractionally charged quarks)} \end{aligned} \qquad (7)$$

For the integer-charge quarks, photon "sees" quark-colours, thus photon-hadron collisions can produce colour above appropriate threshold. However, below threshold for colour-production, (assuming all low-lying hadrons are colour-singlets), only the colour-singlet part of electromagnetic-current is operative and thus for all dynamical purposes (such as parton-model-calculations), even integer-charge quarks would act just as though they carried fractional charges. These remarks apply to electro-production and to electron-positron-annihilation.

3. EXTENDED LOCAL SYMMETRIES; THE MIRROR FERMIONS

The group $\mathcal{G} = SU(2)_L \times SU(2)_R \times SU(4)'_{L+R}$ is anomaly-free. It requires two basic coupling constants g and f . If one wishes to carry the unification to a stage where the gauge-lagrangian would involve only one basic coupling constant, it would be necessary to embed $\mathcal{G}$ within higher unifying symmetries. (Examples of such higher symmetries[8] are: either the maximal symmetry $SU(32)$ permissible by the kinetic energy term of the sixteen four-component fermions, or any of its natural[7] subgroups such as $SU(16)_L \times SU(16)_R$ or $SU(4)_L \times SU(4)_R \times SU(4)'_L \times SU(4)'_R$.) All such extensions, however, would possess anomalies and thus conflict with renormalizability, unless the basic set of fermions F is accompanied by a mirror set F' , the two sets F and F' being coupled with opposite chiral projections to the same set of gauge bosons. Thus the hypothesis of either a maximal gauging (upto mirror-symmetry) and (or) one unifying coupling parameter suggests that there ought to exist the mirror.

The two sets F and F' may be displayed by the 4 x 4-arrays

$$F_{L,R} = \begin{bmatrix} p_a & p_b & p_c & p_d = \nu_e \\ n_a & n_b & n_c & n_d = e^- \\ \lambda_a & \lambda_b & \lambda_c & \lambda_d = \mu^- \\ \chi_a & \chi_- & \chi_c & \chi_d = \nu_\mu \end{bmatrix}_{L,R} \quad ; \quad F'_{L,R} = \begin{bmatrix} p'_a & p'_b & p'_c & p'_d = E^0 \\ n'_a & n'_b & n'_c & n'_d = E^- \\ \lambda'_a & \lambda'_b & \lambda'_c & \lambda'_d = M^- \\ \chi'_a & \chi'_b & \chi'_c & \chi'_d = M_0 \end{bmatrix}_{L,R} \qquad (8)$$

Here χ denotes charm, p' is mirror to p and E^Q and M^Q are heavy leptons.

Assume the local symmetry $\mathcal{G} = SU(4)_L \times SU(4)_R \times SU(4)'_L \times SU(4)'_R$; this permits left$\leftrightarrow$right as well as valency colour discrete symmetries in addition to the mirror-symmetry $F_{L,R} \leftrightarrow F'_{R,L}$ $(F'_R \sim F_L = (4 , 1 , \bar{4} , 1)$; $F'_L \sim F_R = (1 , 4 , 1 , \bar{4}))$. The anomaly-free "strong" gauge lagrnagian generated by $SU(4)'_L \times SU(4)'_R$ is:

$$\mathcal{L}_S = \frac{f}{2} [\vec{V_1} \cdot (\bar{F}_L \vec{\lambda}_c \gamma_\mu F_L + \bar{F}'_R \vec{\lambda}_c \gamma_\mu F'_R) + \vec{V_2} \cdot (\bar{F}_R \vec{\lambda}_c \gamma_\mu F_R + \bar{F}'_L \vec{\lambda}_c \gamma_\mu F'_R)] . \qquad (9)$$

Here λ_c's act on the colour indices (a , b , c , d). Spontaneous symmetry breaking can be arranged[6,8] such that the two octets of vector and axial-vector gauge eigenstates $(V_1(\underset{\sim}{8}) + V_2(\underset{\sim}{8}))$ pertaining to $SU(3)'_L \times SU(3)'_R$ are relatively light ($\approx$ 3 to 10 GeV), while the remaining $(X_V , X_A , S^0_V$ and $S^0_A)$, like the $(X$ and $S^0)$ of the basic model, remain heavy. The $SU(3)'$ colour-octet of gauge bosons $(V_1(8) + V_2(8))$ being light, generate effective strong interactions between qq and $q\bar{q}$-pairs. The important feature of this theory (with both F and F') is theinvariance of the effective strong lagrangian for the larger global symmetry $U(8)_L \times U(8)_R \times SU(3)'$, where $U(8)_{L,R}$ act over the space of <u>eight valency indices</u> $[(p , n , \lambda , \chi) + (p', n' , \lambda' , \chi')]_{L,R}$.

This global $U(8)_L \times U(8)_R$ symmetry is broken by quark mass terms and, of course, also by the weak and electromagnetic interactions. There are a number of alternative intermediate symmetries through which such a bigger symmetry might be broken. One attractive possibility is that only one multiplet (say F') receives a mass in the zeroth order (of some appropriate coupling), and the members of other multiplet (say F) receive their mass through radiative (or tree-graph)-corrections to the masses of the first. (The masses of the two-multiplets might be related by a natural symmetry.) The global $U(8)_L \times U(8)_R$ would break in this case via the chain:

$$U(8)_L \times U(8)_R \quad SU(4)_F \times SU(4)'_F \times U(1)_F \times U(1)'_F \qquad (10)$$

The two $SU(4)$'s would break down to $SU(3)$'s and $SU(2)$'s also by the quark-mass terms; the eight quantum numbers, which are $(I_3 , Y , C , I'_3 , Y' , C')$ and the two individual fermion numbers $U(1)_F$ and $U(1)'_F$, would be violated, in general, by weak interactions due to Cabibbo-like $(n-\lambda)$-mixings and $F-F'$-mixing. Only the sum $U(1)_F + U(1)'_F$ = fermion-number would still be conserved.

If the mass splittings between (p' , n' , λ') are relatively small, the mirror global symmetries $SU(2)_M$, $SU(3)_M$ would be good symmetries of hadrons <u>in addition to</u> the familiar $SU(2)$ and $SU(3)$. There is, however, no reason why some members of F' (e.g. p' and n') could not be lighter than the charmed quark χ . We allow such possibilities in the interpretation of J/ψ .

The charges of F and F' multiplets as much as the excitations of different quantum numbers (colour, charm and mirror) are important in determining the R-parameter for electron-positron-annihilation. Note that the charges of these two multiplets must be identical (<u>either both integral or both fractional</u>, as exhibited in Eq(6)). This is because electric charge is a sum of (left + right)-generators and because there is the mirror symmetry $F_{L,R} \leftrightarrow F'_{R,L}$ in the theory. Some typical values for R (based upon the simple formula $R = \sum_{\text{quarks}} Q_i^2$) for different possible excitations of the valency and colour-quantum numbers are noted below:

$R = \dfrac{\sigma(e^-e^+ \to \text{hadrons})}{\sigma(e^-e^+ \quad \mu^-\mu^+)}$	<u>Excitations</u>
$= 10/3$	(If only (p,n,λ,χ) are excited without excitations of colour and mirror)
$= 5\ 1/3$	(If charm and mirror (partly) are excited involving $(p,n,\lambda,p',n',\lambda',\chi)$ - but no colour)
$= 6$	(If colour and charm are excited but no mirror corresponds to excitations of all F quarks with quarks carrying integer charges, see added note)
$= 6\ 2/3$	(If all eight valencies are excited, but not colour).

Cases where colour is not excited allow two possible interpretations: either,

i) quarks carry integer charges, but the available energy is below threshold for colour-production, or

ii) quarks carry fractional charges, so that photon is devoid of colour.

4. <u>J/ψ PARTICLES</u>

It is natural to consider that the J/ψ -particles may reflect at least some of the new quantum numbers (i.e. colour, charm and mirror) arising in our scheme. The presently attained value of $R = 5.9 \pm .9$ at $E_{CM} = 7.4$ GeV and (possibly also) the lack of increase of K/π - ratio in e^+e^- - annihilation appear to exclude the hypothesis that the three J/ψ -particles (which we shall call $\psi_1(3.1)$, $\psi_2(3.7)$ and $\psi_3(4.1)$ are all charm-anticharm $\bar{\chi}\chi$ - composites. Depending on relative masses of χ, p', n', λ' and χ' and of colour-octet states, a number of possibilities arise. Note, however, that the two lowest states (ψ_1 and ψ_2) must both be assigned either to colour, or to mirror, or to charm. (This is because $\psi_2 \to \psi_1 + \pi + \pi$.) A few typical possibilities are:

Model I

ψ_1 and ψ_2 are colour, ψ_3 may be charm-anticharm or mirror-antimirror:

$$\begin{aligned} &\psi_1(3.1) = \text{colour-gluon } U \\ &\psi_2(3.7) = (q\bar{q})\text{-colour-octet composite } C_U \\ &\psi_3(4.1) = \chi\bar{\chi}\text{-composite } \phi_c \quad (\text{or mirror-antimirror-composite}) \end{aligned} \tag{11}$$

The existence of the gauge particle U as well as the composite C_U is analogous to the existence of the gauge-photon as well as composite $^3S_1$-positronium. With this assignment, the extreme narrowness of ψ_1 and ψ_2 can be attributed[15] to the fact that (a) their strong decays to normal hadrons is forbidden by colour-symmetry, (b) their radiative decays ($U \to$ hadrons + γ) are damped relative to ($\rho \to \pi^0 + \gamma$) , since (dispersively) only high-mass colour-octet intermediate states ($m^2_{col} \gtrsim 10$ (GeV)^2) contribute to the former to be compared with low mass contributions ($m^2_{val} \sim m^2_\omega$) for the latter. The characteristic features for colour-assignment to ψ_1 and ψ_2 may be summarized below:

(i) $$\frac{\sum_{\text{hadrons}} \Gamma(\psi_1 \to \text{hadrons} + \gamma)}{\Gamma(\psi_1 \to \text{All})} \approx (20 \sim 60)\%$$

(ii)
$$\begin{aligned} &\psi_1 \not\to \pi^0\gamma \quad , \ (\text{forbidden}) \\ &\psi_1 \not\to (\text{odd number of pions} + \gamma) \quad (\text{forbidden}) \\ &\psi_1 \not\to \eta + \gamma \quad (\text{suppressed by } SU(3)) \\ &\psi_1 \to \eta' + \gamma \quad (\text{allowed; } \Gamma(\psi_1 \to \eta' + \gamma) \approx 5 \text{ to } 10 \text{ KeV}) \\ &\psi_1 \to (\text{even number of pions}) + \gamma \quad (\text{allowed}) \end{aligned} \tag{12}$$

In the presence of non-electromagnetic colour-symmetric breaking term (which arises within the gauge theory approach through radiatively corrected Higgs-scalar-potential and quark-mass terms), G -parity conserving hadronic decays (i.e. $\psi_1 \to$ odd number of pions) can dominate over G -parity-violating ($\psi_1 \to$ even number of pions)-decays, which appears to be the case experimentally. The remarks about selection-rules and radiative decays of ψ_1 of course, also applies to radiative decays of ψ_2 . All the features listed above (Eq.(12)) appear to be consistent with the presently available data. It is crucial to search for radiative decays of ψ_1 and ψ_2 , in general, and for mono-energetic γ-rays appropriate to the ($\eta' + \gamma$)-mode in order to test whether ψ_1 and ψ_2 are associated with colour.

The assignment that the relatively broad structure $\psi_3(4.1)$ represents charm-anticharm $\chi\bar{\chi}$ (or alternatively mirror-antimirror $p'\bar{p}'$) has the merit that its large partial width (≈ 250 MeV) might be accounted for by assuming that its decay into normal hadrons is suppressed by the normal Zweig factor ($\approx 1/100$) appropriate to $\phi \to \rho + \pi$ -decay.

Also, in this case (with ϕ_c lying at 4.1 GeV), the charm-composites $D = (\bar{p}\chi$ and $\bar{n}\chi)$ and $F(= \bar{\lambda}\chi)$ could be relatively massive $\gtrsim 3.2$ GeV and thus not produced at SPEAR until E_{CM} exceeds 6.4 GeV. This could be one possible explanation of lack of increase of K/π-ratio below 6.4 GeV.

Model II

ψ_1 and ψ_2 are mirror-antimirror composites[16] involving two-mirror components (p' and n'); ψ_3 is either the colour gluon U^0 or charm-anticharm composite ϕ_c (or a superposition of the two): in particular, assign

$$\begin{aligned} &\psi_1(3.1) = \frac{\bar{p}'p' - \bar{n}'n'}{\sqrt{2}} \equiv \rho^0_M \ (I_m = 1) \\ &\psi_2(3.7) = \text{radial excitation of } \rho^0_M \\ &\psi_3(4.1) = \ \text{either, charm-anticharm composite } \phi_c = \bar{\chi}\chi \ , \\ &\qquad\qquad \text{or, colour gluon } U^0 \ , \\ &\qquad\qquad \text{or, superposition of a broad } \phi_c \text{ and a narrow colour-gluon } U^0 \ . \end{aligned}$$

The above assignment has the merit that the extreme narrowness of ψ_1 might be attributed to two sources (i) violation[17] of mirror iso-spin I_m in the decays of $\psi_1 = \rho^0_M$ (with $I_m = 0$) . Such violation might be of order α , and (ii) a normal Zweig-rule suppression (1/100). With this assignment, a mirror ω ($\omega_M = (\bar{p}'p' + \bar{n}'n')/\sqrt{2}$) nearly degenerate with ρ^0_M would be expected to exist with a production cross-section (in e^-e^+ -annihilation) a factor 9 lower than for ρ^0_M (analogous to ω : ρ-situation). However, its width-suppressed only through the normal Zweig rule (but not through electromagnetism) would be considerably larger than that of ρ^0_M , making it harder to detect.

The assignment of ψ_3 to $\bar{\chi}\chi = \phi_c$ is as in Model I. On the other hand, if $\psi_3(4.1)$ represents primarily the colour-gluon U^0, one must attribute the large width (≈ 250 MeV) to allowed strong decays ($\psi_3(4.1) = U^0 \to \pi(\text{colour}) + \text{pions}$).

Quite clearly there are alternative possibilities (most notably, the lower ones ψ_1 and ψ_2 could be charm-anticharm-composites ϕ_c and ϕ_c' . All such possibilities, including the ones listed above would receive their decisive tests in the discovery (or non appearance) of associated composites carrying the new quantum numbers. Such particles can be produced in pairs in e^-e^+-annihilation and in (pp)-collisions. The charged colour-gluons ($V^\pm_\rho$, $V^\pm_{K*}$) which should be nearly degenerate in mass with their neutral partners (like U^0) can be distinguished from the charmed (D , F) or mirrored particles most notably by their decay modes. The charged colour gluons (if they are the lightest colour-octet states) can ceday only weakly (due to mixing[5,15] between $V^\pm_\rho$ and $W^\pm$). Hence, the allowed decay modes are:

$$\begin{aligned} V^+_\rho &\to \mu^+ + \nu_\mu \\ &\to \pi^+\pi^0 \ , \ 3\pi \ , \ K\bar{K} \quad \text{etc.} \\ &\to \pi\pi\mu\nu \ , \ K\bar{K}\mu\nu \quad (\text{with hadrons in } I = 0 \ , \ SU(3)\text{-singlet state}) \end{aligned}$$

The leptonic mode of colour-gluon decays should compete favourably with the hadronic modes. While this is not apriori expected for the D and F, the important feature is that D and F can decay semileptonically with <u>only one kaon or one η</u> (i.e. $D^0 \to K^- \mu^+ \nu_\mu$, something not permissible for the colour-gluons.

Besides the well known F and D states, <u>full</u> mirror excitation would require the existence of thirty two mixed $(\bar{q}q')$ and $(\bar{q}'q)$-composite states (with spins 0, 1). Examples of these are

$$\bar{p}p' ,\ \bar{n}p' ,\ \bar{\lambda}p' = G^0 ,\ G^+ ,\ H^+$$

$$\bar{p}n' ,\ \bar{n}n' ,\ \bar{\lambda}n' = N^- ,\ N^0 ,\ P^0$$

Note that the decays of the lowest-lying <u>mixed</u> composites arise through weak interactions which violate all valency quantum numbers conserving only fermion number = $U(1)_F + U(1)'_F$.

5. FERMI MASS MATRIX, THE WEAK GAUGES

Now we exhibit certain new complexions in the weak gauge interactions, which arise due to the presence of both F and F'. For this purpose, assume a smaller local symmetry [18] $\mathcal{G}_0 = SU(2)_1 \times SU(2)_2 \times SU(4)'_L \times SU(4)'_R$ with $F'_R \sim F_L = (2+2, 1, \bar{4}, 1)$ and $F'_L \sim F_R = (1, 2+2, 1, \bar{4})$. Splitting $F_{L,R}$ and $F'_{L,R}$ into valency doublets, i.e. $F_{1L,R} = \begin{pmatrix} p \\ n \end{pmatrix}_{L,R}$ and $F_{2L,R} = \begin{pmatrix} \chi \\ \lambda \end{pmatrix}_{L,R}$, the Fermi mass term would take the form:

$$\mathcal{L}_{mass} = \sum_{i,j=1}^{2} \left[a_{ij}\, \bar{F}_{iL} \langle\phi\rangle F_{jR} + b_{ij}\, \bar{F}'_{iL} \langle\phi\rangle F'_{jR} + \epsilon_{ij}\, \bar{F}_{iL} F'_{jR} + \epsilon'_{ij}\, \bar{F}'_{iL} F_{jR} + H.C. \right] \tag{13}$$

Here $\langle\phi\rangle$'s are vacuum expectation values of appropriate Higgs-Kibble fields and a_{ij}, b_{ij}, ϵ_{ij}, ϵ'_{ij} are constant parameters [19]. Note that $\langle\phi\rangle$ can induce familiar Cabibbo mixings between (n_L, λ_L), (n_R, λ_R) etc., while ϵ, ϵ' terms give rise to F-F' mixing. (Note $\epsilon \neq \epsilon'$ would induce P and CP violating mass terms.) In the presence of both types of mixing, the $SU(2)_1 \times SU(2)_2$ weak gauge interactions, expressed in terms of the <u>diagonal</u> Fermi fields [20], in general take the form (suppressing a,b,c colour indices):

$$\mathcal{L}_W = \frac{g}{2} \sum_{i=1}^{2} \left[\bar{F}_{iL}(\Theta)\, \vec{\tau}\, F_{iL}(\Theta) + \bar{F}'_{iR}(\Theta)\, \vec{\tau}\, F'_{iR}(\Theta) \right] \cdot \vec{W}_1 + (\text{Leptonic Terms}) + (L \leftrightarrow R,\ W_1 \to W_2) \tag{14}$$

where $F_{iL,R}(\Theta)$ and $F'_{iL,R}(\Theta)$ are the rotated doublets, in general involving familiar Cabibbo angles $(\theta_{L,R})$ and eight angles $(\phi, \xi, \delta, \eta)_{L,R}$ specific to F-F' mixing between $(p, p')_{L,R}$ $(n_c, n'_c)_{L,R}$ .... We shall refer to these as "<u>skewness</u>" angles. (For example,

after diagonalization, $p \to p \cos\phi + p' \sin\phi$ and $p' \to -p \sin\phi + p' \cos\phi$, etc., c denotes Cabibbo rotated fields.) F-F' mixing can give rise to several intriguing possibilities. We list below three among them, two of which have the property that they provide a simple explanation of the ν-$\bar{\nu}$-y distribution anomaly (for simplicity, all left skewness angles are set equal to zero).

<u>Model I</u>: (All skewness angles are small) $\lesssim$ Cabibbo angle. In the limit of all skewness angles $\to 0$, we recover the "normal" theory with no special effect appearing due to the presence of mirror. Of course the skewness angles should not all be identically zero, otherwise $\bar{F}F'$ composites would be stable.

<u>Model II</u>: Allow skewness angles ϕ_R and η_R to be nearly maximal [21] (i.e. $p_R \leftrightarrow p'_R$ and $\chi_R \leftrightarrow \chi'_R$), the $\vec{W}_1$ and $\vec{W}_2$ gauge boson couplings are:

$$\vec{W}_1 \cdot \left[\begin{pmatrix} p \\ n_c \end{pmatrix}_L + \begin{pmatrix} \chi \\ \lambda_c \end{pmatrix}_L + \begin{pmatrix} p \\ n'_c \end{pmatrix}_R + \begin{pmatrix} \chi \\ \lambda'_c \end{pmatrix}_R \right] + \vec{W}_2 \cdot \left[\begin{pmatrix} p' \\ n_c \end{pmatrix}_R + \begin{pmatrix} \chi' \\ \lambda_c \end{pmatrix}_R + \begin{pmatrix} p' \\ n'_c \end{pmatrix}_L + \begin{pmatrix} \chi' \\ \lambda'_c \end{pmatrix}_L \right] \tag{15}$$

In addition to the familiar weak interactions generated by the lighter W_1 mesons, the following new features arise:

a) Above threshold for production of heavy mesonic $n'\bar{p}$, $n'\bar{n}$ and baryonic $(n'qq)$ composites (relevant for x small), the right current $\bar{n}'\gamma_\mu(1 + i\gamma_5)p$ coupled to W_1^- gives rise to a <u>y-independent</u> term to antineutrino scattering cross-section $d^2\sigma(\bar{\nu} + N \to \mu^+ + X)/dx\,dy$ within a parton model context, without making an analogous contribution to neutrino scattering. This, <u>together</u> with the contribution from the familiar V-A current $\bar{p}\gamma_\mu(1 - i\gamma_5)n$ (which leads to distributions proportional to $f(x)$ and $f(x)\,(1-y)^2$ for ν and $\bar{\nu}$, respectively), gives a simple explanation of the observed anomaly [11] in $(\nu, \bar{\nu})$ charged current scattering processes. These show that for small $x < 0.1$, both ν and $\bar{\nu}$ distributions are nearly independent of y, contrary to the expectations from the simple (V-A) theory.

b) The neutral weak boson Z^0 in the present theory is coupled to the following hadronic current in the (p,n) space: $J_\mu^{Z^0}(p,n) = -(1/2)\,(\bar{p}\gamma_\mu p - \bar{n}\gamma_\mu\gamma_5 n)$. This violates parity and has vector $I = 0, 1$ and axial $I = 0, 1$ pieces.

c) If χ is heavier than mirror λ', D and F particles could decay into $(\lambda'\bar{p})$ and $(\lambda'\bar{\lambda})$ composites plus pions (in addition to the familiar $(K\pi)$ and $K\bar{K}$) decays).

<u>Model III</u>: An alternative model for weak interactions, which could arise from Eq.(5), is:

$$\vec{W}_1 \cdot \left[\begin{pmatrix} p \\ n_c \end{pmatrix}_L + \begin{pmatrix} \chi \\ \lambda_c \end{pmatrix}_L + \begin{pmatrix} p \\ n'_c \end{pmatrix}_R + \begin{pmatrix} \chi \\ n \end{pmatrix}_R \right] + \vec{W}_2 \cdot \left[\begin{pmatrix} p' \\ \lambda \end{pmatrix}_R + \begin{pmatrix} \chi' \\ \lambda'_c \end{pmatrix}_R + \begin{pmatrix} p' \\ n'_c \end{pmatrix}_L + \begin{pmatrix} \chi' \\ \lambda'_c \end{pmatrix}_L \right] \tag{16}$$

Besides explaining $\nu,\bar{\nu}$ anomaly (see above), this complexion for weak currents provides a new term for the effective $|\Delta S| = 1$ non-leptonic interaction [22]
$G_F \cos\theta_L (\bar{n}\gamma_\mu(1 + i\gamma_5)\chi)(\bar{\chi}\gamma_\mu(1 - i\gamma_5)\lambda)$ in addition to the familiar term
$G_F \cos\theta_L \sin\theta_L (\bar{n}\gamma_\mu(1 - i\gamma_5)p)(\bar{p}\gamma_\mu(1 - i\gamma_5)\lambda)$. This term is pure $\Delta I = 1/2$ and is not suppressed [23] by Cabibbo factor $\sin\theta_L$.

Note that the neutral current[24] coupled to Z^0 in this model is pure $I = 1$ vector $(\bar{p}\gamma_\mu p - \bar{n}\gamma_\mu n)$.

A choice between Models I and II, on the one hand, and Model III, on the other, can be made by examining the decay modes of charmed D and F particles. Model III (but not Models I and II) permits their decay into pions at rates comparable to $K\pi$ or $K\bar{K}$ decays.

We stress that, depending upon the Fermi-mass-matrix, there would be other possible variations [25] of these models arising within the general mirror-gauging pattern (Eq.(14)).

SPONTANEOUS VIOLATIONS OF BARYON AND LEPTON NUMBERS; THE CASE OF THE MISSING QUARK

One of the intriguing possibilities, which arises within the quark-lepton unification hypothesis is that baryon and lepton numbers (B and L), though conserved by the basic Lagrangian, are likely to be violated by spontaneous symmetry breaking, which provides masses to the gauge particles. This, in turn, would have the important implication that if quarks are integer charged, they would decay, for example, into (lepton + pions) with relatively short lifetimes and thus would have been missed in the familiar quark searches, even though they were not so heavy ($m_q \approx 2$ to 3 GeV) and were produced with relatively large cross-section ($\approx 10^{-31} \sim 10^{-32}$ cm^2). This would provide a simple resolution of the missing quark puzzle without the hypothesis of quark confinement. This possibility arises only provided quarks are integer-charged.

The proton being a three quark composite $(B = F = 3)$, can decay into (lepton + pions) only in the third order of quark → lepton-effective decay interaction, assuming quarks and diquarks are heavier than the proton. Thus quarks could be relatively short lived ($\tau < 10^{-10}$ secs.) and yet proton extraordinarily long lived ($\tau_{proton} \approx 10^{27}$ to 10^{32} years), consistent with the known experimental lower limit on $\tau_{proton} = 2 \times 10^{30}$ years.

This suggestion of baryon and lepton-number non-conservation and the consequent quark and proton instability has been made earlier [6]. Below we give a summary of some recent estimates [12] of quark and proton decays and certain selection rules for quark decays, as they arise within the basic gauge model.

Within our scheme, such a violation of B and L arises naturally as follows. Prior to spontaneous symmetry breaking, the basic gauge model presented in Sec.2, conserves baryon-number (B), lepton-number (L) and, of course, their sum-fermion-number $F = B + L$. Spontaneous symmetry breaking induces a mixing between valency W $(B = L = 0)$ and X $(B = -L = \pm 1)$ gauge mesons; this leads to the basic transition (Fig.1)

$$\text{quark} \rightarrow \text{lepton} \tag{17}$$

which satisfies

$$\Delta B = -\Delta L = -1 \; , \; \Delta F = 0 \; . \tag{18}$$

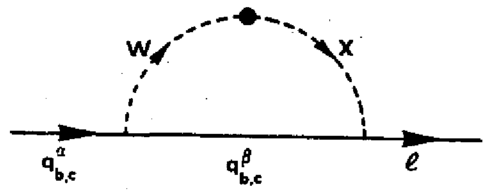

Fig.1 (quark → lepton)

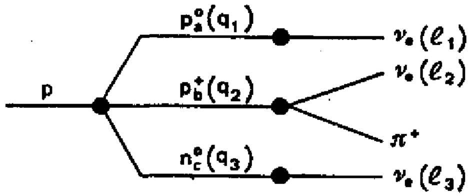

Fig.2 (proton-decay)

The strength of $q \rightarrow \ell$ transition (characterized primarily by Fig. 1) is given by the effective Hamiltonian

$$\mathcal{H}_{eff}(q \rightarrow \ell) = (\Delta) m_q \, \bar{\ell}(1 + \gamma_5) q \; , \tag{19}$$

where

$$\Delta \approx \frac{1}{8\pi^2}\left(\frac{f g \, m_V m_{W_L}}{m_X^2}\right) \log\left(m_X^2 / m_{W_L}^2\right) \tag{20}$$

$$\Delta \leq \Delta_{max} = 4 \times 10^{-9} \text{ (basic model)} \tag{21}$$

A summary of results:

Yellow and blue quark decays satisfy the selection rules: Either $\Delta S = \Delta C = 0$ with $\Delta I_3 = +1$; or $\Delta S = -\Delta C = +1$ with $\Delta I_3 = 0$. The red quark decays, on the other hand (for the case $m_q < m_V \approx 3$ to 5 GeV), conserve I_3 , strangeness and charm separately. These selection rules are based on the structure of the dominant decay mechanism (see Fig.1) for yellow and blue quarks, and on the analogous structure (involving double mixing $V_\rho \rightarrow W \rightarrow X$) for the decay of red quarks. For these purposes leptons carry I_3 , Y and C as denoted by the symbols in Eq.(1). Some allowed transitions are:

Yellow and blue quark decays	Red quark decays
$p^+_{b,c} \rightarrow \nu_e \pi^+$	$p^0_a \rightarrow \nu_e \pi^0$, $e^- \pi^+$
$\rightarrow e^- \pi^+ \pi^+$	$n^-_a \rightarrow \nu_e \pi^-$, $e^- \pi^0$
$\rightarrow \nu_\mu + K^+$	$\lambda^-_a \rightarrow \nu_e K^-$, $e^- \bar{K}^0$, $\mu^- \eta$
$n^0_{b,c} \rightarrow \nu_e \pi^0$, $\nu_\mu K^0$	$\chi^0_a \rightarrow \nu_e D^0$, $e^- D^+$
$\lambda^0_{b,c} \rightarrow e^- \pi^+ \bar{K}^0$, $\mu^- F^+$	

while some of the forbidden transitions are: $p^{+}_{b,c} \nrightarrow \nu_\mu \pi^{+}$ & $p^{+}_{b,c} \to \mu^- \pi^+ \pi^+$, $\lambda^0_{b,c} \nrightarrow \mu^- K^+$ etc.
The decay rates for (yellow, blue) and red quarks are:

$$\left.\begin{aligned} \Gamma(q_{b,c} \to \ell + \pi) &\approx \left(\frac{g^2_{NN\pi}}{4\pi}\right)\left(\frac{m_q}{m_N}\right)^3 \Delta^2 \left(\frac{m_N}{2}\right) \\ \sum_n \Gamma(q_{b,c} \to \ell + n \text{ mesons}) &\approx (10 \sim 100)\, \Gamma(q_{b,c} \to \ell + \pi) \end{aligned}\right\} \text{Yellow and Blue Quarks}$$

$$\Gamma(q_{red} \to \ell + \pi) \approx \left(\frac{m_V}{m_{W_L}}\right)^2 \Gamma_{\text{Yellow, Blue}} \quad (m_{q_{red}} < m_V)$$

$$\Gamma(q_{red} \to V + \ell) \approx \left(\frac{f^2}{g^2_{NN\pi}}\right)\left[3\, \frac{(m_q - m_V)}{m_q}\right] \Gamma_{\text{Yellow, blue}} \quad (m_{q_{red}} > m_V)$$

$$\Gamma(\text{Proton} \to 3\nu + \pi^+) \approx \left[(t_p \Delta^3 \epsilon)\, \frac{g_{NN\pi}}{m_N}\right]^2 \left(m_p^7/(2\pi)^5\, (768) \times 60\right)$$

$$\epsilon \approx (m_V/m_{W_L})^2 \tag{22}$$

In the above we use PCAC value $g_{qq\pi} \approx (m_q/m_N) g_{NN\pi}$. *The constant* (t_p/m_V^2) *denotes the* dissociation strength for proton → 3 quarks. We expect $t_p \approx 1$. Substituting $\Delta \approx \Delta_{max}$ for numerical estimates we obtain the following values for lifetimes:

$$\tau(q_{\text{yellow, blue}}) \approx (10^{-11} \sim 10^{-12} \text{ sec.}) \quad (m_q \approx 3 \text{ GeV})$$

$$\tau(q_{red}) \approx (2.5)(10^{-6} \text{ to } 10^{-7} \text{ sec}) \quad (m_q \approx 3 \text{ GeV} < m_V)$$

$$\tau(q_{red}) \approx 10^{-10} \text{ sec.} \quad (m_q \approx 3 \text{ to } 4 \text{ GeV} > m_V)$$

$$\tau(\text{proton}) \approx t_p^{-2}\, (10^{32} \text{ Years}) \tag{23}$$

Our conclusion, thus, is that if the resolution of the missing quark puzzle is to be attributed to short lifetimes of quarks ($\tau < 10^{-10}$ secs.) with quarks being not excessively massive ($m_q < 5$ GeV), proton cannot live much longer than 10^{32} years. We urge experimental tests of these ideas a) through search for integer-charge quarks decaying into (lepton + pions) ((lepton + pions)-mass correlation studies in production experiments would be of major interest) and b) through improvement on the measurement of proton lifetime.

More detailed discussions of these considerations may be found in Ref.12.

One important question is: are the prompt leptons produced in pp collisions due to $(q\bar{q})$ pair production, followed by decays of quarks to (leptons + pions)?

7. QUARKS AND LEPTONS MADE OUT OF "PRES" (THE PRE-FERMIONS AND THE PRE-BOSONS)

There appears to be a necessity for a basic sixteen-fold of four-component fermions $F_{L,R}$ and in many ways also for the mirror set $F'_{L,R}$. Together, they comprise 32 "basic" particles. This would appear to be an excessive number of fundamental entities until one realizes that nature does not manifest 32 "attributes". Without the mirror, the attributes needed are only eight:

$$\begin{aligned} 8 = {} & 4 \text{ valencies } (p,n,\lambda,\chi) \ (= f^i) \\ & + 4 \text{ colours } (a,b,c,d) \ (= \xi_\alpha) \end{aligned} \tag{24}$$

In many ways, therefore, it is attractive to postulate, as was suggested [26] in Ref.6, that the fundamental entities are not truly quarks and leptons, but the four fermions f^i signifying valency and the four bosons ξ_α (spin 0 or 1) signifying colour. We call them therefore, the "pre-fermions" and the "pre-bosons", respectively.[27] There exists (presumably "medium-strong") force between f^i and ξ_α to produce composites $(f^i \xi_\alpha)$, which are the sixteen fermions F^i_α (= 12 quarks + 4 leptons):

$$F^i = (f^i) \times (\xi_\alpha) \tag{25}$$

$$= \underset{\text{Spin } \frac{1}{2}}{\begin{pmatrix} p \\ n \\ \lambda \\ \chi \end{pmatrix}} \times \underset{(\text{spin-}0)}{(a, b, c, d)} \tag{26}$$

The basic strong (or super-strong) interaction is generated by the SU(4)' symmetry of the 4-colour bosons (ξ_α), while the basic weak interaction is generated by the chiral SU(4) symmetry of the 4-valency fermions f^i (or its subgroup $SU(2)_L \times SU(2)_R$)'. This pattern is indeed identical to the basic model (which was developed with the prescription that the 16 fermions F^i_α are fundamental). It has, however, the merit that it provides a natural explanation for why strong interactions are necessarily parity conserving, while weak interactions are chiral. The answer lies in the spins (0 or 1) for the bosons ξ_α and 1/2 for the fermions f^i. With sixteen four-component fermions there appears to be no a priori reason why effective strong interactions must be parity conserving.

The binding between f *and* ξ *may arise through a U(1)-vector gluon coupled to both* f and ξ. Thus the gauge symmetry may have the pattern

$$SU(2)_L \times SU(2)_R \times SU(4)'_{L+R} \times U(1) .$$

(It is, of course, not necessary for the U(1) to contribute to electric charge). The U(1) interaction would be given by

$$\kappa\left[\bar{f}\gamma_\mu f + (\xi^\dagger \partial_\mu \xi - \xi \partial_\mu \xi^\dagger)\right] G^0_\mu \tag{27}$$

It is the G^0 singlet gluon which provides the fundamental link (coupling) between the *fermions* f and the bosons ξ. The quarks and leptons are composites of f^i and ξ_α held together by the exchange of G^0. The quarks interact strongly among themselves through the exchange of the colour octet of gluons $V(\underset{\sim}{8})$ (coupled to the (a,b,c) colour bosons) as before. This provides the (qqq) and $(q\bar{q})$ binding to form the known baryons and mesons in the colour-singlet state: Thus,

$$\text{Nucleon} = (qqq) = \epsilon_{abc}(f^i\xi_a)(f^j\xi_b)(f^k\xi_c)$$

$$\text{Pion} = q\bar{q} = \sum_a (f^i\xi_a)\overline{(f^j\xi_a)} \qquad (28)$$

In other words, truly the nucleon is a composite of three pre-fermions and three pre-bosons, while the pion is a composite of $(f\bar{f}\xi\bar{\xi})$. Of course, the physics of nucleons and pions at the present level of interactions would be better dealt with in terms of quarks and anti-quarks rather than the pre-fermions and pre-bosons (which, for short, we will call "pres"), just as the physics of nucleus is better dealt with in terms of nucleons rather than quarks.

The picture, which thus emerges is that the basic fields are no more than the basic "attributes" appearing in nature. Of course, their symmetry would generate the gauge particles (W,V,G^0).

If these ideas are basically correct, there appear to arise intriguing questions including the possibility of new interpretations for J/ψ particles and their narrow widths. These come about by asking what are the characteristics of ff, $f\bar{f}$, fff, $\xi\xi$, $\xi\bar{\xi}$, $\xi\xi f$, etc., composites?

First remark that the binding between pre-fermions (i.e. ff, $f\bar{f}$ and fff etc.) would be generated only through G^0 exchange and thus would be relatively weaker. If f's are not very light, these composites would be very heavy.

The binding of pre-bosons $(\xi_\alpha\xi_\beta, \xi_\alpha\bar{\xi}_\beta)$ of the first three colours (red, yellow and blue) would arise through the strong force due to "light" colour-octet gluon $(V(8))$ exchange. Thus, these may be relatively lower-lying (masses $3 \sim 5$ GeV, with $\xi\bar{\xi}$ lighter than $\xi\xi$).

The important remark is that the decays of colour-octet $(\xi\bar{\xi})$ composites and also the colour-gluon U^0 to (hadrons + photon) cannot proceed through (strong + electromagnetic) interactions alone. They need the intermediacy of the relatively weak G^0 interaction. Since π,ρ,K etc. have $(f\bar{f})$ pairs as much as $(\xi\bar{\xi})$ pairs, one must create $(f\bar{f})$ pairs by utilizing the G^0 field. The G^0 interactions being medium strong $(\kappa^2/f^2 \approx 1/5$ to $1/10)$ would provide a damping of the radiative decay widths of U^0 and $\xi\bar{\xi}$.

It is thus conceivable that $\psi_2(3.7)$ is a bosonic colour-composite $(\xi\bar{\xi})$ rather than $(q\bar{q})$-colour-octet composite; $\psi_1(3.1)$ still being the colour-gluon U^0.

If one pursues the ideas along the lines suggested above, there are additional possibilities. Notably, both the valency and the colour may represent fermionic fields $(4 + 4)$, while there is one singlet fermion ζ. The quarks are composites of three fields; $(f\ \xi\ \zeta_{\text{fermion}})$; the singlet gluon being still coupled to f, ξ and ζ to provide their binding. This thus requires nine attributes. It has the virtue that it provides a natural mechanism for generating the massless neutrino [28]. To bring in the mirror into this picture, one might have added four new attributes. But, there is also the alternative that the mirror-quantum number is only one additional attribute (opposite chirality) reflected through a second singlet fermion ζ' (mirror to ζ) making ten elementary

entities in the pre-quark scheme.

These considerations incline one to the view that there are eight or ten (including mirror) fundamental attributes[29] at a level more basic than the quarks and the leptons.

REFERENCES AND FOOTNOTES

1) Reports by (1) S.C.C. Ting, (2) V. Luth, (3) P. Monnacelli and (4) G. Wolf at this Conference.

2) C. Rubbia, report at this Conference.

3) N. Cabibbo, report at this Conference.

4) Reports by (1) Y. Yamaguchi, (2) F. Close and (3) P. Matthews at this Conference.

5) J.C. Pati and Abdus Salam, Phys. Rev. D8, 1240 (1973).

6) J.C. Pati and Abdus Salam, Phys. Rev. D10, 275 (1974).

7) By this I mean a gauge-symmetry, in which the basic lagrangian conserves fermion number F, baryon number B, lepton number L, as well as left$\leftrightarrow$right symmetry; violations of these originating entirely from spontaneous symmetry breaking.

8) J.C. Pati and Abdus Salam, Phys. Rev. D11, 1137 (1975) (see Addendum p.1149).

9) J.C. Pati, Abdus Salam and J. Strathdee, Nuovo Cimento 26, 72 (1975).

10) Topics (a) and (b) are considered in a recent paper by J.C. Pati and Abdus Salam, Mirror fermions,, J/ψ-particles, Kolar-mine events and neutrino-anomaly, Trieste preprint (IC/75/73), Phys. Letters (to be published).

11) C. Rubbia and D. Cline, reports at this Conference.

12) J.C. Pati, S. Sakakibara and Abdus Salam, The missing quark mystery, Trieste preprint (IC/75/93).

13) The charge pattern exhibited for V-fields corresponds to the interger-charge assignment for quarks.

14) These are renormalized effective coupling constants relevant for low energies $E \lesssim 1$ GeV. The two "effective" constants g and f appearing in weak and strong gauging of $\mathcal{G}$ reflect the passage from the higher unifying symmetries $SU(32)$ or one of its natural subgroups $SU(16)_L \times SU(16)_R$ or $SU(4)_L \times SU(4)_R \times SU(4)'_L \times SU(4)'_R$ (see later) with one coupling constant down to $\mathcal{G}$ through finite renormalization effects.

15) Details of this discussion may be found in J.C. Pati and Abdus Salam, Phys. Rev. Letters 34, 613 (1975), University of Maryland Technical Report 75-056 (February 1975);
J.C. Pati, invited talk, proceedings of the Second Orbis Scientae, Coral Gables, Florida (January 1975), to appear.

16) J/ψ-particles have been interpreted as composites of three new heavy coloured quark triplets by R.M. Barnett (Harvard preprint) and H. Harari. Barnett's new quarks exhibit $V + A$ and $V - A$ weak interactions, these are naturally comprised within the mirror-set F' (Ref.8). Harari uses $V - A$ only; in this respect and in the classification symmetry adopted by him, there are crucial differences between his and our model. For the sake of unification, we would need two sets F and F' each with a 4×4-structure (not 3×3) and the mirror-helicity flip coupling of F' (Ref.8).

17) The possible role of a new isospin in the decays of ψ, was first suggested by Barnett. He uses (χ, n') (in our notation) rather than (p', n'). These, as well as other choices, are, in general, permissible.

18) Not all the features arising within the smaller symmetry $\mathcal{G}^0$ can be realized by starting from a bigger local symmetry such as $\mathcal{G} = SU(4)^0_L \times SU(4)_R \times SU(4)'_L \times SU(4)'_R$. This is being studied.

19) Note with $a_{ij} = 0$, $b_{ij} \neq 0$, $\epsilon_{ij} = \epsilon'_{ij} \neq 0$, the masses of F may be derived from the masses of F' in a natural symmetry manner. In this case, one would have the amusing relation that the normal fermion masses would be inversely proportional to mirror fermion masses, (i.e. $m_{F_i} \propto \epsilon^2/m'_{F_i}$) i.e. $m_p = \epsilon^2/m'_p$, $m_n = \epsilon^2/m'_n$, etc. If this is true, $m_\chi > m_\lambda > m_n > m_p$ may correspond to $m'_p > m'_n > m'_\lambda > m'_\chi$. (Of course, one can rename the particles to go with the convention that p' would be the lightest among the mirror set. We presume this convention.) However, note: relations such as $(m_n - m_p) = (\epsilon^2 |m'_p - m'_n|)/(m'_p m'_n)$.

20) For convenience use the same notation for the diagonal fields as in Eq.(8). Note, given $F - F'$-mixing, (μ , ν_μ) could start life from F' , (E^- , E^0) originating from F .

21) The effects are proportional to $\sin^2 \phi_R$.

22) This type of interaction was first suggested by R.N. Mohapatra (Phys. Rev. D6, 2023 (1972)) in the context of CP violation. Its $\Delta I = \frac{1}{2}$ character has recently been noted in a preprint by A. De Rujula, H. Georgi and S.L. Glashow; other merits of this non-leptonic interaction have been toted by P. Minkowski and H. Fritzsch) (preprint). (We learnt of these works in the process of writing Ref.9; private communications by R.N. Mohapatra and H. Fritzsch.)

23) This, by itself, does not constitute evidence for Model III since there exists a satisfactory explanation of $\Delta I = \frac{1}{2}$ rule and octet enhancement for "normal" theories within the framework of asymptotic freedom (M. Gaillard and B.W. Lee, Phy. Rev. Letters 33, 108 (1974); G. Altarelli and L. Maiani, Phys. Letters 52, 351 (1974)), together with arguments based on three-colour model and current algebra (J.C. Pati and C.H. Woo, Phys. Rev. D3, 2920 (1971)). Also note that due to the presence of the mirror, the enhancement factor for $\Delta I = \frac{1}{2}$ would be larger in any case for the "normal" theories without the $(\chi\, n)_R$-current. (See remarks by Treiman et al. (preprint).)

24) We stress that in all three models, I, II and III, and their variations, there are large isoscalar vector as well as axial vector neutral-current contributions, which arise from $S^0_V = (S^0_L + S^0_R)/\sqrt{2}$ and $S^0_A = (S^0_L - S^0_R)/\sqrt{2}$ interactions. The S^0_V and S^0_A need be no heavier than 1000 GeV with $(f^2/m^2_{S_{V,A}}) \lesssim G_{Fermi}$. These contributions can supersede the Z^0 contribution and may account for the lack of $I = 3/2$ N^* production. These new contributions arise only due to enlarged local symmetries. See also Ref.8 for possible effective scalar and pseudoscalar neutral-current interactions, which arise (through X particle gauge coupling) due to Fierz reshuffling and which may also be relevant in accounting for the threshold behaviour for pion production in neutral-current processes (S. Adler, IAS preprint, March 1975).

25) One such variant possibility arising within Eq.(14) has recently been considered by G. Branco, T. Hagiwara and R.N. Mohapatra (City College preprint, August 1975). This corresponds to the interchange of the doublets $\begin{pmatrix} p \\ n'_c \end{pmatrix}_R \longleftrightarrow \begin{pmatrix} p' \\ \lambda \end{pmatrix}_R$ of model III (Eq.(16)). Such variations differ from models II and III in two respects: (i) They do not provide any simple explanation of the ν-$\bar{\nu}$-y-distribution anomaly, and (ii) they give $(\sigma_{\bar{\nu}}/\sigma_\nu) \to (1/4)$. Models such as II and III, on the one hand, account for the y-distribution, but (by the same token) predict (if Cabibbo mixing angle $\cos\theta'_R$ between $(n', \lambda')_R \approx 1$) that asymptotically (sufficiently above mirror threshold) $(\sigma_{\bar{\nu}}/\sigma_\nu)$ should approach 4/3 (for model II) and 1 (for model III), as stressed by Branco et al. Since only low x-phenomena $(x < 0.1)$ appear to reveal the y-anomaly, one may infer that mirror production is relevant only at small x even at high $E_\nu \approx 100$ GeV. Thus, one may still be far from reaching the asymptotic value for the mirror contribution to the ratio of total cross-sections. It appears difficult to judge the issue of approach to scaling for all (x,y) region for processes involving heavy mass mirror thresholds (4 ∿ 5 GeV) on the basis of one's experience involving low-mass thresholds alone. Thus, there appears to be no compelling reason at present to choose between models II and III, on the one hand, and variations (as above), on the other, on the basis of the ratio $(\sigma_{\bar{\nu}}/\sigma_\nu)$ alone. Of course, the correct solution (which might be consistent with both y-distribution and $\sigma_{\bar{\nu}}/\sigma_\nu$) may correspond to the mixing angle parameter $\cos\theta'_R$ being large (but not ≈ 1). The correct expressions (without antiquark contributions) for model III are the following: $d\sigma_{\bar{\nu}} \propto [\cos\theta_R + (1-y)^2]$; $d\sigma_\nu \propto [(1-y)^2 \cos\theta_R + 1]$ and asymptotically (sufficiently above mirror threshold) $(\sigma_{\bar{\nu}}/\sigma_\nu) \to (\cos\theta'_R + \frac{1}{3})(1 + \frac{1}{3}\cos\theta'_R)^{-1}$.

26) See especially footnote 7 of Ref.6.

27) These may also be part of a supersymmetry.

28) Compare with the suggestion for masslessness of neutrino in Ref.6.

29) It may, of course, be that there are three sets, each with four basic "attributes". This number 4 appearing and reappearing makes one wonder whether these particle attributes might not be linked with space-time.

Note added

Shortly after the conference, we obtained the following result regarding the question of colour brightening in theories based on integer-charge quarks. It was found that within the class of gauge theories, in which (i) valency and colour are gauged independently, (ii) leptons are treated as colour-singlets and (iii) the massless photon is generated via spontaneous symmetry breaking as a mixture of valency and colour-gauge mesons, there is a general suppression of colour relative to valency production in lepto-production experiments. The reason is this: In these theories, before spontaneous symmetry breaking, leptons interact with the valency current $(J^{valency})$ but not with the colour current (J^{colour}). Spontaneous symmetry breaking induces mixing between valency and colour-gauge mesons. This generates (through the diagonalization of fields) the massless photon A_μ , but inevitably also the orthogonal colour-gauge partner $\tilde{U}_\mu$ (with mass m_U), both of which contribute to lepton-colour interaction. This has the consequence that (barring logarithmic factors from renormalization group-considerations), while lepton-valency interaction has the matrix element $(J^{lepton}\, 1/q^2\, J^{valency})$, the corresponding expression for lepton-colour interaction has the matrix element $J^{lepton}((q^2)^{-1} - (q^2 - m_U^2)^{-1})J^{colour}$. It is the crucial negative sign between the two propagators in the second case, resulting from a diagonalization of fields, which suppresses colour brightening effects.

In other words, in theories of the type described above, there is a purely kinematic factor $\Delta^2(q^2) = (m_U^2/q^2 - m_U^2)^2$ between colour versus valency production. This has the consequences that: (i) Colour production is severely damped by the kinematic factor $\Delta^2(q^2)$ for space-like $q^2 (< 0)$ especially in regions $(|q^2| \gtrsim 2m_U^2)$, where one might have expected no dynamical damping of colour production. (ii) For time-like processes $(e^- e^+ \to X)$, the colour gluon $\tilde{U}$ itself (being orthogonal to A_μ) is produced without any Δ factor. (iii) Colour continuum (due to the limited number of channels and meagre phase-space available, assuming colour threshold $\gtrsim (m_U + 2m_\pi) \approx 3 \sim 5$ GeV) is produced with no undue enhancement in the region $m_U < \sqrt{q^2} \leq \sqrt{2}\, m_U$. (iv) For fairly large $q^2 \gtrsim 3m_U^2$, the damping $\Delta^2(q^2)$ begins to be significant, even in the time-like region. (v) For truly asymptotic $q^2 \to \infty$, if the rates of decrease of photon and $\tilde{U}$ propagators (controlled by logarithmic corrections following from renormalization group-considerations) are different, colour may be revived at such asymptotic q^2 . The important deductions are that $e^- e^+$ annihilation can still produce the colour gluon $\tilde{U}$ and colour-resonant states with no special damping, but electro- and muon- (similarly neutrino-) production experiments are efficient in probing only the fractional aspect (valency charge) of integer-charge quarks; they are not efficient in probing the colour charge. The situation changes if we use real photon as the probe. These questions are discussed in more detail in a paper by J.C. Pati and Abdus Salam (ICTP, Trieste, preprint IC/75/95, 3 August 1975).