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Lepton Quarks*

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ABSTRACT

This paper will present a scheme whereby e^-, ν, μ^- form a U(3) triplet. In a natural way a fourth weak quark ℓ will be introduced to form an SU(4) quartet. The $\psi(3105)$, $\psi(3695)$, and apparent channel opening at about E_{cm}=4 Gev observed in the recent SPEAR data will then be explained. The fourth weak quark ℓ has I=0 and Q=+2 .

*Work done under the auspices of the U. S. Atomic Energy Commission.

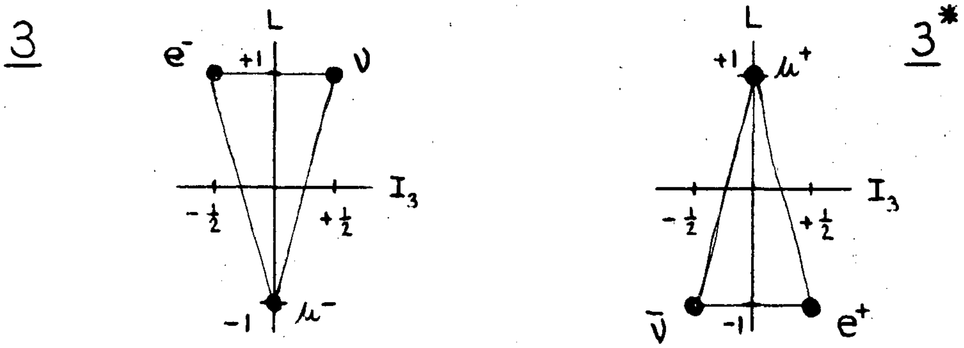
I. The "Weak" Quarks

The first part of this paper will be to construct a "weak" U(3) in analogy with the "strong" SU(3) of hadronic physics. The additive quantum numbers of this weak U(3) shall be I_3, Q, L in analogy to I_3, Q, Y of strong SU(3). There are precisely four candidates for the three weak quarks. The candidates are $e^-, \nu_e, \mu^-, \nu_\mu$. Also there are two lepton numbers L_e and L_μ as choices for L. Our over abundance of leptons and quantum numbers is easily resolved if we use the old Konopinski-Mahmoud (1) single lepton number scheme.

Particle	Standard Two Lepton Number Scheme L_e	L_μ	Konopinski-Mahmoud L
e^-	1	0	1
ν_e	1	0	1 (helicity=-1)
μ^-	0	1	-1
$\bar{\nu}_\mu$	0	-1	1 (helicity=+1)
Anti-particle			
e^+	-1	0	-1
$\bar{\nu}_e$	-1	0	-1 (helicity=+1)
μ^+	0	-1	1
ν_μ	0	1	-1 (helicity=-1)

Only one ν is now needed. The subscripts on $\nu_e, \bar{\nu}_\mu$ were redundant in that they specified the helicity of the neutrino. The various reactions which previously were forbidden by lepton conservation of two numbers are now forbidden by one lepton number and angular momentum conservation (where the ν now has exactly zero rest mass).

The fundamental U(3) triplets are



The choice of e^- and μ^- as quarks is also experimentally motivated by the fact that both behave exactly like point particles. They have no form factor. Thus one might expect them not to be made up of smaller building blocks.

II. The U(3) Generators

We shall use the tensor basis for U(N). The generators are the N x N array A^{ij} which satisfy the commutation relations (2)

$$[A^{ij}, A^{kl}] = \delta^{il} A^{kj} - \delta^{kj} A^{il}$$

Let the eigenvalue of the generator A^{ii} be a_i, and C is the eigenvalue of the casimir operator $\sum_{i=1}^{3} A^{ii}$.

Hence we must have

$a_1+a_2+a_3 = C$ — Definition of C

$\frac{1}{2}(a_2-a_1) = I_3$ — I_3 is to be the SU(2) additive quantum number of a U(2) subgroup of U(3). (1)

$2(a_2+a_1) = L$ — $\Delta L=2$ between e^- and μ^-. Also L should be a casimir operator for the SU(2) I-spin subgroup.

Inverting gives

$$a_1 = \frac{1}{4} L - I_3$$

$$a_2 = \frac{1}{4} L + I_3 \qquad (2)$$

Now the weight vectors of $\underline{3}$ are

	a_1	a_2	a_3
e^-	$\frac{3}{4}$	$-\frac{1}{4}$	$-\frac{1}{4}$
ν	$-\frac{1}{4}$	$\frac{3}{4}$	$-\frac{1}{4}$
μ^-	$-\frac{1}{4}$	$-\frac{1}{4}$	$\frac{3}{4}$

(3)

The particular $\underline{3}$ representation with $C = \frac{1}{4}$ has been chosen so that equations (1) give the proper L for e^-, ν, μ^- . The charge Q must be a linear combination of L, I_3, C .

$$Q = \alpha C + \beta I_3 + \gamma L$$

$$e^- \qquad -1 = \alpha\left(\tfrac{1}{4}\right) + \beta\left(-\tfrac{1}{2}\right) + \gamma(1)$$

$$\nu \qquad 0 = \alpha\left(\tfrac{1}{4}\right) + \beta\left(\tfrac{1}{2}\right) + \gamma(1)$$

$$\mu^- \qquad -1 = \alpha\left(\tfrac{1}{4}\right) + \beta(0) + \gamma(-1)$$

Solving for α, β, γ gives

$$Q = I_3 + \frac{1}{4} L - 3C \qquad (4)$$

This of course is the analog of the relation $Q = I_3 + \frac{1}{2} Y$ from strong SU(3) whose origin is the requirement $\sum_{i=1}^{3} A^{ii} = 0$. Hence the origin of equation (4) should be $\sum_{i=1}^{3} A^{ii} = C$. This gives us the value of a_3.

$$a_3 = -\frac{5}{12} L + \frac{1}{3} I_3 - \frac{1}{3} Q \tag{5}$$

Inverting equations (2) and (5) gives

$$Q = a_2 - 3C \tag{6}$$

III. Extension to SU(4)

Table (3) looks extremely suggestive. The values of a_1, a_2, a_3 are precisely the first three components of three fundamental SU(4) weight vectors. Thus we shall make the extension to SU(4) and introduce the new fourth weak quark ℓ .

	a_1	a_2	a_3	a_4
e^-	$\frac{3}{4}$	$-\frac{1}{4}$	$-\frac{1}{4}$	$-\frac{1}{4}$
ν	$-\frac{1}{4}$	$\frac{3}{4}$	$-\frac{1}{4}$	$-\frac{1}{4}$
μ^-	$-\frac{1}{4}$	$-\frac{1}{4}$	$\frac{3}{4}$	$-\frac{1}{4}$
ℓ	$-\frac{1}{4}$	$-\frac{1}{4}$	$-\frac{1}{4}$	$\frac{3}{4}$

(7)

Since the group is SU(4)

$$\overbrace{a_1+a_2+a_3}^{C}+a_4 = 0$$

So $C = -a_4$ and equations (1) and (6) are replaced by

$$\begin{aligned} I_3 &= \frac{1}{2}(a_2-a_1) \\ L &= 2(a_2+a_1) \\ Q &= a_2+3a_4 \end{aligned} \tag{8}$$

Using the weight vectors from table (7) and equations (8) we get

	I_3	L	Q
e^-	$-\frac{1}{2}$	1	-1
ν	$\frac{1}{2}$	1	0
μ^-	0	-1	-1
ℓ	0	-1	+2

(9)

Thus the new weak quark has electric charge = +2 , I-spin = 0 , L = -1 . Notice that the sum over all particles in an SU multiplet of an additive quantum number such as Q, I_3, or L is always zero. Hence we could have deduced that Q = +2 for the new quark without going through all the above gyrations.

IV. Colliding $\underline{4}$ and $\underline{4}^*$

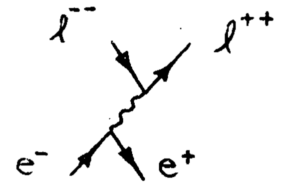
Colliding a particle in $\underline{4}$ with a particle in $\underline{4}^*$ should produce the states in the SU(4) $\underline{1}$ and $\underline{15}$ dimensional representations since

$$\underline{4} \times \underline{4}^* = \underline{1} + \underline{15}$$

Linear combinations of e^-e^+, $\nu\bar{\nu}$, $\mu^-\mu^+$, $\ell^{--}\ell^{++}$ give the three I_3=L=Q=0 objects in the center of $\underline{15}$ and the one in $\underline{1}$. So if we ignore orbital angular momentum excitations of the weak quarks we would expect four I_3=L=Q=0 objects.

V. Comparison with Experiment

1) The step in $R = \dfrac{\text{Hadron events}}{\mu^-\mu^+}$ seen in the SPEAR data is consistent with the opening of a channel in which a pair $\ell^{--}\ell^{++}$ is produced.



For the production of a pair of μ like charge ± 1 objects one would expect R to jump by one (or less since the object's entire decay may not be into hadrons). For a charge ± 2 pair R should jump by four or less. The SPEAR data showing a jump in R of about three is consistent with a charge ± 2 but inconsistent with a charge ± 1 .

2) Since ℓ^{--} and ℓ^{++} must decay to singly charged objects, there should be a rapid increase in 4-prong, 6-prong, etc. events relative to 2-prong events when above the threshold at 4 Gev.

3) The γ, $\psi(3105)$, $\psi(3695)$ could be three of the four $I_3=L=Q=0$ resonances in $\underline{4} \times \underline{4}^*$. Perhaps e^-e^+ will also couple to the fourth one.

4) The L=2 $I_3=-\frac{1}{2}$ Q=0 state of $\underline{15}$ should appear in $e^-\mu^+$. The L=-2 $I_3=+\frac{1}{2}$ Q=0 state of $\underline{15}$ should appear in $e^+\mu^-$. These could be searched for in the MIT group's experiment[3] with a μ trigger on one arm of the spectrometer.

5) If the rise in R at 4 Gev is due to the production of a pair, then the particle must be point like since the form factors for typical extended objects like protons

are very small for $q^2=16$. A point object is consistent with the notion of it being a weak quark.

6) The new weak quark ℓ^{++} has a two body decay channel which conserves L and Q.

$$\ell^{++} \longrightarrow e^+ \pi^+$$
$$\ell^{--} \longrightarrow e^- \pi^-$$

This should result in a final state bump in the $e^{\pm}\pi^{\pm}$ mass plots at $m_{\ell}=2$ Gev.

VI. Acknowledgements

Special thanks goes to John Jaros for many fun discussions (in particular for pointing out that the jump in R was consistent with charge ±2). Also the local members of the SPEAR collaboration deserve much praise for their courageous rapid revelation of their preliminary data.

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