KEK Preprint 98-59
June 1998
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High Energy Accelerator Research Organization (KEK), 1998

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A UNIFIED COMPOSITE MODEL OF QUARK-LEPTON COLOR INTERACTIONS

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Abstract

Proposed is a unified composite model of quark-lepton $SU(4)_c$ color interactions in which fifteen gauge bosons including a color-octet of gluons, a color-triplet of leptoquarks and their antiparticles, and a “B-L gluon” are made of a subquark and an antishquark carrying the quark-lepton color quantum number. The $SU(4)_c$ symmetry is spontaneously broken down to $SU(3)_c$ due to the condensation of subquark-antishquark pairs and the B-L gluon becomes $\sqrt{3}/2$ times heavier than the leptoquarks.

A quark has not only the flavor quantum number but also the color quantum number [1]. The strong interaction of quarks can be well described by quantum chromodynamics (QCD) [2], the Yang-Mills gauge theory of color $SU(3)_c$ in which a color-octet of gluons mediate the interaction. Also, the electroweak interactions of quarks and leptons can be well described by the spontaneously broken Glashow-Salam-Weinberg unified gauge theory of $SU(2)_w \times U(1)$ [3] in which a triplet of weak gauge bosons and the photon mediate the interactions. Furthermore, both the strong interaction and the electroweak interactions may be described by grand unified gauge theories in which a color-triplet of quarks and a lepton are assumed to form a quartet of Pati-Salam quark-lepton color $SU(4)_c$ [4] or in which a color-triplet of quarks and a weak-isospin-doublet of leptons are assumed to form a quintet of Georgi-Glashow color-weak-isospin $SU(5)_G$. In either way, the interactions of quarks and leptons are assumed to be mediated not only by the photon, weak gauge bosons, and gluons but also by the leptoquark gauge bosons changing a quark into a lepton (and *vice versa*). Also, in unified composite models of quarks and leptons as well as Higgs scalars and gauge bosons [6, 7], the existence of not only the leptoquark gauge bosons but also scalar leptoquarks has been predicted [8].

Since not only the CDF anomaly [9] indicating the possible substructure of quarks and gauge bosons but also the HERA anomaly [10] indicating the possible existence of leptoquarks was reported (although neither one of these indications have not been confirmed), not only the possible substructure of quarks and leptons as well as Higgs scalars and gauge bosons [11] but also the possible existence of leptoquarks [12] have

been extensively re-investigated. The purpose of this letter is to propose a unified composite model of quark-lepton $SU(4)_c$ color interactions in which fifteen gauge bosons including a color-octet of gluons, a color-triplet of leptoquarks and their antiparticles, and a “B-L gluon” are made of a subquark and an antishquark carrying the quark-lepton color quantum number.

The minimal composite model of quarks and leptons [7] consists of an isodoublet of spinor subquarks with charges $\pm 1/2$, w_1 and w_2 (called “wakerns” standing for weak and electromagnetic) [6], and a $SU(4)_c$ color-quartet of scalar subquarks with charges $+1/2$ and $-1/6$, C_0 and C_i ($i = 1, 2, 3$) (called “chroms” standing for colors) [4]. All these six subquarks, w_i ($i = 1, 2$) and C_α ($\alpha = 0, 1, 2, 3$), may have “subcolors”, the additional degrees of freedom [13], and belong to the fundamental representation of subcolor symmetry. Although the subcolor symmetry, if any, is unknown, a simplest and most likely candidate for it is $SU(4)_{sc}$. There are many reasons for this (which have been presented in Ref. 7). Therefore, for simplicity in this letter, all the subquarks are assumed to be quartet in subcolor $SU(4)_{sc}$. Also, although the confining force between subquarks is unknown, a simplest and most likely candidate for it is the one described by quantum subchromodynamics (QSCD), the Yang-Mills gauge theory of subcolor $SU(4)_{sc}$ [13]. The quantum numbers of these six subquarks are summarized in Table 1. Note that the subquark charges satisfy not only the Nishijima-Gell-Mann rule of $Q = I_3 + (B - L)/2$ but also the “anomaly-free condition” of $\sum_w Q_w = \sum_C Q_C = 0$. Note also that both baryon and lepton numbers are conserved separately as far as chrom numbers are conserved. (The conservation of baryon and lepton numbers would be

violated if the neutral, color-singlet, and subcolor-singlet combination of $C_0 C_1 C_2 C_3$ condensates in the QSCD vacuum).

In this model, we expect that there exist at least 36 ($= 6 \times 6$) composite states of a subquark and an antishquark which are subcolor-singlet. They include 1) 16 ($= 4 \times 2 \times 2$) spinor states corresponding to one generation of quarks and leptons, and their antiparticles of

$$\nu = \bar{C}_0 w_1 \quad u_i = \bar{C}_i w_1 \quad \bar{\nu} = C_0 \bar{w}_1 \quad \bar{u}_i = C_i \bar{w}_1$$

$$l = \bar{C}_0 w_2 \quad d_i = \bar{C}_i w_2 \quad \bar{l} = C_0 \bar{w}_2 \quad \bar{d}_i = C_i \bar{w}_2 \quad (i = 1, 2, 3),$$

2) 4 ($= 2 \times 2$) vector states corresponding to the photon and weak bosons of

$$W^+ = w_2 w_1 \quad \gamma, Z = \bar{w}_1 w_1, \quad \bar{w}_2 w_2, \quad \bar{C}_0 C_0, \quad \bar{C}_i C_i \quad W^- = \bar{w}_1 w_2$$

or 4 ($= 2 \times 2$) scalar states corresponding to the Higgs scalars of

$$\phi^i_j = \begin{pmatrix} \bar{w}_1 w_1 & \bar{w}_2 w_1 \\ \bar{w}_1 w_2 & \bar{w}_2 w_2 \end{pmatrix} \quad (i, j = 1, 2),$$

and 3) 16 ($= 4 \times 4$) vector states corresponding to a) the gluons, “leptogluon”, and “barygluon” of

$$G^a = \bar{C}_i \left(\frac{\lambda^a}{2} \right)_{ij} C_j \quad G^0 = \bar{C}_0 C_0 \quad G^9 = \bar{C}_i C_i \quad (i, j = 1, 2, 3),$$

where λ^a ($a = 1, 2, 3, \dots, 8$) is the Gell-Mann’s matrix of $SU(3)_c$, and b) the “vector leptoquarks” of

$$X_i = \bar{C}_0 C_i \quad X_i = \bar{C}_i C_0 \quad (i = 1, 2, 3),$$

or 16 ($= 4 \times 4$) scalar states corresponding to the “scalar gluons”, “scalar leptoquark”, “scalar barygluon”, and “scalar leptoquarks” of

$$\Phi^\alpha_\beta = \bar{C}_\alpha C_\beta \quad (\alpha, \beta = 1, 2, 3, 0).$$

These 36 composites are summarized in Table 2. Quarks or leptons with the same quantum numbers but in different generations can be taken as dynamically different composite states of the same constituents (which have been discussed in Ref. 7). In addition to these “meson-like composite states” of a subquark and an antisubquark, there may also exist “baryon-like composite states” of 4 subquarks which are subcolor singlet. These exotic states have also been discussed in Ref. 7.

The most fundamental Lagrangian of subchromodynamics for (massless) subquarks is given by

$$L_{sc} = -\frac{1}{4}(F_{\mu\nu}^A)^2 = w_i\gamma^\mu(i\partial_\mu + F\frac{\Lambda^A}{2}A_\mu^A)w_i + |(\partial_\mu - iF\frac{\Lambda^A}{2}A_\mu^A)C_\alpha|^2, \quad (1)$$

where F is the coupling constant, $\Lambda^A (A = 1, 2, 3, \dots, 15)$ is the $SU(4)_{sc}$ matrix, A_μ^A is the subgluon field, and $F_{\mu\nu}^A = \partial_\mu A_\nu^A - \partial_\nu A_\mu^A + Ff_{ABC}A_\mu^BA_\nu^C$ with f_{ABC} for the structure constants of $SU(4)_{sc}$. Obviously, this Lagrangian is symmetric not only in the chiral $U(2)_L \times U(2)_R$ transformation for w_{iL} and $w_{iR} (i = 1, 2)$ but also in the $U(4)_c$ transformation for $C_\alpha (\alpha = 1, 2, 3, 0)$. After the gauge-induction [6] of local $SU(4)_c$ from global one or the gauge-transmutation [14] of $SU(4)_{sc}$ into $SU(4)_c$, the effective, Lagrangian of quark-lepton color interactions for chroms should become

$$L_c = -\frac{1}{4}(G_{\mu\nu}^A)^2 + |(\partial_\mu - if\frac{\Lambda^A}{2}G_\mu^A)C|^2 + \dots, \quad (2)$$

where f is the effective coupling constant, $G_\mu^A (A = 1, 2, 3, \dots, 15)$ is the 15-plet gluon field, and $G_{\mu\nu}^A = \partial_\mu G_\nu^A - \partial_\nu G_\mu^A + f f_{ABC}G_\mu^BG_\nu^C$.

Suppose that a subcolor singlet pair of C_0 and $\bar{C}_0$ condensates in the vacuum of QSCD, i.e. $\langle \bar{C}_0 C_0 \rangle_0 = (V/\sqrt{2})^2 \neq 0$ where V is a non-vanishing constant. Then,

the $SU(4)_c$ symmetry is spontaneously broken down to $SU(3)_c$. Since the effective Lagrangian provides non-vanishing mass terms as

$$L_c = \dots + (\frac{fV}{2})^2 [|\frac{G_\mu^9 + iG_\mu^{10}}{\sqrt{2}}|^2 + |\frac{G_\mu^{11} + iG_\mu^{12}}{\sqrt{2}}|^2 + |\frac{G_\mu^{13} + iG_\mu^{14}}{\sqrt{2}}|^2 + \frac{3}{4}(G_\mu^{15})^2], \quad (3)$$

a color-triplet of leptoquarks (and their antiparticles)

$$X_1 = (G^9 + iG^{10})/\sqrt{2}, \quad X_2 = (G^{11} + iG^{12})/\sqrt{2}, \quad X_3 = (G^{13} + iG^{14})/\sqrt{2} \quad (4)$$

and the physical B-L gluon $G^B (= G^{15})$ would become massive with the masses

$$m_X = fV/2 \text{ and } m_{G^B} = \sqrt{3/2}(fV/2) (= \sqrt{3/2}m_X) \quad (5)$$

while the ordinary gluons $G^a (a = 1, 2, 3, \dots, 8)$ remain massless.

Note that the physical B-L gluon must be $\sqrt{3/2}$ times heavier than the leptoquarks. Since the presently available lower bound on the leptoquark gauge boson is $m_X \geq 225$ GeV (95% CL) [15], the mass of the physical B-L gluon in this model can be bounded by $m_{G^B} = \sqrt{3/2}m_X \geq 276$ GeV. Since the gluon coupling constant f is determined by $f \equiv (4\pi\alpha_s)^{1/2} \cong 1.2$ (for the renormalization point at $Q^2 = m_Z^2$ [16]), the constant V can be bounded as $V = 2m_X/f \gtrsim 0.4$ TeV. This lower bound on V seems to be consistent with the expectation that the energy scale of QSCD, Λ_{sc} , must be much higher, say $\Lambda_{sc} \gtrsim 1$ TeV, than that of QCD, $\Lambda_c (\cong 0.2$ GeV [16]). In short, the physical B-L gluon should appear as a neutral, color-singlet, but strongly interacting vector boson which is $\sqrt{3/2}$ times heavier than the leptoquarks and which couples universally with the B-L current of quarks and leptons.

In conclusion, we must mention that the unified composite model of quark-lepton color interactions proposed in this letter is not yet complete and not unified either

in a sense that it describes only the strong interaction. To explain how the realistic electroweak interactions of quarks and leptons come out of QSCD is a subject for future investigation.

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Tables

Table 1. The quantum numbers of the subquarks							
name	charge	baryon no.	lepton no.	spin	isospin	color	subcolor
	Q	B	L	J	$SU(2)_w$	$SU(4)_c$	$SU(4)_{sc}$
w_1	+1/2	} 0	} 0	} 1/2	2	1	4
w_2	-1/2						
C_0	+1/2	0	-1	} 0	1	4	4
C_i ($i=1,2,3$)	-1/6	-1/3	0				

Table 2. The composite states of a subquark and an antsubquark				
	w_1	w_2	$\bar{C}_0$	$C_j(j = 1, 2, 3)$
w_1	$W_1^1(\phi_1^1)$	$W^+(\phi^+)$	ν	u_j
w_2	$W^-(\phi^-)$	$W_2^2(\phi_2^2)$	l	d_j
C_0	$\bar{\nu}$	$\bar{l}$	$G_0^0(\Phi_0^0)$	$G^{j+2/3}(\Phi^{j+2/3})$
C_i ($i=1,2,3$)	u_i	d_i	$G_i^{-2/3}(\Phi_i^{-2/3})$	$G_i^j(\Phi_i^j)$