Composite model for quarks and leptons

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A new composite model in which two types of fundamental fermions exist is proposed. These consist of light quarks $q_B(u,d)$ and new lepton quarks with fractional charges $(-\frac{2}{3}, \frac{1}{3})$ and a lepton number $L=\frac{1}{3}$ such that leptons are composites of three lepton quarks $(3q_L)$ while nonstrange baryons are $3q_B$ composites. In addition, heavy quarks are obtained as $q_Bq_L\bar{q}_L$ composites which throw interesting light on the mechanism of heavy-quark decay modes.

Recent investigations on the composite model[1] for quarks, leptons, and weak bosons suggest an interesting variation in the experimental limits of mass scale Λ of the substructures. While Λ is in the high-TeV range for lepton and light quarks, the heavy quarks (t,b,c,s) can have a lower value of mass scale Λ in the 100-GeV range. In particular, tests for substructures and limits of Λ for heavy quarks have been suggested recently.[2] In view of this result, we suggest a composite model which allows for a varying degree of compositeness for light quarks, leptons, and heavy quarks.

The main idea of this work is to suggest a new approach to the quark-lepton relationship. The light quarks $q_B(u,d)$ are taken as elementary while leptons are composites of three preons $q_L(r,v)$, and heavy quarks are $q_Bq_L\bar{q}_L$ composites. The basic elementary fermions (u,d) and (v,r) are assigned a baryon number $B=\frac{1}{3}$ and lepton number $L=\frac{1}{3}$, respectively. The left-handed fermions are isodoublets of a weak $SU(2)_l$ flavor group so that $T=\frac{1}{3}$, $T_3=+\frac{1}{2}, -\frac{1}{2}$ for (u,d) and (v,r). In addition, the weak charge $Q=T_3+\frac{1}{2}Y$ is obtained as $Q_u=\frac{2}{3}$, $Q_d=-\frac{1}{3}$; $Q_v=\frac{1}{3}$, $Q_r=-\frac{2}{3}$ for $Y=B-L$. The weak bosons $W^{\pm}$, Z^0, γ are elementary in this model. For color symmetry, we consider an extended $SU(3)_B\otimes SU(3)_L$ group such that (u,d) transform as $(3,1)$ and (v,r) as $(1,3)$ representation. The nonstrange baryons are $3q_B$ composites governed by QCD $[SU(3)_B]$ gluons, while leptons are $3q_L$ preon composites governed by forces due to $SU(3)_L$ hypergluons. The mass scale Λ for (rrv), (vvr) composites is at the high-TeV range for (e^-,ν_e) while (μ,τ) are multipreon composites. The new preonic bosons $(q_l\bar{q}_L)$ are the extra bosons at high-energy ranges.

To obtain heavy quarks, we consider (c,s) as $q_B\phi$ composites of spin $\frac{1}{2}$, weak $SU(2)_l$ isodoublet belonging to the $(3,1)$ representation of $SU(3)_B\otimes SU(3)_L$ where ϕ is a $q_L\bar{q}_L$ composite with a substructure $(\frac{1}{2})^{1/2}(v\bar{v}+r\bar{r})$, neutral hypercolor, and $T=0$ scalar boson. The (t,b) can have extended substructures $(u\phi\phi, d\phi\phi)$ where ϕ provides the generation component, and $\phi(\bar{\phi})$ have different interactions with (u,d). In strong interactions, the heavy quarks preserve their composite structures so that strangeness, charm, and beauty quantum numbers are conserved. However, the scalar-boson ϕ decays play an important role in weak and electromagnetic interactions. Since $\phi(\bar{\phi})$ couple differently with q_B, this allows for conservation of generation number in certain reactions,

$$b\to s+s+\bar{d} \quad (d\phi\phi\to d\phi+d\phi+\bar{d})\ ,$$

$$b\to c+s+\bar{u} \quad (d\phi\phi\to u\phi+d\phi+\bar{u})\ ,$$

while others are forbidden,

$$b\to s+\bar{s}+d \quad (d\phi\phi\to d\phi+\overline{d\phi}+d)\ ,$$

$$b\to\bar{c}+s+u \quad (d\phi\phi\to\bar{u}\,\bar{\phi}+d\phi+u)\ ,$$

$$b\to c+\bar{c}+d \quad (d\phi\phi\to u\phi+\bar{u}\,\bar{\phi}+d)\ ,$$

as is also predicted by certain other models.[3] The generation number is $G=+1$ for ϕ and $G=-1$ for $\bar{\phi}$ in the present model. For leptons, the substructures are preonic so that (μ,τ) heavy leptons are not merely $(e\phi, e\phi\phi)$ electron-ϕ bound states, but of a different structure.

For weak and electromagnetic interactions, we consider the $SU(2)_l\times U(1)_Y$ gauge group so that weak bosons are elementary in this model. The left-handed fermions (u,d) and (v,r) couple to $W^{\pm}, W_3$ while the right-handed fermions can couple to neutral isoscalar B. The preonic boson $\phi(q_L\bar{q}_L)$ can have weak and electromagnetic decays $\phi\to W^+W^-$, $\phi\to Z^0\gamma$; $\phi\to\gamma\gamma$ which give rise to Cabibbo-like mixing and flavor-changing transitions. Thus while two light or two composite fermions (u,d), (c,s), (t,b) can have large couplings with charged $W^{\pm}$, the substructure effects show up in (c,d) (u,s) couplings.

$$c\to u\phi\to(uW^-)W^+\to dW^+\ ,$$

$$s\to d\phi\to(dW^+)W^-\to uW^-\ ,$$

which have the same magnitudes but opposite signs $\sim s$, accordingly, as W^- or W^+ is absorbed. In a similar way, the (t,s) and (b,c) couplings are obtained by single ϕ decay as

$$t\to u\phi\phi\to(uW^-\phi)W^+\to s+W^+\ ,$$

$$b\to d\phi\phi\to(d\phi\,W^+)W^-\to c+\overline{W}\ ,$$

which again occur with the same magnitudes $\sim s'$ and opposite signs. For (t,d) and (b,u) couplings, a decay of $\phi\phi\to W^+W^-$ of a much lower order is expected so that these are nearly zero. For flavor-changing electromagnetic transitions, one may obtain $Z^0 \to K^{*0}$, D^{*0} according to

$$s \to d\phi \to dZ^0,\ \ c \to u\phi \to uZ^0\ ,$$

whose experimental limits are discussed in Ref. 2. The preonic boson ϕ can also decay to quark-antiquark $(q_B\bar{q}_B)$ pairs by $q_L\bar{q}_L \to q_B\bar{q}_B$, a four-point interaction allowed by the extended color symmetry $SU(3)_B \otimes SU(3)_L$ which can have $\Lambda \sim 100$ GeV. This allows for special decay models, which are flavor-changing transitions, inducing an effective $(q_B\phi)\bar{q}_B \to q_B(q_B\bar{q}_B)\bar{q}_B$ vertex, giving new contributions to $K^0 \to$pions, $D^0 \to$pions which, however, will be considerably smaller than ordinary weak nonleptonic decays. For neutral-current processes $b \to ss\bar{d}$, flavor mixing in this model comes from two sources. The first is the direct decay, a four-fermion interaction. However, this is suppressed relative to the usual weak interactions by $(m_W/\Lambda)^4 \sim 10^{-4}$. The second source is mixing in the mass matrix $b(d\phi\phi) \to s(d\phi)$. This contribution is not suppressed by inverse powers of Λ but provides nonzero values for the usual Kobayashi-Maskawa (KM) mixing angles. The model thus predicts nontrivial KM angles, and also, at a smaller level, new neutral-current processes like $b \to ss\bar{d}$. The same suppression applies to $b \to s\mu^+\mu^-$.

For processes in which lepton pairs are created from effective four-fermion vertices.

$$K_L^0 \to \mu^\pm e^\mp,\ \ K^+ \to \mu^+\nu_e,\ \ K^+ \to \pi^+\mu^+e^-\ ,$$

there will be some extra suppression (coming from numerical values of the coefficient, and not from extra powers of Λ) due to the production of two extra lepton-quark pairs. This pushes the experimental limits[4] farther up for such processes.

The general idea of the model is thus to consider two pairs of basic fermions in separate color spaces which can be generalized to arbitrary dimensions. The leptons have composite structure on a hypercolor mass scale Λ while higher generations of quarks are consequences of the interaction of (u,d) with the preonic boson ϕ. There are no strong interactions for ϕ which is $q_L\bar{q}_L$ and the main ideas of QCD are preserved by the model. The idea of the scalar boson as a generation component has been suggested by using a Higgs[5] boson and supersymmetry[6] but at different levels of compositeness. The present model incorporates the symmetry group $SU(3)_L \otimes SU(3)_B \otimes SU(2)_I \otimes U(1)_Y$ which is a much smaller group than the local SU(8) theory proposed by some authors.[7] Thus a new look at the quark-lepton relationship can considerably simplify preon models while keeping the good features of the theory. The actual existence of ϕ or $\phi\bar{\phi}$ bosons and their excitations in the high-TeV range would be positive evidence for the model.

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