Gravitational decays of heavy quarks and leptons

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Gravitational decays of hypothetical heavy quarks and leptons which are stable with respect to all other interactions are discussed. Composite quarks and leptons with "dimensions" $\sim M^{-1}$ (M is the grand unified mass) and a mass on the order of $G_F^{-1/2}$ decay (into known quarks and leptons) at the rates of ordinary weak decays. The same mechanism generates composite-neutrino masses in the electron volt range.

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The idea that a black hole might not conserve baryon charge was advanced by Wheeler some time ago.[1] Zel'dovich[2] and Hawking *et al.*[3] have discussed the gravitational annihilation of the proton by virtual black miniholes (with a Planck mass, $M_0 \cong 10^{19}$ GeV)[1)] and have derived a corresponding proton lifetime, $\tau_p \sim 10^{45}$ yr. At the moment, unfortunately, it is not technically feasible to observe such a slow decay. The standard grand unified models,[4] on the hand, predict a much less stable proton ($\tau_p \sim 10^{30-33}$ yr).

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There is another case in which the mechanism of Refs. 2 and 3 might be studied. This approach would involve detecting the gravitational decays of hypothetical heavy quarks and leptons which are stable with respect to all other interactions. Such quarks and leptons (Q,L) will necessarily appear [along with ordinary quarks and leptons (q,l)] in the fermion spectrum of composite grand unified models,[4] in particular, in the SU(8) model which I recently proposed.[5] Since the "radius" of the composite fermions $(R \sim M^{-1}$, $M \sim 10^{15}$ GeV) is approximately equal to the gravitational radius $(R_0 \sim M_0^{-1})$, the decays of (Q,L) states into known quarks and leptons (q,l) resulting from the mechanism of Refs. 2 and 3 should be greatly accelerated. To estimate these rates in order of magnitude, we must specify some model for the preon structure of the composite fermions and their masses. For this purpose we turn to the SU (8) model.[5]

In SU(8) model with the metacolor group[2)] $SO(3)_L \otimes SO(3)_R$, the three families of known quarks and leptons

$$(u\, d\, e\, \nu_e),\ (c\, s\, \mu\, \nu_\mu),\ (\ t?\ b\, \tau\, \nu_\tau\ ) \tag{1}$$

are contained in a representation (with a dimensionality of 216) which is formed by bound states of "left-handed" preons, $\mathscr{P}_{i\alpha L}$ $(i,j,k = 1,2,3)\mathrm{SO}(3)_L$ $\{\alpha,\beta = 1,...,8$ $[\mathrm{SU}(8)]\}$:

$$\psi^{(1)\alpha}_{[\beta\gamma]}(x) = \hat{D}(\gamma_\mu \mathscr{P}_{i\beta L}(x))(\bar{\mathscr{P}}^{\alpha}_{jL}(x)\gamma_\mu \mathscr{P}_{k\gamma L}(x))\,\epsilon_{ijk}, \tag{2}$$

where $\hat{D} = \gamma_\nu D_\nu$, and D_ν is a covariant derivative [covariant with respect to the SU(8) indices of the preons]. In the approximation of "valence" preons, the preon current in (2) corresponds to a graphic model in which a bound state of three preons with a zero mass $(p^2 = (p_1 + p_2 + p_3)^2 = 0)$ is formed by massless preons $(p_1^2 = p_2^2 = p_3^2 = 0)$ which are moving in a common direction. It is then clear that a state with a spin of $\frac{1}{2}$ (and a helicity of $-\frac{1}{2}$) can be obtained only by "assembling" two preons and one antipreon into a quark or lepton. With all the states in (2) we may associate a "left-handed" preon number $N_L = 1$. In a similar way we can construct the preon current $\psi^{(2)\alpha}_{[\beta\gamma]R}$, which corresponds to a multiplet of states (again with a dimensionality of 216, but in this case with a helicity of $+1/2$) for "right-handed" preons, by making the replacements $L \rightarrow R$ and $i, j, k \rightarrow s, t, u$ $[\mathrm{SO}(3)_R]$ in (2), with the "right-handed" preon number $N_R = 1$.

A decomposition of the $216^{(1)}_L$ and $216^{(2)}_R$ multiplets in $\mathrm{SU}(5) \otimes \mathrm{SU}(3)$ yields

$$216 = (\bar{5}.\bar{3}) + (10.\bar{3}) + (\overline{45}.1) + (24.3) + (5.8) + (5.1) + (1.3) + (1.\bar{6}). \tag{3}$$

After breaking, all the states in these multiplets, except the three left-hand-helicity SU(5) families $(q,l) = (\bar{5} + 10.\bar{3})_L$ and the three right-hand-helicity families $(Q,L) = (\bar{5} + 10.\bar{3})_R$ acquire masses $\sim M$ (Ref. 5), and we will not discuss them. The (q,l) families are the known quarks and leptons [see (1)], while the (Q,L) families are new quarks and leptons with the $(V + A)$ weak-interaction structure, but with the same set of $\mathrm{SU}(3)_c \otimes U(1)_{EM}$ charges as for the families in (1). The masses of the (Q,L) states have an upper limit on the order of v, where v is the vacuum expectation of the Higgs scalar, which also furnishes masses for the weak bosons $W^\pm$ and Z^0; $v = (2\sqrt{2}G_F)^{-1/2}$. There are no transitions between the (q,l) and (Q,L) families, since the condition of separate conservation of the left-hand preon number and of the right-hand preon number, $\Delta N_L = \Delta N_R = 0$, is satisfied everywhere in the composite SU(8) Lagrangian. It follows that the lightest quarks and leptons in the "right-handed" (Q,L) families are stable with respect to all SU(8) interactions.

We thus have a situation in which the mechanism of Refs. 2 and 3 can operate without any competition and in which the global quantum charges are not necessarily conserved.[1] In this case, a quark Q from a right-handed family may be captured by a virtual black hole, and an ordinary quark q (with the same gauge flavors) may be emitted in its place. These transitions with $\Delta N_L = \Delta N_R = \pm 1$ cause a nondiagonal fermion mass term in the composite SU(8) Lagrangian. When we take into account the structure of the composite fields $\psi^{(1,2)}$ [see (2)], we see that this term should be of the form[3)]

$$\Delta \mathcal{L} \sim (M/M_0)^7 M[\bar{\psi}_L^{(1)} \psi_R^{(2)} + h.c.] \,. \tag{4}$$

This term leads to a slight mixing of the q and Q quarks in the weak currents of the diagonalized q' and Q' quarks, with an angle $\phi \sim (M/M_0)^7 (M/m_Q)$ (m_Q is the mass of Q). Assuming for definiteness that the lightest of the Q quarks in the U quark (an analog of the q quark), we have the decay $U' \to d + e^+ + v_e$ with the rate

$$\Gamma_Q \cong \phi^2 (m_Q/m_\mu)^5 \Gamma_\mu \sim (M/M_0)^{14} (M/m_Q)^2 (m_Q/m_\mu)^5 \Gamma_\mu \tag{5}$$

(it is convenient to compare this decay with the kinematically equivalent decay of a muon). The experimental lower limit on the proton lifetime requires[4)] $M \geqslant 10^{14}$ GeV. On the other hand, an upper limit on M can be derived from (4): Relation (4) generates Dirac masses for the neutrinos whose left-hand components belong to (q, l) families, (1), and whose right-hand components belong to (Q, L) families. The magnitude of this mass is $m_{v_i} \sim (M/M_0)^7 M$ ($i = e, \mu, \tau$). Assuming $m_{v_e} \lesssim 30$ eV, in accordance with experiment,[4] we find $M \lesssim 5 \times 10^{15}$ GeV. Finally, the best description of the hierarchy of mass scales in the composite grand unified models is achieved at the values[4)] $M \sim (5.0 - 1) \cdot 10^{16}$ GeV (Refs. 1 and 7). Adopting $M = 5 \times 10^{15}$ GevV, we find the interval of decay rates $\Gamma_Q \sim 10^{2-5}$ s^{-1} for the masses $m_Q \sim 10^{2-3}$ GeV. These are (in order of magnitude) the decay rates of the lightest lepton, E, of the right-hand family and of the lightest hadrons containing U quarks.

The creation of pairs of such hadrons and leptons in accelerators, followed by a slow decay of one of them, would constitute evidence for the mechanism of Refs. 2 and 3 for the nonconservation of global quantum numbers (in this case, the chiral preon number), as a result of gravitational fluctuations of the vacuum at ultrashort distances. Since the contribution of this mechanism seems to be vanishingly small for elementary fermions,[3] the observation of these decays could also be taken as experimental evidence for a preon confinement radius $R \sim 10^{15}$ GeV^{-1}.

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[1)]Here and below, we have in mind the gravitational fluctuations of vacuum with the topology of the black hole and an average density: a Planck-volume fluctuation.[3]

[2)]The metacolor group, which corresponds to the forces which "assemble quarks and leptons from preons," must have a chiral structure in order to prevent the appearance of a preon condensate, which would unavoidably lead to masses $\sim R^{-1}$ for the composite fermions, where R is the metaconfinement radius.[5,6]

Here we must set $R \lesssim 10^{-14}$ GeV^{-1} if the decay rate of the proton due to the elastic redistribution of preons within the proton is not to "go beyond" the experimental boundary[6] $\Gamma_p \lesssim 10^{-30}$ yr^{-1}.

[3)]*The seventh power of the Planck mass M_0 in the denominator in (4) follows from the effective six-preon* interaction, which we must write for this transition in the preon Lagrangian. The mass M corresponds to "dimensions" $R \sim M^{-1}$ for the composite Q quarks.

[4)]Remarkably, these three independent (albeit approximate) estimates of $M \sim R^{-1}$ all fall in the interval 10^{14-16} GeV (these estimates are based on the proton lifetime, the neutrino mass, the gauge hierarchies).

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