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Dynamical symmetry breaking through preons and the sizes of composite quarks and leptons

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It is observed that the assumptions that quarks and leptons are composites and that they acquire masses dynamically through preonic condensates rather than through the vacuum expectation value of a Higgs field lead to a relatively low upper bound of only 1 to 3 TeV for the inverse size of the heaviest family—e.g., the τ family. It is furthermore stressed that the e and μ families, within a large class of models, must, on the other hand, have a relatively large inverse size exceeding about 150 TeV; this is so in order that the limits from rare processes such as $K_L \rightarrow \bar{\mu}e$ and K^0-$\bar{K}^0$ may be satisfied. Certain theoretical and experimental implications of these two observations are noted.

I. INTRODUCTION

If quarks and leptons are composites[1] of more elementary objects—preons—the most important parameter from an experimental standpoint pertains to their size. They may well be composite, but if their sizes are far smaller than 10^{-17}–10^{-18} cm, i.e., if their inverse sizes are much larger than 10 TeV, say, their compositeness will unfortunately remain undetected in machines of the near future.

Most theoretical models which suggest a compositeness scale (i.e., inverse size) of order 1 TeV for quarks and leptons base their suggestion, on the one hand, on the *lower limits* on this scale derived from experiments involving, for example, measurements of $(g-2)_{e,\mu}$ and $e^-e^+ \rightarrow e^-e^+$, $\mu^-\mu^+$ scatterings,[2] and on the other hand, from the fact that the electroweak symmetry-breaking scale characterized by $G_F{}^{-1/2}$ is nearly 300 GeV. Quite often the suggestion for such a low compositeness scale has in fact been made primarily on the basis of a desire for experimental observability of compositeness rather than on the basis of any compelling theoretical argument.

The main purpose of this Rapid Communication is to observe that within a large class of composite models in which at least the heaviest composite quark receives its mass through the formation of bilinear fermionic-preon condensates rather than via a Higgs-type mechanism, the inverse size of the heaviest family—which one could identify with the τ family—is bounded from above by nearly 1 to 3 TeV. For reasonable values of certain effective coupling constants, the range of 1 to 3 TeV in fact represents the true value of the inverse size of the heaviest family. We furthermore draw attention to the fact that within a class of preonic models (this includes the "minimal" fermion-boson or the flavon-chromon models,[3] which have recently been used widely in the literature[4,5]), the limit from the $K_L \rightarrow \bar{\mu}e$ decay rate requires that the inverse sizes of the e and μ families (Λ_{0e} and $\Lambda_{0\mu}$) must exceed about 150 TeV (Ref. 6). In some cases,[5] where the μ family is merely a quantum pair excitation of the e family, the known strength of the K^0-$\bar{K}^0$ transition imposes the more severe constraint that Λ_{0e} and $\Lambda_{0\mu}$ must exceed about 1000 TeV. These lower limits on Λ_{0e} and $\Lambda_{0\mu}$ are at variance with the suggestions of certain recently suggested models.[5] Some theoretical and experimental implications of the observations of the relatively large size of the τ family, on the one hand, versus the possible small sizes for the e and the μ families, on the other hand, are noted.

II. AN UPPER BOUND

Consider the class of preonic models in which the preons are bound by an underlying QCD-like force to make composite quarks and leptons, which are neutral with respect to the binding force. Consider the heaviest composite quark q^H. This may correspond to the top quark, or to a t' quark belonging to a fourth τ' family, if it exists. (I) Assume that the composites $q^H_{L,R}$ consists of—among their constitents—spin-$\frac{1}{2}$ preons $f^H_{L,R}$ which, in the chiral limit, define the flavor-chiral transformation properties of $q^H_{L,R}$, such that the system $(q^H_L + \bar{q}^H_R)$ has the same strong-interaction quantum numbers as $(f^H_L + \bar{f}^H_R)$. (II) Assume that at least this heaviest composite quark q^H acquires its mass through a dynamical breaking of chiral symmetry owing to the formation of *bilinear fermionic-preon condensates* $\langle \bar{f}^H_L f^H_R \rangle \equiv \Lambda(f^H)^3$, rather than via an effective Higgs-type mechanism involving either elementary or composite Higgs bosons of very small size ($<< 1$ TeV^{-1}). Here, we are presuming, of course, that the condensate $\langle \bar{f}^H f^H \rangle$ is formed under the influence of a preonic technicolorlike force under which the preon f^H is non-neutral. Unlike familiar technicolor models,[7] however, we are assuming, in the spirit of a preonic model, that the condensate-forming fermion f^H is itself the constituent[8] of the heaviest quark q^H. For this reason, one does not need to introduce extended technicolor.

Now the argument on the inverse size of q^H goes as follows. By the assumption narrated above, since f^H is a constituent of q^H, we expect the four-fermion process $q^H_L + f^H_R \rightarrow q^H_R + f^H_L$, or equivalently $q^H_L + \bar{q}^H_R \rightarrow f^H_L + \bar{f}^H_R$, which conserves all quantum numbers of the strong binding interactions, to be of order $\kappa^2/\Lambda_{0,H}{}^2$. Here Λ_{0H} denotes the inverse size of q^H, which is expected to be of the order of the scale parameter of the binding force, and κ^2 is a dimensionless strong-interaction parameter of order unity. Now the four-fermion process leads to an effective interaction

$$(\kappa^2/\Lambda_{0,H}{}^2)(\bar{q}^H q^H)(\bar{f}^H f^H) \; .$$

Subject to the formulation of the condensate $\langle \bar{f}_H, f_H \rangle$, this in turn leads to a mass term for q^H:

$$m(q_H) = \kappa^2[\Lambda(f^H)^3/\Lambda_{0,H}{}^2] \; , \qquad (1)$$

i.e.,

$$\Lambda_{0,h} = \kappa[\Lambda(f^H)^3/m(q^H)]^{1/2} \; .$$

Since the condensate $\langle \bar{f}^H f^H \rangle$, while breaking global

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flavor-chiral symmetry, breaks the electroweak gauge symmetry $SU(2)_L \times U(1)$ as well, it follows, from the empirically observed scale of electroweak breaking, that the condensate parameter $\Lambda(f^H)$ is bounded above by about $\frac{1}{3}$ TeV: $\Lambda(f^H) \lesssim \frac{1}{3}$ TeV. The equality or near equality would apply if the condensate $\langle \bar{f}^H f^H \rangle$ is the only source or the dominant source of $SU(2)_L \times U(1)$ breaking. Now, from the experimental searches at DESY PETRA and $\bar{p}p$ colliders it appears that the mass of the top quark lies above about 30 GeV and it may well lie between 40 and 50 GeV. In any case, if we substitute, conservatively, $m(q^H) = m_t > 30$ GeV, $\Lambda(f^H) \lesssim \frac{1}{3}$ TeV, and $\kappa^2 \lesssim 10$, we obtain an upper bound on the inverse size of the heaviest quark:

$$\Lambda_{0,H} \lesssim 3.3 \text{ TeV} \quad [\text{for } m(q^H) = m_t > 30 \text{ GeV}] \ . \tag{2}$$

If the heaviest quark is a t' belonging to a fourth family with a mass $m_{t'} \simeq \frac{1}{10}$ to 1 TeV, say, its inverse size would be bounded above by $\Lambda_{0,H} \lesssim 2.4$ to 0.8 TeV. This is the reason for our assertion that the inverse size of at least the heaviest composite quark is bounded above by about 1 to few TeV. This is a *theoretical upper bound,* based primarily on the assumption of dynamical mass generation for the heaviest quark through bilinear fermionic-preon condensates.[8] Assuming that all members belonging to a given family have the same composite structure, the stated upper bound applies to the inverse size of all members of at least the heaviest family. The heaviest family may correspond to the τ family, or alternatively to a fourth τ' family, if it exists. A few remarks are now in order.

(i) In the analysis presented so far, we have set aside the question of the origin of the mass splittings within a family, represented, for example, by $(m_t - m_b)$, $(m_c - m_s)$, $(m_b - m_\tau)$, $(m_s - m_\mu)$, etc., and of the mass differences between the families represented, for example, by $(m_t - m_c)$, $(m_b - m_s)$, etc. These may, in general, arise (a) due to a nonperturbatively generated hierarchy in the sizes of the condensates involving different preon flavors,[10] or (b) due to a hierarchy in the sizes of the families[9] (e.g., $\Lambda_{0e} = \Lambda_{0\mu} >> \Lambda_{0\tau}$), or (c) due to symmetries which may provide extra protection to the mass of one family relative to another.[11] One can, in general, conceive of a combination of these mechanisms (see, e.g., Refs. 9 and 12) to solve the full fermion-mass-hierarchy problem. In this note, we do not wish to address ourselves to this admittedly ambitious problem. The point of this note has been that the assumption of dynamical chiral-symmetry breaking through fermionic preons seems to provide an interesting upper bound [see (2)] on the inverse size of the heaviest family, regardless of the mechanism of the generation of mass hierarchy. For this purpose, we have found it reasonable to focus attention on the mass generation for the heaviest quark as this truly represents the scale of $SU(2)_L \times U(1)$ breaking in the context of dynamical symmetry breaking through preons.

(ii) While we have stated the result (2) as an upper bound on $\Lambda_{0,H}$, it is clear from Eq. (1) that for a reasonable value of $\kappa^2 \simeq 1$ to 10, and with $m(q^H) \simeq 40$ GeV–1 TeV, and $\Lambda(f_H) \simeq 300$ GeV, say, we expect $\Lambda_{0,H} \simeq \frac{1}{5}$–3.3 TeV. In other words, the inverse size of at least the heaviest family is in fact *equal* to about 1 TeV within a factor of 3, say, either way. We thus see that the chiral-symmetry-breaking parameter $\Lambda(f^H)$, which is about 300 GeV, is indeed comparable to the inverse size of at least the heaviest family. We have $\Lambda_{0,H}/\Lambda(f^H) \simeq 0.66$–10. This naturally suggests that one and the same force binds the heaviest family (τ and/or τ') and also breaks chiral symmetry. In other words, judged at least from the point of view of the heaviest quark which could be identified with the top, it seems to us that *chiral symmetry is broken by quantum preon dynamics very much as in the case of QCD.*[13] This becomes apparent, even more so, if there exists a fourth family with a t' quark with mass ~ 100 to few hundred GeV. The lightness of the e and μ families compared to the mass of the τ or a fourth τ' family as well as the lightness of the bottom quark and the τ lepton compared to the mass of the top quark may well have its origin in one or several of the three mechanisms mentioned above.

III. THE SIZES OF THE e AND μ FAMILIES

We now discuss the question of the sizes of the e and μ families within the minimal fermion-boson or flavon-chromon preon models,[3] which are being actively pursued.[4,5] The essential feature of this class of models is that quarks and leptons are composites of two types of preons —those which carry only flavor and those which carry only color; quarks *and* leptons in a given family are composed of the same flavor attributes ("flavons"), i.e., $f(q_d) = f(e^-)$, $f(q_s) = f(\mu^-)$, etc., but they differ from each other only in respect of their color attributes ("chromons"), i.e., $C(q_d)^* \neq C(e^-)^*$ and $C(q_s)^* \neq C(\mu^-)^*$. In the interest of economy, the *"minimal"* models of this type furthermore assume that the e *and* μ families are made of the same chromons for quarks and leptons, i.e., $C(q_d)^* = C(q_s)^* \equiv C_q^*$ and $C(e^-)^* = C(\mu^-)^* \equiv C_l^*$. In addition, these models assume that one *and* the same force binds the preons of the e *and* μ families giving them a common inverse size $\Lambda_{0e} = \Lambda_{0\mu} = \Lambda$.

In this class of models the four-fermion process $q_d + \bar{q}_s \rightarrow e^- + \mu^+$, and, therefore, the decays $K_L \rightarrow \bar{\mu} e$ and $K_L \rightarrow \pi \bar{\mu} e$, would consist of an underlying preonic transition $(f_d + C_q^*) + (\bar{f}_s + C_q) \rightarrow (f_d + C_l^*) + (\bar{f}_s + C_l)$, which clearly conserves all quantum numbers defined by the preonic strong interaction. We thus expect the four-fermion process to be induced through preon dynamics with an amplitude of order (A^2/Λ^2), where $A^2 \sim 1$ to 10, say. From the presently known lower limit on the rate of $K_L \rightarrow \bar{\mu} e$ decay,[14] one can thus deduce[15] that the inverse sizes of the e and μ families, at least for the *minimal* fermion-boson models, must exceed about 150 TeV (for $A^2 > 1$):

$$\Lambda_{0e} = \Lambda_{0\mu} > 150 \text{ TeV} \ . \tag{3}$$

Now, consider the class of models in which the μ family has precisely the same preonic quantum numbers (attributes) as the e family, but differs from it, say, by a quantum pair excitation, with the pair being *neutral* with respect to all conserved quantum numbers. The recently suggested fermion-boson preon models based on a quasi-Nambu-Goldstone-fermion (QNGF) approach, with two flavors plus four colors,[5,12] in fact belong to this class. In these models, the process $q_d + q_d \rightarrow q_s + q_s$, and therefore $K^0 \leftrightarrow \bar{K}^0$, can easily be induced through the strong preonic force via the excitations of relevant preonic pairs. The corresponding amplitude is expected to be of order B^2/Λ^2, where $B^2 \sim 1$–10, say. Comparing with the known strength of the real part of the K^0-$\bar{K}^0$ transition, we would need $(B^2/\Lambda^2) \lesssim 10^{-12}$ GeV^{-2}, or for $B^2 \gtrsim 1$,

$$\Lambda \gtrsim 1000 \text{ TeV} . \tag{4}$$

Thus the QNGF models, based on two flavors plus four colors, together with the suggestion[5] that the inverse sizes of the e and μ families are of order one to few TeV only, seem to be inconsistent with the limit from $K_L \to \bar{\mu}e$ as well as that from K^0-$\bar{K}^0$ transition.

If we consider the fermion-boson model, with four flavors plus four (or more) colors, as suggested in Refs. 1 and 9, the e and μ families can differ from each other at least in terms of their flavor attributes, i.e., $f(q_d) \neq f(q_s)$. In this case, the preon dynamics by itself will not induce the process $q_d + q_d \to q_s + q_s$ prior to Cabibbo mixing, and as such the strong constraint mentioned above from the K^0-$\bar{K}^0$ transition would not apply. But even in this case, one must ensure that the preon dynamics of the e and μ families must respect the equivalent of a Glashow-Iliopoulos-Maiani (GIM) mechanism at the preon level, such that the four-fermion processes (i) $q_d + q_d \to q_d + q_d$, (ii) $q_s + q_s \to q_s + q_s$, and (iii) $q_d + q_s \to q_d + q_s$ induced through compositeness respect GIM invariance to better than about $(10^{-12}$ GeV$^{-2}/\sin^2\theta_C)$ in the amplitude. Otherwise, subject to Cabibbo rotation these can induce $|\Delta S| = 2$ transitions (and therefore K^0-$\bar{K}^0$) with an amplitude $> 10^{-12}$ GeV^{-2}. *This suggests that the e and μ families have identical preon dynamics, although their preonic attributes (like their flavons) may differ from each other.* Alternatively, if one wishes to consider a model in which the e and μ families have differing preon dynamics, one must ensure that such a difference arises only at a scale exceeding about 200 TeV so that $(\sin^2\theta_C/\Lambda^2) \lesssim 10^{-12}$ GeV^{-2}. For example, if the e and μ families are bound by different preonic forces and thus have different sizes (i.e., $\Lambda_{0e} \neq \Lambda_{0\mu}$), it is imperative that both Λ_{0e} and $\Lambda_{0\mu}$ exceed about 200 TeV.[16]

To summarize, the assumption of dynamical mass generation for composite quarks and leptons suggests[17] that $\Lambda_{0\tau}$ and/or $\Lambda_{0\tau'} \lesssim 1$ to few TeV, and the limit from $K_L \to \bar{\mu}e$ decay suggests, that at least for the minimal fermion-boson models, for which the e and μ families have identical color-carrying preons, Λ_{0e} and $\Lambda_{0\mu}$ should exceed about 150 TeV.

Let us note briefly certain implications of these constraints on model building. First, observe that these two constraints are incompatible with each other if one insists on a universal size for e, μ, τ, and/or τ'. They suggest that, one way or another, one must go beyond the minimal fermion-boson model. Insofar as one wishes to maintain the assumption of dynamical mass generation for quarks and leptons, there appears to be two alternative ways of reconciling these two constraints:

(i) One may arrange the preon model so as to avoid the constraints of $K_L \to \bar{\mu}e$ and K^0-$\bar{K}^0$ and thereby hope to maintain relatively low universal inverse size of order 1 to few TeV for all three or four families. This could be possible, for example, by introducing four flavons

$$f_{L,R} = (u,d\,|\,c,s)^i_{L,R} \equiv (f_{\rm I}|f_{\rm II})^i_{L,R}$$

and eight complex spin-0 chromons

$$C = (r,y,b,l\,|\,r'\,y'\,b'\,l')^1 \equiv (C_{\rm I}|C_{\rm II})^i \ ,$$

as in Ref. 9, and assuming that these are nontrivial under a metacolor local gauge symmetry G_M with a scale parameter Λ_M as well as the familiar flavor-color local gauge symmerty $SU(2)_L \times SU(2)_R \times SU(4)^C$ (Ref. 3). Here, both $C_{\rm I}$ *and* $C_{\rm II}$ are quartets of the familiar color symmetry $SU(4)^C$. We can, in this case, construct four metacolor-singlet composite quark-lepton families, all of inverse size $\sim \Lambda_M$, out of "two-body" flavon-chromon composites:[18] $\psi_1 = f_{\rm I}C_{\rm I}^*$, $\psi_2 = f_{\rm II}C_{\rm I}^*$, $\psi_3 = f_{\rm I}C_{\rm II}^*$, and $\psi_4 = f_{\rm II}C_{\rm II}^*$. We can identify these composite families with the e, μ, τ and τ' families in a few alternative ways. But with the e and μ families being built out of two different sets of chromons (and possibly even different sets of flavons), e.g., with $F_e = \psi_1$ and $F_\mu = \psi_3$, or ψ_4, the straightforward arguments leading to the constraints from $K_L \to \bar{\mu}e$ and K^0-$\bar{K}^0$ do not apply. In this case, one may be able to choose $\Lambda_M \sim$ few to 10 TeV, say, so that all four families would have an inverse size of this order.[19] Details of this type of model will be presented elsewhere.

(ii) *Alternatively,* one may arrange the model so as to satisfy both constraints, i.e., $\Lambda_{0\tau} = 1$ to few TeV and $\Lambda_{0e} = \Lambda_{0\mu} > 150$ TeV. There is an intriguing mechanism for realizing this possibility by starting with the same four-flavon–eight-chromon system mentioned above, but assuming that the primed chromons $C_{\rm II} = (r',y',b',l')$ are associated with a new hypercolor gauge symmetry $SU(4)^H$ with a scale $\Lambda_H \sim 1$ TeV, rather than with the ordinary color. The metacolor gauge force with a scale $\Lambda_M \gtrsim 150$ TeV could be used to bind the e and μ families, while the τ and a fourth τ' family could be built as composites of composites through the hypercolor force. Details of this two-scale model have recently been presented in a separate note.[8,9]

Needless to say, for either alternative to be viable, one must examine the consistency of each alternative with hierarchical fermion masses and mixing angles as well as with cosmological problems such as the question of the generation of baryon excess in the early universe. These questions will be treated separately.

To conclude, the main point of this Rapid Communication is the observation that the assumption of dynamical mass generation through fermionic-preon condensates leads to a relatively low value of only 1 to few TeV for the inverse size of the τ and/or τ' family. This says that there is an *a priori* fairly compelling theoretical reason to expect that high-energy machines of the near future should help discover compositeness of quarks and leptons at least through the heaviest τ and/or τ' families. Even if the e and μ families are made as small-size composites (i.e., $\Lambda_{0e} = \Lambda_{0\mu} \gtrsim 150$ TeV), the eventual mass mixing of these families with the large-size τ and/or τ' families, through whatever mechanism,[20] should permit one to observe signals of compositeness of a few-TeV scale even for these families, albeit with some damping due to mixing. With such a mixing one would expect to see clear signals of compositeness through family-nondiagonal processes such as $(e^-e^+$ or $q_e\bar{q}_e)$ $\to \tau^-\tau^+$, $q_b\bar{q}_b$, $q_t\bar{q}_t$, etc., for center-of-mass energies ~ 1 TeV. If the e and μ families have a very small size $\ll (1$ TeV$)^{-1}$, the signals will not, however, be prominent at these energies in the family-diagonal processes[2] such as $(e^-e^+$ or $q_e\bar{q}_e) \to e^-e^+$ and $q_e\bar{q}_e$, unless the mixing is large $\sim 50\%$ (say), which is unlikely.

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[1]For a review, see, e.g., M. E. Peskin, in *Proceedings of the 1981 International Symposium on Lepton and Photon Interactions at High Energies, Bonn, 1981,* edited by W. Pfeil (Physikaliches Institut, Universität Bonn, Bonn, 1981), p. 880; L. Lyons, Prog. Part. Nucl. Phys. **10**, 227 (1983).

[2]See, e.g., E. J. Eichten, K. D. Lane, and M. E. Peskin (unpublished), and references therein.

[3]J. C. Pati and Abdus Salam, Phys. Rev. D **10**, 275 (1974), footnote 7; J. C. Pati, Abdus Salam, and J. Strathdee, Phys. Lett. **59B**, 265 (1975).

[4]See, e.g., H. Terazawa, Y. Chikashige, and K. Akama, Phys. Rev. D **15**, 480 (1977); O. W. Greenberg and J. Sucher, Phys. Lett. **99B**, 339 (1981); H. Fritzsch and G. Mandelbaum, *ibid.* **102B**, 319 (1981).

[5]O. W. Greenberg, R. N. Mohapatra, and M. Yasue, Phys. Rev. Lett. **51**, 1737 (1983).

[6]J. C. Pati, in *Proceedings of the 21st International Conference on High Energy Physics, Paris, 1982,* edited by P. Petiau and M. Porneuf [J. Phys. (Paris) Colloq. **43**, C3-297 (1982)]; J. C. Pati (unpublished); I. Bars, in *Proceedings of the XVIIth Recontre de Moriond, Les Arcs, France, 1982,* edited by J. Tran Thanh Van (Editions Frontieres, Gif-sur-Yvette, 1982), Vol. 1, p. 54; M. E. Peskin (private communications); and Ref. 1.

[7]See E. Farhi and L. Susskind, Phys. Rep. **74**, 277 (1981), for a review and relevant references.

[8]For a discussion on dynamical symmetry breaking through preons, see Pati (Ref. 6). The fact that a class of preonic models, in which the e and μ families differ from each other by some attribute, have an in-built Glashow-Iliopoulos-Maiani mechanism and, therefore, avoid excessive flavor-changing neutral-current processes, has been noted in this paper. We stress that in some cases the condensate forming fermion f_H, which is also the constituent of q_H, need not be elementary; it may be a composite of more elementary objects (as in Ref. 9).

[9]J. C. Pati, Phys. Lett. (to be published); work presented at the 1983 Workshop of the International Centre for Theoretical Physics, Trieste (unpublished).

[10]M. Cvetic and I are examining this possibility.

[11]See, e.g., Ref. 5, and references therein.

[12]R. N. Mohapatra, J. C. Pati, and M. Yasue, Univ. of Maryland Technical Report No. 84-145 (unpublished). In the quasi-Nambu-Goldstone fermion model the e and the μ families, following the suggestion of Ref. 9, and barring mixing, are assigned a very small size $<< (1\ \text{TeV})^{-1}$, while the τ family is interpreted as a composite of composites (Ref. 9), having a relatively large size $\sim (1\ \text{TeV})^{-1}$.

[13]As a side remark, it is good to stress that even if the quantum preon dynamics that is relevant for the heaviest family like τ, breaks chiral symmetry in a manner similar to that of QCD, the dynamically generated mass of the composite q^H, owing to its cubic dependence on $\Lambda(f^H)$ [see Eq. (1)], may easily differ by more than one order of magnitude from the scale parameter Λ_{QPD} of the preon-binding force. For instance, it is not unreasonable to have $\Lambda(f^H) \simeq \frac{1}{3}\Lambda_{\text{QPD}}$, say, while $\Lambda_{0,H} \simeq (2\text{ to }3)\Lambda_{\text{QPD}}$, say. Then, following Eq. (1), one may expect $m(q_H) \simeq (\frac{1}{10}\text{ to }\frac{1}{25})\Lambda_{\text{QPD}}$, even if $\kappa^2 \simeq 10$. Thus, with $m_t \simeq 40$ GeV and $\Lambda_{\text{QPD}} \sim 1$ TeV, say, the assumption of preservation of chiral symmetry for the τ family is not needed. We believe that the chief difference between QCD versus QPD, which is relevant for the binding of the τ family is that the former conserves vectorial flavor symmetry while breaking chiral flavor symmetry, but the latter breaks both. The underlying reason, we suspect, is supersymmetry (Ref. 9).

[14]The published upper limit for the branching ratio $B(K_L \to \bar{\mu}e)$, on the basis of the experiment by A. R. Clark *et al.* [Phys. Rev. Lett. **26**, 1667 (1971)] is 1.57×10^{-9}. Considering that the same experiment set the limit $B(K_L \to \bar{\mu}\mu) < 1.82\times10^{-9}$, and that $K_L \to \bar{\mu}\mu$ decay was subsequently seen by many groups [W. C. Carithers *et al.*, Phys. Rev. Lett. **20**, 1336 (1973); Y. Fukushima *et al.*, Phys. Rev. Lett. **36**, 348 (1976); M. J. Shochet *et al.*, Phys. Rev. Lett. **39**, 59 (1977)] with a branching ratio $\simeq 10^{-8}$, it seems fair to say that the rate for the $\kappa_L \to \bar{\mu}e$ decay is not very much greater than that of the $K_L \to \bar{\mu}\mu$ decay. Thus we take as a fair estimate $B(K_L \to \bar{\mu}e) \lesssim 10^{-8}$.

[15]For analogous considerations for the limit on the masses of the leptoquark gauge bosons of $\text{SU}(4)^{\text{color}}$ (Ref. 3), see S. Dimopoulos, S. Raby, and G. L. Kane, Nuc. Phys. **B182**, 77 (1981); N. G. Deshpande and R. J. Johnson, Phys. Rev. D **27**, 1193 (1983). These limits were based, however, on the stringent upper limit of $B(K_L \to \bar{\mu}e) \lesssim 1.57\times10^{-9}$ (see Ref. 14).

[16]A similar remark would apply to models in which the e and μ families are built out of the *same* flavor and color attributes, but differ from each other in respect of, for example, flavon and/or chromon numbers. For instance, suppose $\psi_e = (fC^*)$ and $\psi_\mu = (fffC)^*$, both ψ_e and ψ_μ being neutral under the preon-binding force. A model of this kind has been considerd by Terazawa, Chikashige, and Akama (Ref. 4). In this case, owing to different composite structures for the e and μ families, we expect that the amplitudes for $q_d + q_d \to q_d + q_d$ and $q_s + q_s \to q_s + q_s$ would differ from each other by terms of order (B'/Λ^2) and, thus, we must have $(B' \sin^2\theta_C)/\Lambda^2 \lesssim 10^{-12}\ \text{GeV}^{-2}$, i.e., $\Lambda \gtrsim 200$ TeV (for $B' \gtrsim 1$), for this model.

[17]Needless to say, this prediction would not hold, if we introduced elementary or effectively elementary Higgs fields, with Yukawa couplings with the preonic or the composite fermions, because in this case the fermion masses would have only a linear dependence on the scale of the Higgs-field vacuum expectation value.

[18]Strictly speaking, quarks and leptons are composites of the form fC^*V where V denotes gluons of the preonic gauge symmetry (see Ref. 9, footnote 1). The presence of V will not, however, alter selection rules.

[19]A fermion-boson preon model with a single scale parameter $\sim$ few to ten TeV is, however, likely to suffer from other difficulties involving cosmological issues, as stressed in Ref. 9. First, one must face the problem of the generation of the baryon excess in the early universe, the relevant temperature scale for which far exceeds 10 TeV. Second, in these models, flavon and chromon numbers are good global symmetries of the preonic Lagrangian. Unless they are broken spontaneously, one would expect stable members which are likely to conflict with present energy density. If they are broken spontaneously, as in Ref. 9, there would be massless Goldstone bosons, which would be sufficiently weakly coupled and, therefore, consistent with observation, only provided $\Lambda \gtrsim 10^9$ GeV [see Y. Chikashige, R. N. Mohapatra, and R. D. Peccei, Phys. Lett. **98B**, 265 (1981); G. B. Gelmini, S. Nussinov, and T. Yanagida, Nucl. Phys. **B219**, 31 (1983)].

[20]An explicit realization of such a mixing in the context of a two-scale preon model has recently been presented in Ref. 9.