CAN THE PREON SCALE BE SMALL?

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SUMMARY

The preon scale Λ_p is bounded from below by rare or unobserved processes and from above by the cosmological abundance of stable heavy composites. On the other hand composite models can be tested by the Superconducting Super Collider (SSC) or by low energy precision experiments only if Λ_p is allowed to be at most 5-10 TeV. In search of such models we re-examine some conditions that must be fulfilled if Λ_p is small, and point out the possibility of certain mechanisms that could avoid the dangerous rare processes. In addition, certain properties of exotic composite particles, their possible role in breaking the electroweak symmetry and in producing observable signals beyond the standard model are also discussed.

1. LOW ENERGY CONSEQUENCES OF PREON SYMMETRIES

The structure of a preon theory is similar to QCD in many ways. Quarks are confined by color forces at a scale Λ_{QCD} to form hadrons; preons are confined by precolor forces at the scale Λ_p to form composite quarks and leptons (and maybe some exotics). Like the quarks, preons come in several (pre) flavors that define the preonic symmetries. The major difference from QCD is that the preonic chiral symmetries must remain unbroken in the vacuum[1]. They are slightly broken when perturbed by another force which is small compared to precolor. This generates the small masses, $m \ll \Lambda_p$, of quarks and leptons.

At low energies ($E \ll \Lambda_p$), in analogy to the sigma model that follows from QCD, we may write an effective theory (see e.g. ref. 2) that describes the low lying composite states of the preon theory. This must have the form

$$L_{eff} = L(\text{standard}) + L(\text{non-renormalizable}).$$

The symmetry structure of L_{eff} is dictated at the scale Λ_p where the bound states form. At Λ_p all known forces (including QCD) are small compared to the confining precolor interactions. It is therefore useful to consider the limit in which all forces except for precolor is turned off. The fully conserved preonic flavor symmetries G_F that show up in this limit govern the classification of all composite states. These may include

(i) 3 or more generations of <u>massless</u> quarks and leptons

(ii) <u>Massless</u> exotics (color, weak isospin, charge)

(iii) Heavy composites $m \gtrsim \Lambda_p$ classified in irreducible representations {r} of G_F.

Only the states (i) and (ii) are included in L_{eff}. At energies $E \gtrsim \Lambda_p$ the states (iii) are also considered.

The symmetries G_F also govern the structure of the 4-fermi and other non-renormalizable interactions that appear in the effective low energy Lagrangian. SU(3) x SU(2) x U(1) must be a subgroup of G_F. It is gauged. The classification and structure of interactions provided by G_F are only slightly changed when QCD, electroweak or other mass generating interactions are turned on (however, the model should have the property that these symmetry breaking interactions must not mediate undesirable levels of neutral $\Delta S = 1,2$ or other reactions that may be introduced via mass generation and "Cabibbo" mixing).

The important role of the 4-fermi interactions for testing compositeness at low energies was first discussed in Ref. 2 and later in the 82 workshop[3] and other articles[4]. In the effective theory the 4-fermi interactions are assumed to have the strength $\lambda^2/2\Lambda^2_p$. If they mediate a rare or unobserved process then Λ_p may be required to be large. Here are some of the bounds on Λ_p taken from Ref. 2.

Process	Limit on Λ_p
Proton decay	$\Lambda_p \gtrsim \lambda \times 10^{13}$ TeV
K^0-$\bar{K}^0$ mixing	$\Lambda_p \gtrsim \lambda \times 400$ TeV
D^0-$\bar{D}^0$ mixing	$\Lambda_p \gtrsim \lambda \times 50$ TeV
$K^+ \to \pi^+ \mu e$	$\Lambda_p \gtrsim \lambda \times 30$ TeV
$K_L \to \mu e$	$\Lambda_p \gtrsim \lambda \times 25$ TeV

Naively the magnitude of λ (unless $\lambda=0$ because of symmetry) is estimated to be of order 1 by analogy[2,6] to QCD. [Note different definitions of the scale Λ used by others authors[3,4].] We see that from the point of view of the SSC the most interesting models are those with enough symmetries that require $\lambda=0$ to supress each one of the above (and similar rare) processes.

It is remarkable that many of the proposed preon models can be banned from the TeV regime (i.e. $\Lambda_p \gg$ few TeV) thanks to the existence of the few precision measurements listed above. There are proposed experiments to improve the limits of K-decays. The impact of future experiments on Λ_p can be estimated by noting that the dependence of the decay rates on Λ_p is quartic[2]: Γ (K-decay)$\sim(1/\Lambda_p)^4$.

It is not difficult to find models[2] with symmetries that suppress the 4-fermi and higher dimension interactions (i.e. $\lambda=0$ indentically) that mediate (1) proton decay, (2) K^0-$\bar{K}^0$ mixing and (3) D^0-$\bar{D}^0$ mixing. The criteria to eliminate these are as follows[2]: (1) Baryon number must be one of the conserved quantum numbers in the form of a U(1) embedded in G_F. (2) There must be no symmetry embedded in G_F that can transform the left-right components of the composite strange quark when written in the form (s_L, s^c_L), where s^c_L is the charge conjugate of s_R. This may be assured by requiring s_L, s_R to belong to distinct representations of the (sub)group(s) of G_F. (3) There must be no symmetry in G_F that can mix the left-right components of the composite charmed quark in the form (c_L, c^c_L) where c^c_L is the charge conjugate of c_R. Again, this may be assured by requiring c_L, c_R to belong to distinct representations of the (sub)group(s) of G_F. [The following provides an undesirable example: if the Georgi-Glashow SU(5) is embedded in G_F then the <u>10</u> contains (c_L, c^c_L) and they can mix via a generator of SU(5)$<G_F$. If this happens then D^0-$\bar{D}^0$ mixing will occur via the 4-fermi interactions, and will require $\Lambda_p > 50$ TeV]. These criteria are compatible with the symmetry structure of the standard model based on SU(3) x SU(2) x U(1) which is expected to emerge as the low energy limit of the preon theory.

However, as pointed out in ref. 2, the case of K-decays is more delicate because, unlike the other processes, $\lambda=0$ may not be so easy to achieve by symmetries which classify the quarks and leptons together in repetive families. $K^+ \to \pi^+ \mu e$ or $K_L \to \mu e$ can be eliminated by symmetries only by deviating from the intuitive classification of families suggested by the standard model as described below.

The mass spectrum of quarks and leptons together with SU(3) x SU(2) x U(1) anomaly cancellation arguments within the standard model have led to the notion that a single family contains both quarks and leptons and that there exists at least 3 families of increasing masses. A complete family contains 16 or 15 fermion degrees of freedom. [The structure of Grand Unified Theories reinforces the notion that quarks and leptons belong together in one family.] The repetition as replicas of the first one is not explained in theories of elementary quarks and leptons. In composite models it has been suggested[2] that the repetition is required at least in certain classes of models, due to anomaly cancellation of precolor in the underlying preon theory, thus connecting the existance of families to underlying dynamics.

In the limit of zero gauge couplings for SU(3) x SU(2) x U(1), and absence of a Higgs, the standard model shows a big symmetry: SU(48) (or SU(45)→15 per family) corresponding to 48 (or 45) left handed free fermions. Thus, in the absence of the gauge couplings and masses in the standard model the family structure is completely washed out. This is an accident simply because L (standard) is quadratic in the fermions. However, in a composite model, if there is a family structure, it will show up in the structure of the 4-fermi and other non-renormalizable interations. Thus the preonic symmetry G_F that provides a family structure must be a subgroup of SU(48) or a larger group if there are more families. There are, of course, many possibilities, but the one that suggests itself most intuitevely (when the masses and gauge couplings are turned on) is a cross product of the form

$$SU(48) > (G_V \times G_H) = G_F \qquad (1.1)$$

where G_V (V for vertical) acts on the 16 (or 15) members of a family, and is the same for all families,

$$SU(16) > G_V, \qquad (1.2)$$

While G_H (H for horizontal) acts on the 3 families. In the limit of zero mass G_H might satisfy $U(3) > G_H$ or $U(3) \times U(3) > G_H$, etc, depending on the number of irreducible representations in which G_V classifies the 16 fermions. [Examples of such structures occur also in grand unified theories; e.g. for SO(10) grand unification G_V= SO(10), G_H=U(3); for SU(5) grand unification G_V=SU(5), $G_H=U(3)_5 \times U(3)_{10}$; for Pati-Salam unification $G_V = SU(4) \times SU(2)_L \times SU(2)_R$, $G_H = U(3)_L \times U(3)_R$ etc]. The main thing to notice is not the particular group, but the vertical x horizontal structure that one might expect if families are to be explained by compositeness, and that such an explanation is likely to lump together quarks and the leptons of 1 family within representations of G_V. This type of structure includes the possibilities that

a) Family quantum numbers are carried by a set of family preons while the rest of the usual quantum numbers are carried by other preons.

b) Family quantum numbers come from scalars or pairs of fermions that occur different number of times in different families.

c) Family quantum numbers come from radial quantum numbers.

Thus, under the assumption $G_F \sim G_V \times G_H$, where G_V lumps quarks and leptons in one family, and G_H distinguishes families, we may analyze the kinds of 4-fermi interactions that must occur with a coupling $\lambda^2/2\Lambda_P^2$, where λ is of order 1. Here we find that there is always a term that mediates $K^+ \to \pi^+ \mu e$ and/or $K_L \to \mu e$, namely

$$\frac{\lambda^2}{2\Lambda^2}[\bar{s}_o \frac{(1\pm\gamma_5)}{2} d_o][\bar{e}_o \frac{(1\pm\gamma_5)}{2} \mu_o] + G_F \text{symmetric terms} \qquad (1.3)$$

where the o-index implies that these are the states before mass generation or Cabibbo mixing is taken into account. Assuming that these mixing angles are not large we see that the symmetry $G_F = G_V \times G_H$ can never eliminate this term and thus we must require

$$\Lambda_P \gtrsim (20\text{-}30) \text{ TeV}. \qquad (1.4)$$

[Note that the decays occur for zero Cabbibo angles.] Models satisfying the reasonable assumptions above are therefore just beyond the reach of the SSC (E (max)≈ 10 TeV in parton + parton center of mass with any appreciable luminosity).

Any model that manages to avoid the conditions of the theorem above is likely to do it in one of the following ways: either

(i) Quarks and leptons are not linked within a family.

or (ii) There is a set of one or more preonic U(1)'s that assign different quantum numbers to quarks than leptons and simultaneously distinguish families.

or (iii) The mixing angles are large so that the mass eigenstate τ, μ, s, d correspond to $e_o \approx \tau$, $\mu_o \approx \mu$, $s_o \approx s$, $d_o \approx d$. Instead of τ, e_o may correspond to an even heavier lepton.

To these one could add less attractive possitilities that destroy the repetitive family structure, but we will not consider them here, since understanding family repetitions is one of the goals of compositeness.

In the first case it is evident we must give up a simultaneous explanation of quarks and leptons belonging to the same family. In such models it may turn out that leptons could artificially be added to the models by throwing in preonic degrees of freedom that are not required by the precolor dynamics. That is the model could be constructed for only the quarks[7]. We recall that the $U(1)_Y$ gauge anomaly in the standard model is the only evidence of a link between quarks and leptons of the same family. this guage coupling has nothing to do with the precolor dynamics that yield composite quarks and leptons. A model which does not provide a dynamical link between quarks and leptons (in the absence of negligible couplings) may be possible, but we have to ask how palatable it is, since it breaks one of our intuitive expectations.

In the second case I suggest that it is attractive to associate the desired global U(1)'s with the hypercharge Y of the standard model, since this is the only apparent link between quarks and leptons in each family. For example, consider 3 conserved preonic U(1)'s that assign separately the hypercharges in each family. [The gauge $U(1)_Y$ is the "diagonal" U(1)]. These U(1)'s or an appropriate discrete subgroup embedded in them are sufficient to eliminate the dangerous terms of type (1.3). While this sounds attractive a model of this type has not yet been constructed.

The third case[6] of large mixing angles is also counter intuitive. However, here there may be room for much further investigation since an attractive mass generating mechanism does not yet exit. Note that even though mixing angles may completely be rotated away in the lepton sector in L (standard) (certainly so, if ν_R do not exist), this is not necessarily the case in L(4-fermi), Since L(4-fermi) is not quadratic in the fermions. Thus, in this mechanism the burden of suppressing K_L, K+ rare decays rests with the mass generating mechanism without compromising the suspected linkage between quarks and leptons. The classification scheme for mass eigenstates is then expected to look as follows

$$\text{1st family } \binom{\tilde{u}}{d}_L \; u_R \; d_R \; \binom{\nu_\tau}{\tau}_L \; \tau_R \; \nu_{\tau R}$$

$$\text{2nd family } \binom{\tilde{c}}{s}_L \; c_R \; s_R \; \binom{\nu_\tau}{\mu}_L \; \mu_R \; \nu_{\mu R} \qquad (1.5)$$

$$\text{3rd family } \binom{\tilde{t}}{b}_L \; t_R \; b_R \; \binom{\nu_e}{e}_L \; e_R \; \nu_{eR}$$

where $\tilde{u}$, $\tilde{c}$, $\tilde{t}$ are the (u,c,t) mass eigenstates rotated by the Cabibbo-Kobayashi-Maskawa mixing angle. With such a mass scheme, e.g. some of the models discussed in ref. 2,6 would completely avoid all the bounds discussed above.

Furthermore, by mixing the (u,c,t) quarks rather than the (d,s,b) quarks, $\Delta s=1,2$ neutral current 4-fermi interactions do not occur. the family changing interactions that are generated by this mixing scheme are not restricted by known phenomenology. In L(standard) it does not matter whether the ups or the downs mix, however, in L(4-fermi) it makes an important phenomenological difference. Of course, the mass generating mechanism holds the secret for why the ups rather than the downs (or both?) should mix.

An example of trouble free 4-fermi interactions that illustrate the points above is explicity exhibited in section 3.

2. COSMOLOGICAL UPPER BOUND ON Λ_p

In the previous section we discussed bounds coming from low energy physics. However, cosmological consideration can help probe the heavy sector $M \sim \Lambda_p$ of a preon model if there are long lived states. This idea was first implemented in ref. 6, as outlined below.

A preon model often has some (naively) conserved U(1) quantum numbers. The low mass quarks and leptons can be taken neutral under some U(1) but some heavy states are charged. Then, in the same way that the proton is stable, such states are also (naively) stable.

Note that I emphasized naively conserved U(1). This is because after stronger precolor instanton effects this U(1) may be broken (it is broken in ref. 6). However, one must still analyze the effective instanton interaction and estimate the rate at which the heavy state is allowed to decay. Then, an interesting huge suppression may be found if the only allowed decays are to a large number of particles, despite a strong effective coupling constant. For example, the lifetime of a heavy scalar particle, $M \sim \Lambda_p$, that decays to N massless particles in the final state must be larger than

$$\tau \geq \frac{1}{(G^2\Lambda_p)} \frac{(16\pi^2)^{N-1}}{\pi} \frac{(3N-4)!}{(4N-4)!} (2N-1)!\;(2N-2)! \qquad (2.1)$$

Here G is a dimensionless effective coupling that measures the strength of the (instanton) interaction. A realistic model may require N of order 16, corresponding to the 16 members of a family, as in the example considered in ref. 6. Then

$$\tau \geq \frac{(100\ \text{TeV})}{G^2\ \Lambda_p} \quad (4 \times 10^{34}) \quad \text{years.} \qquad (2.2)$$

Thus, even for a large value of Λ_p, the lifetime of such a particle is larger than the lifetime of the universe. This illustrates that U(1)'s that are broken by instanton effects should not be dismissed, as they may still lead to almost stable particles.

In the event that a preon model has long lived particles (even for lifetimes than several minutes), cosmological considerations can put limits on its Λ_p. In ref. 6, mainly the case of $\tau \geq \tau$ (universe) was discussed. It is estimated that the abundance of such stable particles in today's universe is

$$\left(\frac{N}{N_\gamma}\right)_{\text{today}} \approx \left(\frac{\Lambda p}{M_{\text{planck}}}\right) \ln\frac{(\text{Mplanck})}{\Lambda_p} \qquad (2.3)$$

For these not to dominate today's matter (baryons) dominated universe, we must require

$$\Lambda_p \leq 250\ \text{TeV}. \qquad (2.4)$$

It may be possible to improve this bound by taking into account clustering of such particles in the form of galaxies. In any event, the fact that there is an upper bound in certain potentially realistic models and that the bound is fairly low is rather interesting from the point of view of the SSC.

3. A MODEL WITH EXOTICS

A preon model can be tested at low energies if it has exotic bound states that are G_F- partners of the (massless) quarks and leptons. The mass of such states is likely to be in the range

$$m_{top} < m < \Lambda_p, \qquad (3.1)$$

thus requiring energies lower than Λ_p for discovering them. The recent jet activity around m~150 seen at the UA1 and UA2 detectors at CERN may be attributed to exotics, as discussed in the Compositeness Subgroup at the SSC Workshop[9]. The model presented here is an example which has a minimal number of exotics [1 color nonet (8+1)], and can provide signals of the type seen at CERN.

The precolor group is taken as $G_p=SU(4)xSU(4)$ and the preons are placed in the three representations $R_1=(\underline{4},\underline{4})$, $R_2=(4,1)$, $R_3=(1,4)$. The numbers and helicities of the preons are

$$1_L\ R_1 + 4_L\ R_2 + (10_L + 6_R)R_3 \qquad (3.2)$$

Thus, the preflavor symmetry G_F which classifies the preons and composites is (after instanton effects)

$$G_F = SU(4) \times SU(10) \times SU(6) \times [U(1)]^2 \times Z^2 \qquad (3.4)$$

The massles composites which satisfy anomaly, decoupling and certain other conditions for the entire conserved G_F are:

$$(4,\ 10,\ 1)_L^{(1,0)}\ (4,\ 1,\ 6)_R^{(0,1)} \qquad (3.4)$$

This solution was used before in refs. (2,6) (without exotics) with a different interpration of the "flavor" quantum numbers than the one suggested below.

We embed SU(3) x SU(2) x U(1) in G_F so that the preons are classified as follows:

$$R_2:\ 4_L \to (3,1)_{1/6} + (1,1)_{-1/2} \qquad (3.5)$$

$$R_3:\ \begin{array}{l} 10_L \to (1,2)_0 + (1,2)_0 + (1,2)_0 + (\overline{3},1)_{-1/6} + (1,1)_{1/2} \\ 6_R \to (1,1)_{1/2} + (1,1)_{-1/2} + (1,1)_{1/2} + (1,1)_{-1/2} + (1,1)_{1/2} + (1,1)_{-1/2} \end{array}$$

The subscripts are the U(1) quantum numbers. Note that this embedding is anomaly free for gauged SU(3) x SU(2) x U(1), as it should be. QCD is embedded in SU(4) a la Pati-Salam. Therefore, the composites are classified as $(4 \to 3 + 1)$

$$(4,\ 10,\ 1)_L \begin{cases} 3:\ 3\times(3,2)_L^{1/6} + (3,1)_L^{2/3} + (1,1,)_L^{0} + (8,1)_L^{0} \\ 1:\ 3\times(1,2)_L^{-1/2} + (\overline{3},1)_L^{-2/3} + (1,1)^0_L \end{cases}$$

$$(4,\ 1,\ 6)_R \begin{cases} 3:\ 3\times(3,1)_R^{2/3} + 3\times(3,1)_R^{-1/3} \\ 1:\ 3\times(1,1)_R^{0} + 3\times(1,1)_R^{-1} \end{cases} \qquad (3.6)$$

This corresponds to 3 usual families of quarks and leptons plus a fourth up quark, plus a color nonet $(3\times3^*,1) = (1,1)_L^0 + (8,1)^0_L$ and a singlet $(1,1)^0_L$. The quarks and leptons may be indentified as in (1.5) so that Λ_p is not restricted by the rare processes discussed in section 1.

The point of this model is the presence of the nonet so that the singlet and octet have the same global quantum numbers, corresponding to a conserved U(1) embedded in G_F. Suppose the octet is heavy. If produced in $p\bar{p}$ reactions at CERN it can decay to a pair of quark + antiquark plus the neutral singlet that carries the same global quantum number as the octet. Thus in the final state one would see a pair of highly energetic jets plus missing energy. Since one of the quarks may sometimes be slow, the event (after the cuts) can also look as 1 energetic jet plus missing energy. The cross section for production + decay is quite large and can explain the rates seen at CERN, as discussed in the compositeness group in this workshop.[9] Note that the octet of this model has some properties similar to the gluino in supersymmetric theories, if the gluino its taken at around the same mass, and may be confused with it.

More model independent properties of exotics, are discussed in ref. 9.

I wish to propose another important role for exotics in a composite model. Marciano[10] suggested that high color states (6, 8, 10 etc.) may condense at the electroweak scale $F_\pi \sim 250$ GeV, thus providing a mechanism of mass generation analogous to technicolor but only with QCD forces. In the context of composite models this idea is quite attractive because

(i) Exotics occur naturally

(ii) The 4-fermi interactions provide masses for quarks and leptons after condensation.

In the models of elementary quarks and leptons discussed in ref. 10. it was difficult or unattractive to implement a substitute for (ii).

To use this mechanism one must address questions[12] about the asymptotic freedom of QCD because, if QCD looses its asymptotically free behaviour due to many exotics, condensation would take place at the highest values of α_{QCD}, thus at the highest scales. This is not desirable. For this I emphasize that in a composite model we must separately consider the calculation of β_{QCD} in the regimes below Λ_p and above Λ_p. Below Λ_p there are few and non-exotic preons. In terms of preons β_{QCD} must and can easily be negative for asymptotic freedom to be correct. Below Λ_p the behaviour of α_{QCD} or β_{QCD} may be smooth or complicated depending on the number of exotics and their thresholds. In the range $\Lambda_{QCD} < \mu < \Lambda_p$ condensation will occur if $\alpha_{QCD}(\mu)$ attains the critical value at $\mu = F_\pi = 250$ GeV

$$\alpha_{critical} = \alpha_{QCD}\ (F_\pi) \qquad (3.7)$$

[$\alpha_{critical}$ may approximately be estimated [10,11] via the quadratic casimir for the exotic representation R, $C_2(R)\,\alpha(F_\pi) \approx 1$]

For $\mu > F_\pi$, $\alpha(\mu)$ must never exceed αcritical, otherwise the scheme will not have any meaning. Two possibile situations are shown in Figs. 1 and 2

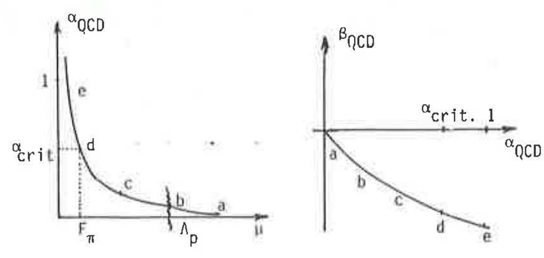

Fig. 1. Few exotics. $\beta < 0$ for all scales.

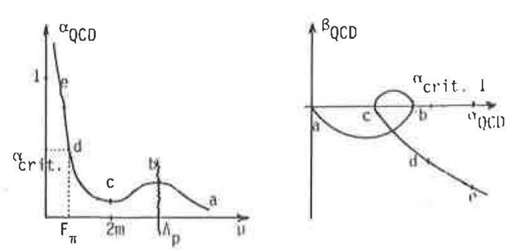

Fig. 2. Many exotics. $\beta > 0$ above 2m threshold; $\beta < 0$ above Λ_p.

In Fig. 1, even below Λ_p, there are few exotics so that the β function (slope of $(\alpha(\mu))$ always remains negative. In Fig. 2, there are too many exotics below Λ_p. The threshold for producing the exceeding exotics is $\mu=2m$, above which β_{QCD} is positive. However beyond Λ_p β_{QCD} is again negative since the computation is done in terms of preons. Note the interesting multivalued plot of β versus α for this case which, as explained, can happen quite naturally in a composite model. Each branch of this curve is computed pertubatively since $\alpha_{QCD}(\mu)$ is small. The non-perturbative phenomena occuring via the underlying precolor forces is what gives rise to such a non-pertubative looking curve.

For these mechanisms to be useful for electroweak symmetry breaking there should be some exotics carrying electroweak quantum numbers, such that $\Delta I^W=1/2$. These could be of the form $(r,2)_L+(r,1)_R$ where r is a complex representation of SU(3), such as r=6, 10, etc., and 2 is a doublet, 1 is singlet of $SU(2)_W$. The numbers of doublets and singlets sould be such that the symmetry breaking preserves a custodial SU(2) (approximately). We cannot allow r = real (e.g.(8,2)) since this would lead to $\Delta I_W=1$ via $(r,2)_L \times (r,2)_L \sim (1,3)$. Any real exotic representation should not simultaneously be a doublet of $SU(2)_W$ e.g.(8,1) is o.k.). As Marciano estimates, 2 sextets together with the usual 3 families just about saturate asymptotic freedom for QCD. Thus, although there is the possibility of a composite model described by Fig. 1, most models with exotics are likely to be described by Fig 2, if they play any role in electroweak symmetry breaking.

Models with exotics now being investigated will be described in future publications.

ACKNOWLEDGEMENT

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REFERENCES

(1) G. 't Hooft, in Recent Developments in Gauge Theories, ed. G. 't Hooft Plenum Press, NY 1980.

(2) I. Bars, Nucl. Phys. B208, 77 (1982); and in proc. Moriond conf. 1982, Quarks, Leptons and Supersymmetry, Ed. Tran Thahn Van, page 541

(3) M. Abolins et. al. in Proc. 1982 DPF Summer Study on Elementary Particle Physics and Future Facilities, page 274.

(4) E. Eichten, M. Peskin and K. Lane, Phys. Rev. Lett, 50, 811 (1983).

(5) The reader should be aware that the different definitions of compositeness scales imply bounds that may seem different by a factor of 5, but can be translated to be in agreement with each other. In QCD the mass of the rho satisfies $m_\rho \approx (3\text{-}5)\ \Lambda_{QCD}$ where Λ_{QCD} is thought to be in the range 150-250 MeV. Λ_p is defined in analogy to Λ_{QCD}. Other authors (e.g. ref 3,4) have used the mass of the expected composite vector meson Λ^* as a convenient scale. By analogy to QCD we might expect $\Lambda^* \approx (3\text{-}5)\ \Lambda_p$. Thus the strength of the 4-fermi interaction parametrized in ref 2 as $\lambda^2/2\Lambda_p^2$, with λ of order 1, is consistent with $4\pi/2\Lambda^{*2}$ used in ref. 3,4.

(6) I. Bars, M. Bowick, K. Freese, Phys. Lett 138B, 159 (1984).

(7) A model which appears to fall in this category was described to me by O. W. Greenberg and S. Nussinov after this workshop: The composites contain a fermion and a boson $(\psi\phi)$; $\psi_{L,R}$ carry $SU(2)_L \times SU(2)_R$, while ϕ^{ai}, ϕ^{4I} carry a=color, 4=lepton, i=quark family, I=lepton family (different than quark family).

(8) I thank H. Harari, M. Bowick and M. Dine for discussions.

(9) Compositeness Subgroup at the SSC Workshop, USC preprint 84/034, to be published published in these proceedings.

(10) W. J. Marciano, Phys. Rev. D21, 2425 (1980). See also K. Konishi and R. Tripiccione, Phys. Lett 121B, 403 (1983); D. Lüst, e. Papentonopoulos and G. Zoupanos, CERN preprint TH. 3790; P. Q. Hung, Fermi lab preprint 80/78-THY (1980).

(11) J. Kogut et.al., Phys. Rev. Lett 50, 393 (1983); Nucl. Phys. B225, 326 (1983).

(12) I thank E. Eichten, H. Harari and other participants of the workshop on Composite Quarks and Leptons, Erice, Sicily, May 1984, for discussions.