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COMPOSITENESS RESOLUTION AND BARYON NON-CONSERVATION

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ABSTRACT

We discuss the resolution of gauge bosons as composites in relation to quark / lepton substructure and show how it will imply a $10^{1 \pm 2}$ TeV inverse size scale in case the proton is observed to decay with a lifetime not much longer than the present lower limit.

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Composite models [1)-10)], based on the substructure of quarks and leptons, have received some amount of attention in the recent past. One of the motivations behind them is the desire to explain the number of generations [11)]. Another is the arbitrariness associated with elementary self-interacting scalar fields - consequent upon the lack of a gauge principle - which has led to Higgs scalars being increasingly regarded [11),12)] as fermion-antifermion composites bound by gauge forces. However, in the currently orthodox approach to unified gauge theories, Higgses are treated on the same level as quarks and leptons. Thus the idea of compositeness, if taken to be a virtue for these scalars, can be naturally extended to quarks and leptons as well. This has led 't Hooft [13)], for instance, to view the latter as bound states of an odd number of more elementary fermions, say preons, with a quark/lepton size-scale [*),**)] $R_o \sim 10^{-18}$ cm or an equivalent preonic mass-scale $m_o \sim 10^{1.5}$ TeV. However, R_o - if at all non-zero - could in principle be much, much smaller.

The magnitude of this size-scale is naturally crucial to the question of the foreseeable experimental resolution of quark/lepton substructure. Current experimental limits on lepton size, for instance, come from the data [14)] on e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$ production in high energy e^+e^- annihilation and from the precision [15)] in the knowledge [***)] of $(g-2)_{e,\mu}$. The direct limits on quark size are not as strong, but the avowed goal of a unified description of quark/lepton phenomena at the preonic level entitles one to use the leptonic limits for R_o. The general empirical conclusion which one can then draw is that $R_o \lesssim 10^{-16}$ cm. Theoretically, also, the successful electroweak theory, formulated in terms of quarks and leptons spans a length scale down to $\sim 10^{-16}$ cm, whereas the proposed minimal grand-unified theory (GUT) then leaps across a structureless desert [17)] down to $\sim 10^{-28.5}$ cm (mass-scale $\sim 10^{15}$ GeV).

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*) The symbol $\sim$ denotes an uncertainty of ±0.5 in the power of ten.

**) The binding of constituents with $(\text{size})^{-1} \sim$ TeV into light (MeV-range) composite fermions is not too peculiar. 't Hooft [13)] has shown how this can occur if a certain condition called naturalness is satisfied. See also the second paper of Ref. 12).

***) To relate $\Delta(g-2)_\mu \simeq 10^{-8}$ to the muon size, one needs a model for the composite muon. For a tight relativistically bound muon made of a heavy fermion and a much heavier boson, one has [16)] $\Delta(g-2)_\mu \sim O(m_\mu m_F m_B^{-2})$ so that $m_B \sim 10^{4.5}$ GeV and $m_F \sim 10^2$ GeV can be accommodated. This tallies with the conclusion $R_o \lesssim 10^{-16}$ cm. A stronger constraint might be sought from the non-observation of the decay $\mu \to e\gamma$; but this is more model-dependent since in many preon schemes (e.g., those which have the muon as the radial excitation of the electron) such a non-diagonal transition is naturally suppressed [7)]. Similar statements apply to the decays $K_L \to \mu\mu$ and $K \to \pi\nu\bar{\nu}$.

The latter scale, characterizing the presumed convergence of non-gravitational gauge couplings as they evolve towards one another with mass, is also the one expected in the minimal theory to control [17] baryon non-conserving processes such as proton decay.

One view, while espousing quark/lepton substructure (for the purpose of associating the constituent preons with the fundamental representation - and quarks/leptons with higher ones - of some underlying symmetry or supersymmetry required, say, in unifying with gravity) is [18] that the preons are bound at distances between $\sim 10^{-28.5}$ cm and the Planck's length $\lambda_P \sim 10^{-32.5}$ cm. We can call this the "unresolved substructure view" since, in the event of its being right, such substructure cannot be resolved in any transition (including baryon non-conservation) which involves physics at distances far larger than λ_P. Quarks and leptons then act in such transitions as elementary local fields of scale dimension $\frac{3}{2}$. Their gauge couplings evolve smoothly with an increasing mass-scale to the common fine structure constant $\alpha_{GU} \simeq 1/40$ without interruption from any preonic effects. The latter are decoupled [19] from processes involving lower masses and larger distances leaving an effectively renormalizable field-theory at the quark/lepton level.

There is an alternative scenario. This corresponds to what we shall call the "resolution viewpoint". Here the quark/lepton size scale R_o significantly exceeds $10^{-28.5}$ cm. Such a viewpoint can, and does, incorporate [11] a trend towards the grand unification of non-gravitational couplings and hence a unified description of all quark/lepton processes at presently probed energy and distance scales. However, it holds that the evolution of quark/lepton gauge couplings will be interrupted (before complete convergence) at the preonic mass-scale. Consequently, baryon-violating processes such as proton decay will have to be described in preonic terms. Now the central question is whether the gauge bosons mediating such processes (and analogously the strong and electroweak gauge bosons) are composites or elementary at the preonic level. There are models [6] in which these are elementary and couple locally to preons in a three-particle coupling. However, in the majority of the proposed schemes for quark/lepton substructure which fall within the ambit of the resolution viewpoint, these bosons are preonic composites; their couplings with preons have to be described globally in terms of multiple local interactions at the preonic level since the quanta mediating local preonic interactions are different from these bosons. About all these schemes we can make a general statement. A priori, R_o for this type *) of resolved preon schemes could lie anywhere

*) Models [6], in which the baryon violating gauge bosons are elementary at the preonic level, escape our conclusion. Here O (see below) can be a four-body preon operator and with $n=4$, $d=6$ one is back to $M_{GU} \sim 10^{15}$ GeV.

between $\sim 10^{-28.5}$ cm and $\sim 10^{-16}$ cm. However, our statement is that the observation of proton decay in the coming generation of experiments (which will probe proton lifetimes around $10^{31.5\pm 1.5}$ years) will pin R_o down for this class *) of resolved substructure models within a much more restricted intervals going down only to $\sim 10^{-19.5}$ cm. This would then require the existence of a new inverse size scale with observable effects in the $10^{1\pm 2}$ TeV range **),[20] (the exact location depending on the model) with thrilling implications for accelerator-based high energy physics of the not-too-distant future. The properties of the latter - if observed - will serve to distinguish between qualitatively different substructure models. On the other hand, their non-existence - despite the observation of the instability of the proton - would negate the resolution viewpoint embodying composite gauge bosons.

In any theory possessing a trend [11] towards grand unification at the level of quarks and leptons, baryon non-conserving processes arise out of the exchange of very heavy bosons (e.g., X with charge ±4/3 and Y with charge ±1/3) among them. The corresponding graphs have to be [21] first evaluated at large external momenta in terms of an effective transition operator, O say, involving only "ordinary" fields (quarks, leptons, Higgs bosons) which are treated as effectively massless; then the graphs are renormalized down to small external momenta. The effective interaction strength may be written as ***),[22]

$$g^{eff}_{d,n} \approx g^{n-2} M^{4-d} . \qquad (1)$$

In Eq. (1) M is the controlling mass scale, while n and g are respectively the number and the fundamental coupling of the elementary fields making up the operator O, which has a scale dimension d. The right-hand side of Eq. (1) contributes a mass power M^{8-2d} to all baryon violating transition rates Γ and in particular to the width of the proton. This has to be balanced by a factor of mass dimension 2d-7 which is a positive number for all d of our interest. The most (kinematically) obvious choice for this factor is the proton mass M_p raised to the $(2d-7)^{th}$, but it is important to understand why other possibly relevant dimensional quantities cannot contribute. The masses of ordinary light objects such as the quarks (we refer to the current quark) and leptons involved in the process cannot contribute since the leading dynamical description of the requisite matrix element of O is in the limit

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*) An added requirement is a global conservation law such as B-L.

**) The existence of new mass scales in the desert is also a qualitative feature [20] of partially unified theories.

***) This is true only if g can be handled perturbatively, i.e., $g^2/4\pi \ll 1$, so that contributions from virtual loops can be ignored. The M dependence is, of course, non-perturbative.

when these are massless [21] and Γ is non-zero for permissible baryon non-conserving decays in this limit. Consider first the unresolved substructure view of a baryon violating reaction such as proton decay. In that case there are no other dimensional parameters involved and the proton lifetime is given by

$$\tau_p \approx g^{4-2n} \left(\frac{M}{m_p}\right)^{2d-8} m_p^{-1} . \tag{2}$$

Now M is the GUT mass [17] M_{GU} whereas n and d are as required [21] by the necessary invariance of the $SU_c(3)\otimes SU(2)\otimes U(1)$ symmetry imposed on the quark and lepton fields (q and ℓ respectively). For instance, in $\Delta B = \Delta L$ transitions (e.g., $p \to e^+\pi^o$), O – in this view – has the structure $qqq\ell$ with $n=4$, $d=6$ relating the standard $M_{GU} \sim 10^{15}$ GeV to a proton lifetime of $10^{31.5\pm1.5}$ years.

Consider, in contrast, what happens if the preonic substructure is resolved in baryon non-conserving processes. M now equals $M_o \simeq R_o^{-1}$ and n, g refer to the preon fields in terms of which O has to be constituted. However, one has to face an important question *) : is Eq. (2) still correct ? In principle, the requisite matrix element of O (describing a four-body quark/lepton reaction, say) now involves preonic wave functions of the quark/leptonic fermions times the multiply-interacting preon graph which generates $g^{eff}_{n,d}$ of Eq. (1). These wave functions will generally lead to a dependence on quark/lepton size which can be characterized by a function $f(R_o)$. For a finite and non-zero $f(0)$ the leading power dependence of M_o in the expression for τ_p will still be correct; otherwise powers of R_o emerging from $f(R_o)$ will alter it. One could draw upon an analogy with the transition matrix element of a quark constituted operator for a hadronic composite system of finite size such as a nucleus. If the transition operator is linearly related to the generator of a global conservation law, then the matrix element has a finite residue in the limit of zero size, proportional to that global charge. For baryon-violating decays also we argue that $f(0) \neq \infty$ or zero since the transition operator O is linearly related to the generator of a global symmetry **), violating B and L but conserving $B-L$, the latter being quite naturally obeyed in the substructure models of interest. Hence our conclusion is that, for resolved preon models describing baryon non-conservation, Eq. (2) is still correct. Therefore, the transition rate is completely controlled by M_o and vice versa through the values of n and d.

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*) We are indebted to L. Maiani for a stimulating discussion of these issues.

**) Evidently, this cannot act in the single particle space of quarks and leptons but needs at least a two-particle space, effecting $|uu\rangle \to |\bar{d}e^+\rangle$, etc. Thus, it has an operator structure $\sim qqq\ell$.

Of course, in the prosaic situation where O is a low-dimensional operator in terms of preon fields, no strong upper bound on M_O will obtain from the observation of baryon non-conservation as in proton decay; e.g., for $n=4$ and $d=6$ $M_O \simeq M_{GU}$. However, this state of affairs can come about for resolved preons only if the mediating boson is elementary [6] at the preonic level. As we have said before, such is not the case for most substructure schemes corresponding to the resolution viewpoint. Consider, for instance, the Harari-Shupe [4] category of models. Here attempts to make O a four-body operator in terms of the preon fields would require the quark-lepton reaction (e.g., $uu \to \bar{d}e^+$ underlying the decay of a proton into a positron and a π^0) to proceed by rearrangement between two (one charged, one neutral) initial and two final preons. To meet this requirement one would need a Y-like boson which is elementary at the preonic level. However, the strong and charged weak gauge bosons are necessarily non-elementary six-preon composites in these schemes. In Pati's model [10], on the other hand, although the electroweak gauge bosons could - in principle - be elementary, the X and Y are forced to be six-preon composites. The prerequisite [11] of the possession of a trend towards grand unification at the quark/lepton level (i.e., of a unified description of quark/lepton/gauge boson epiphenomena) dictates that the strong, electroweak and leptoquark gauge bosons should all have similar preonic structures. This, together with the compulsions of quantum number matching, necessitates that in resolved preon theories embodying composite gauge bosons, the latter have to be all six-preon operators in models of the Harari-Shupe class and multipreon composites in general. Thus, as stated earlier, the quark/lepton reaction describing any baryon-violating transition can only proceed in these schemes through multiple point-coupled preonic vertices and propagators. Consequently, rather large values for n and d become obligatory. This is why a lifetime of about $10^{31.5\pm1.5}$ years for the proton will require *) an M_O around $10^{1\pm2}$ TeV for preon theories incorporating composite gauge bosons resolved in the process.

We present next a systematic discussion of the estimation of M_O in various models of this type.

Category (A) <u>Three-fermion schemes</u> - Each quark/lepton is now a composite of three spin- half preons. The prototype model is that of Harari-Shupe [4] in which there are two types of preons ("rishons") : $T, \bar{T}$ of charge 1/3, -1/3 and neutral $V, \bar{V}$. The operators acting as charged weak bosons at the quark/lepton level are known to interact globally in these schemes - W^+, W^- having the structure (TTTVVV), ($\bar{T}\bar{T}\bar{T}\bar{V}\bar{V}\bar{V}$). Similar structures are carried by the gluons. As argued already, all of the usual gauge bosons

*) In this analysis we are taking the effective mass of the X or Y boson to singificantly exceed M_O.

must be six-body composites for the consistent incorporation of a grand unifying trend [11]. Thus, for instance, the leptoquark X^+ has the structure (TTTTVV). In this picture then the operator O, which has the form $qqq\ell$ at the quark/lepton level and is responsible for proton decay, develops the twelve-body structure $(TTTTVV\bar{T}\bar{T}\bar{T}\bar{T}\bar{V}\bar{V})$. Hence, in relation to Eq. (1), $n = 12$ and $d = 18$. This statement is true of all resolved preon schemes of this category. The only remaining unknown is the fundamental preon coupling g. One does not know a priori how it is related to the electronic charge e. For demonstrative purposes we can consider two extreme cases : i) $g \approx e$, ii) $g \approx 10e$. A value lower than in i) would - via Eq. (1) - begin to generate low enough mass scales interfering with present experiment, whereas a value much greater than in ii) will invalidate the perturbative argument *) leading to Eq. (1). With these two choices of g, though, M_0 can be estimated corresponding to a proton lifetime of $10^{31.5 \pm 1.5}$ years. The ranges of M_0 (rounded off) are given in the first row of the Table.

Category (B) <u>One-fermion, two-boson schemes</u> - These have each quark/lepton composed of one spin-half and two scalar or vector preons. Still $n = 12$, but now the twelve-body operator O has $d = 14$. The permitted ranges of M_0 pertaining to cases i) and ii) are given approximately in the second row of the Table.

Category (C) <u>One-fermion, one-boson schemes</u> - Here each quark/lepton consists of one spin-half and one scalar or vector preon. Now $n = 8$ and $d = 10$. The rough intervals covering M_0 for cases i) and ii) appear in the third row of the Table.

Models which do not quite fall into one of the above categories but are hybrids can also be treated in a similar fashion.

We conclude with the following observations :

(1) Some may consider it premature to delve into specific resolved substructure models in great detail. However, we have shown that one can remain fairly general in discussing the resolution of composite gauge bosons and use only dimensional arguments to link the corresponding preonic mass scales to the observation of proton decay.

(2) The higher the scale dimension of the operator O, the lesser is the dependence of M_0 on the fundamental coupling g.

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*) In a metacolour theory [13], an R_0 much less than the inverse scale constant Λ_M^{-1} for metacolour will make the effective coupling perturbative.

(3) It is quite possible that objects corresponding to the mass scale M_o will be confined. Nevertheless, their presence can show up [23] as visible threshold or structure effects (such as sudden scaling violations and new jets) in the analysis of deep inelastic scattering cross-sections of lepton-lepton, lepton-hadron and hadron-hadron reactions that can be measured in forthcoming accelerators.

(4) Exotic baryon-violating processes, which conserve not B-L but some other combinations of B and L (e.g., those with selection rules such as $\Delta B = -\Delta L$, $\Delta B = \pm\frac{1}{3}\Delta L$, $\Delta B = 2$) - require [22] higher dimensions for the transition operator O. If observed at the same level as expected for $\Delta B = \Delta L$ processes, they would require even lower mass scales for resolved preon theories. However, the analysis of these effects should take into account the breaking of the electroweak $SU(2)\times U(1)$ symmetry at such low masses.

(5) There is one disturbing feature of a preonic mass scale around $10^{1\pm2}$ TeV controlling baryon non-conservation. It corresponds in the early Universe to temperatures much cooler and times much later than those for the standard GUT mass $\sim 10^{15}$ GeV. Consequently, the presently held mechanism [24] for the generation of the observed baryon asymmetry of the Universe is no longer tenable since any asymmetry generated earlier would get washed out at such later times. However, the problem now has to be formulated in terms of preons and preon dynamics and has become more complicated. It is not clear without a detailed analysis whether or not an acceptable preonic mechanism for this purpose can be invented.

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TABLE : Mass scale ranges for different models and couplings

Category	$g \approx e$	$g \approx 10e$
(A) Three fermions	60 GeV $\lesssim M_o \lesssim$ 80 GeV	330 GeV $\lesssim M_o \lesssim$ 420 GeV
(B) One fermion, two bosons	340 GeV $\lesssim M_o \lesssim$ 490 GeV	3.5 TeV $\lesssim M_o \lesssim$ 0.5 TeV
(C) One fermion, one boson	25 TeV $\lesssim M_o \lesssim$ 50 TeV	565 TeV $\lesssim M_o \lesssim$ 1005 TeV

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