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Abdus Salam

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APPROACH TOWARDS MINIMALITY – SUPERSYMMETRY AT THE PREONIC OR PRE-PREONIC LEVEL*

Jogesh C. Pati
International Centre for Theoretical Physics, Trieste, Italy
and
Department of Physics, University of Maryland, College Park, Maryland 20742, USA **

and

Abdus Salam
International Centre for Theoretical Physics, Trieste, Italy
and
Imperial College, London, England.

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* To be submitted for publication.
** Permanent address.

ABSTRACT

Believing that a fundamental theory ought to be manifestly minimal, elegant and somehow unique, we make a beginning in this note in arriving at a minimal system of fundamental substructures (pre-preons), which could give rise to preons of the flavon-chromon type proposed some time ago. Our approach points naturally to a need for supersymmetry at the level of preons or pre-preons. Spin-1/2 flavons and spin-0 chromons appear to receive their simplest interpretation as Fermi-Bose partners of a supersymmetric theory; the emergence of the concepts of flavour and colour, in this picture, is synonymous with supersymmetry-breaking. An alternative picture, in which flavons and chromons arise as Fermi and Bose-components of different superfields and thereby permit the emergence of the concepts flavour and colour prior to supersymmetry-breaking, is also considered. A simple pre-preonic model presented here suggests three quark-lepton families with τ being distinct from e and μ in some of its interactions. The ideas of building supersymmetric Yang-Mills theories with pre-preons and supergravity-theories of preons as composite theories are considered.

I. INTRODUCTION

It is our belief that the fundamental theory of particle physics ought to be visibly economical in its building blocks and parameters. In line with this belief, it appears inevitable to us that quarks, leptons, Higgs and perhaps even the associated gauge bosons (W, Z gluons etc.) are composites of more elementary objects, which we call "preons". The preons themselves may be composites of still more elementary objects which we call "pre-preons". Believing that the quest for elementarity in a field-theoretic sense will end but not until one reaches a stage which is manifestly minimal, monotheistic, perhaps, in an extreme limit, elegant and somehow "unique", we make a beginning in this note in arriving at a minimal system of fundamental substructures (pre-preons), which could give rise to preons of the flavon-chromon type proposed sometime ago[1]. Our approach appears to suggest naturally that the basic Lagrangian possesses a certain Fermi-Bose symmetry. Spin-1/2 flavons and spin-0 chromons appear to receive their simplest interpretation as Fermi-Bose partners in a supersymmetric sense; the emergence of the concepts of flavour and colour, in this picture, is synonymous with supersymmetry breaking. An alternative picture in which flavons and chromons arise as Fermi and Bose components of different superfields is also presented. Within this alternative, flavour and colour can be defined even prior to supersymmetry-breaking. A simple pre-preonic model presented here suggests three quark-lepton familes, with τ being distinct from e and μ in some of its interactions. The ideas of (a) building supersymmetric Yang-Mills theories with pre-preons and (b) composite supergravity-theories of preons are considered at the end.

II. FLAVON-CHROMON PREONS

In order to motivate our remarks, it is useful to recall a few salient features of the flavon-chromon preonic model. The model was proposed in 1974 in the same paper where lepton number was suggested as the fourth colour[1], and has been developed over the years[2,3,4]. The set of ideas behind the model has been used subsequently by a number of authors[5].

In its simplest form, the model assumes that spin-1/2 quarks and leptons carrying flavour and colour are made of two sets*) of entities (preons): (i) the flavons $\left\{f^i_{L,R}\right\}_{i=u,d,\cdots}$ with spin-1/2, which carry flavour but no colour and (ii) the chromons $(C_\alpha)_{\alpha=r,y,b,l}$ with spin-0, which carry colour but no flavour. Each quark or a lepton is an fC^*-composite and thus carries

*) A set is defined by the spin and binding charge of its members, which must be the same for all members.

flavour and colour. A variant[2)] of this model introduces three sets of entities: flavons, chromons and somons $(S^a)^{a=1,2,\ldots}$ each with*) spin-1/2 and assumes that quarks and leptons are composites of the type $f^iC^*S^a$, with the somons being neutral with regard to flavour and colour. One feature of this class of models is that quarks and leptons are made of the same flavons, differing from each other only in respect of colour (i.e. red, yellow, blue (r, y, b) for quarks, versus lilac (ℓ) for leptons). This goes together with the suggestion that lepton number is the fourth colour.

Within this picture, one needs a minimum of two left-handed and two right-handed spin-1/2 flavons plus four spin-0 chromons to build the 16 two component objects belonging to the electron (e) family.

$$f^i_{L,R} = (u, d)_{L,R} \quad , \quad C = (r, y, b, l) \tag{1}$$

Fermions belonging to the μ and/or τ -families may in general be quantum pair-excitations of the e-family: e.g. F_μ and/or $F_\tau = (f^iC^*) \times (\mathrm{Tr}C^+C)$, or $(f^iC^*)\,(\mathrm{Tr}C^+C)^2$, or $(f^iC^*)\,(\mathrm{Tr}\,\bar{f}\,f)^2$ etc. Alternatively μ and/or τ may differ from e by an intrinsic quantum number **); in this case two or as many as four additional flavons (i.e. $(c,s)_{L,R}$ or $(c,s,t,b)_{L,R}$) may have to be introduced to build the μ and τ -families. For the variant involving somons, the three families may be built by introducing three different somons S_e, S_μ and S_τ with flavons and chromons having their minimal structure as in (1), i.e. $F_{e,\mu,\tau} = f^iC^*\,(S_{e,\mu,\tau})$. Here somons play the role of familons.

*) Alternatively, C as well as S's may carry spin-0, with flavons f's carrying spin-1/2. The Somons can, in general, provide the family or generation-quantum number.

**) Considerations based on dynamical symmetry breaking through preons suggest that at least the e and the μ-family differ from each other by some intrinsic quantum number leaving the possibility open that the τ may still be a quantum pair-excitation of the e (see Ref. 6).

Flavons and chromons (and somons for the variant)*) are assumed to be non-neutral with respect to a primordial gauge force F_b, which binds preons to make quarks and leptons of small size ($r_0 \lesssim 1\ \mathrm{TeV}^{-1}$). The lightest composites, identified with quarks and leptons, are assumed to be neutral with respect to F_b. The small size together with the neutrality of quarks and leptons shields them from experiencing the strong primordial force at low energies $\ll 1/r_0$.

As to the nature of the primordial force, we shall assume that it is either the simplest gauge force of all - i.e. an abelian or a dual abelian force[3,4)] like electromagnetism, or it is a Yang-Mills force generated by a non-abelian local symmetry like SU(2)[7)] or SU(3). For the simple abelian theory just one charge would be involved, while for the dual abelian theory flavons and chromons would carry electric and magnetic-type charges satisfying Dirac quantization, such that f^iC^* (for the variant f^iC^*S) is neutral**). For the SU(2) theory, taking the simple case of no somons, each of spin-1/2 flavons and spin-0 chromons would be assumed to be doublets of the primoridal SU(2) with quarks and leptons being singlets. In either case (abelian or nonabelian), one important feature is that neither flavour nor colour gauge-forces are introduced as components of the primordial force. These forces are to be viewed as effective forces arising at a composite (i.e. quark-lepton or preonic) level with W, Z and even the gluons being composites of small size***). This point of view is necessitated by economy for building blocks and parameters at a fundamental level****).

*) As pointed out in Ref. 6, the forces F_{fc}, F_{fs} and F_{cs}, operating between the three pairs - i.e. flavon-chromon, flavon-somon and chromon-somon - may, in general, be different, possessing differing scale-parameters: Λ_{fc}, Λ_{fs} and Λ_{cs}. The sizes of quarks and leptons will be given by the smallest of these three scales; quarks and leptons being neutral with respect to all three forces. The sizes of composite gauge particles - i.e. W's, Z, gluons etc. (see later) - can in this case be much smaller than those of quarks and leptons.

**) Quite clearly all the flavons belonging to a given family must carry the same binding charge g_f, likewise all chromons must carry a charge $-g_c$. For the model without somons $g_f = -g_c$, while for the (fC^*S) model, $g_f + g_c + g_s = 0$, where g_s is somon-charge. In general, for the dual abelian theory, g represents a pair of charges.

***) See remarks later.

****) If one wishes the primordial gauge symmetry to generate not only the preon binding force but also the familiar colour and/or flavour-gauge forces, and at the same time one insists on having a single gauge coupling constant at the primordial level, one would need more preons than there are quarks and leptons, as was shown in Ref. 3. This was the primary reason for giving up the idea of elementarity of flavour and colour in a preonic context.

Before passing to a possible, still earlier underlying pre-preonic stage it is useful to make a few remarks concerning the preonic theory itself:

Given the charge and spin-structure of the flavons and chromons, the minimal model (1) outlined above would possess (if the flavons are massless) at least a global symmetry $G_{fc} = \left[SU(2)_L \times SU(2)_R\right]^{\text{flavour}} \times SU(4)^{\text{colour}} \times U(1)_f \times U(1)_c$, where $U(1)_f$ and $U(1)_c$ denote the flavon and chromon-number symmetries respectively. This is in addition to the primordial local gauge symmetry U(1) (or dual U(1) x U(1) or SU(2)), which provides the binding force and commutes with the flavour-colour symmetry G_{fc}.

Let us assume that the binding force F_b generates spin-1 composites of small size r_0 of the type $W_L \sim \bar{f}^i_L \gamma_\mu f^j_L$, $W_R \sim \bar{f}^i_R \gamma_\mu f^j_R$, $V^c \sim C^+_\alpha \overleftrightarrow{\partial}_\mu C_\beta$, such that the masses of the composites are small compared to their inverse size $M_0 \equiv 1/r_0$.

At present, we have no dynamical reason to believe that the masses of spin-1 composites are small compared to their inverse size M_0. This is unlike spin-1/2 composites, for which one may invoke chiral symmetry to keep the composites massless*). It is conceivable that chiral symmetry and (extended) supersymmetries - together - help preserve masslessness of composite spin-1/2 fermions as well as of their composite spin-0 and spin-1 bosonic partners in the scale of the preon-binding force. (For supersymmetric considerations, see Sec. III.). But we do not yet have a detailed model of this kind.

Now if such spin-1 ($W_{L,R}$ and V^c), spin-1/2 and spin-0 preonic composites do form with small size (r_0) and small mass $m \ll M_0 \equiv 1/r_0$, consistency demands that the effective interactions of these composites at low momenta $Q \ll M_0$ must be describable by a renormalizable interaction (barring

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*) In this context, one must recognize, that masslessness of even spin-1/2 composites is rather unusual compared to our experience with QCD, which breaks quark-chiral symmetry dynamically and gives a mass to the nucleon of the order of its inverse size. Thus the dynamics of the preon-binding force (F_b) must be drastically different from that of QCD in that F_b must produce composite quarks and leptons whose masses are much smaller than their inverse sizes. If chiral symmetry is the basic rationale for masslessness of composite quarks and leptons, then quantum preon-dynamics (QPD) must somehow not break chiral symmetry dynamically. This fundamental distinction between QPD versus QCD may have its origin in the abelian (as in dual magneto-electric theory) versus non-abelian nature of the forces, or alternatively in the character of the non-abelian group (e.g. SU(2) versus SU(3)).

corrections of order $(Q^{\ell}/M_0^n)_{\ell \leq n}$). We shall refer to this demand for consistency as the renormalizability condition[8]. For charge carrying spin-1 composites, this has the remarkable consequence that the effective "low" energy interactions must be describable by a local gauge-symmetry; the small size spin-1 composites must thus be "born" massless as the gauge quanta of a local gauge symmetry. Such composite gauge particles would in general acquire masses through a spontaneous dynamical breaking of the local symmetry, which in our scheme takes place through vacuum expectation values of composite Higgs fields. The composites $W_{L,R}$ and V_c described above thus correspond to the gauge fields of the familiar local symmetry $SU(2)_L \times SU(2)_R \times SU(4)^{\text{col.}}$.

We are now in a position to state our assumption regarding the formation of small size, small mass, composites more succintly.

The nature of quantum preon-dynamics (QPD) is such that spin-1/2, spin-0 as well as spin-1 preonic (or pre-preonic) composites can form with small sizes $r_0 < (1\ \text{TeV})^{-1}$, characterised by the scale (or scales) of QPD, with small masses $m \ll M_0 \equiv 1/r_0$, provided that:

a) these composites lie in attractive channels,

b) they satisfy certain saturation-criteria, and

c) most crucially, such composites define an effective low energy theory, which is renormalizable.

We shall use this assumption as a provisional guide for selecting small mass, small size, composites. The crucial factor here is the renormalizability of the low energy theory. If the low energy local gauge symmetry is chiral, it should automatically keep composite fermions which transform non-trivially under the chiral symmetry, massless. Else the theory will not be renormalizable. The composite fermions, and also the gauge bosons, will acquire masses if at all, through dynamical symmetry breaking. Likewise, only those spin1/2 and spin-1 gauge quanta can be born massless with small size, which can belong to an anomaly-free gauge theory. In general, this will either restrict the low energy gauge-structure or the composite fermion-content or both.

The reader will notice that, one way or another, we are assuming formation of "charged" massless spin-1 composites describing W's, Z's and gluons, which acquire mass through SSB. Does this conflict with Weinberg-Witten (WW) constraint[9]? The simplest way to avoid any conflict with WW-constraint, is to assume that preons of the type discussed above arise as composites of pre-preons and that neither flavour nor colour can be defined even as global symmetries at the pre-preon level. These symmetries arise as effective local, and not just global symmetries at the composite preon-level. In this case, the gauge particles

W's, Z's and gluons, which cause transitions between preons may be viewed as composites of the appropriate sets of pre-preons (see later). Such a possibility clearly does not conflict with the WW-theorem*).

Remark that if there are more than two massless flavons (say four or six), the flavour global symmetry of the preons might have been $SU(4)_L \times SU(4)_R \times U(1)_f$ or $SU(6)_L \times SU(6)_R \times U(1)_f$. Since the emergence of such chiral symmetries as local symmetries would be inconsistent**) with renormalizability on account of the triangle anomaly, we expect that only an anomaly-free subgroup e.g. $\left[SU(2)^e_L \times SU(2)^\mu_L \times SU(2)^\tau_L\right] \times (L \to R)$ (for 6 flavons) would emerge as the effective local symmetry at low energies, with spin-1 composites belonging to the coset-space (e.g. $W^{e\mu}_L$, $W^{e\tau}_L$, $W^{\mu\tau}_L$ etc.) being formed with a relatively heavy mass of order r_0^{-1}, where r_0 is the size of these spin-1 composites.

III. PRE-PREONS AND NEED FOR FERMI-BOSE SYMMETRY

With these remarks to serve as a background for preonic models, we seek for an underlying system of pre-preons ($\mathbb{P}$), which should be more economical than the preonic system and should ideally provide guidance to the number of flavons and chromons and therefore on the number of generations.

Our first observation is this: Assume that the primordial force is generated by either an abelian or a simple nonabelian local symmetry (e.g. SU(N) or SO(N)). Following our preference for a monotheistic system, let us furthermore assume that the fundamental entities of matter belong to a "single" representation of the basic local symmetry group, which is simultaneously minimal.

*) Sudarshan (Ref. 10) has argued that the WW-constraint may be circumvented on more general grounds, if the continuity of certain matrix elements involving massless particles does not hold in passing from space-like to light like momentum-transfers. If this is the case, the gauge particles (i.e. W's, Z's and gluons) need not be formed at the level of preons. Instead they may be formed at a later stage at the scale of the inverse size of quarks and leptons.

**) If mirror partners of basic preons are formed as composites, the full flavour symmetry $SU(6) \times SU(6) \times U(1)_f$ could emerge as an effective local symmetry.

This corresponds to matter belonging to the single fundamental (i.e. defining) rather than a tensorial representation for the non-abelian case, or matter possessing just one kind of charge "g" for the abelian case*). It then follows that quarks and leptons, carrying half integer-spin and being neutral with regard to the primordial gauge symmetry G_b, cannot be formed**) at any stage of compositeness, starting with only fermionic (half integer-spin) or only bosonic (integer-spin) elementary constituents. To build quarks and leptons we need both kinds of matter fermionic as well as bosonic - carrying the same charge "g" for the abelian case or belonging to the same (fundamental) representation N_f of G_b for the nonabelian case.

This simple observation, amounting to a need for both fermions and bosons (arising out of our demand for "minimality"), suggests that nature at a

*) For the magneto-electric abelian theory, one would introduce, for example, just one entity carrying electric type charge and another carrying magnetic type charge, or alternatively two entities carrying different dyonic charges.

**) This follows by noting that if primordial matter (with components α, β, etc) possesses only one kind of charge "g", neutral composites must be of the form $(\alpha\bar{\alpha})^n$, $\alpha^n(\bar{\alpha})^m(\beta)^{n-m}$ etc. If α's and β's carry only integer or only half-integer spins, the neutral composites will necessarily carry integer spin. This conclusion holds even if "g" represents for example the fundamental representation $\underset{\sim}{N}$ of an SU(N). It also holds even if "g" corresponds to a pair of dual charges g and h for a magneto-electric type of theory, where the field of dual charges can contribute a half integer or integer unit of angular momentum depending upon $gh/4\pi = 1/2$ or 1. This is essentially because the field angular momentum of a pair $(\alpha\bar{\alpha})$ is zero in any case even if α's are dyons. If we introduce α with charge (g, 0) and β with charge (0, h), neutrality demands that the composites are of the form $(\alpha\bar{\alpha})^m(\beta\bar{\beta})^n$, whose field-angular momentum is once again integral regardless of whether $(gh/4\pi) = 1/2$ or 1.

fundamental level is supersymmetric, since it is only supersymmetry which makes a Fermi-Bose pairing automatic. To illustrate the ideas, in this section, while we shall always introduce bosons accompanying fermions of a given charge, we shall not insist on full supersymmetry (i.e. equality of numbers of fermions and bosons), in that we shall construct models of pre-preons with or without supersymmetry.

Model I. Assume for simplicity that the fundamental gauge symmetry G_b is just an abelian U(1)-symmetry*) and that fundamental matter consists of just one spin-1/2 left handed particle (α_L), one spin-1/2 right handed (α_R), plus a complex spin-0 particle (α_0), each possessing a charge g**):

Let the Lagrangian be: $$\alpha = \begin{pmatrix} \alpha_{L,R} \\ \alpha_0 \end{pmatrix} \qquad (2)$$

$$\mathcal{L} = \sum_{L,R} \bar{\alpha}_i (-i\gamma_\mu)(\partial_\mu - i g V^0_\mu)\alpha_i + \frac{1}{2}\left|(\partial_\mu - i g V^0_\mu)\alpha_0\right|^2 \qquad (3)$$

Here the subscript zero on α denotes its spin (not its charge). We have not introduced a mass-term for $\alpha_{1/2}$. In general, $\alpha_{1/2}$ may acquire mass dynamically (see later). We shall assume, however, that the effective masses of $\alpha_{1/2}$ and α_0 (dynamical or intrinsic) inside composite preons (or quarks and leponts) are very much smaller compared to inverse sizes of the composites. Without a mass-term for $\alpha_{1/2}$, the global symmetry of the basic Lagrangian is:

$$U(1)_{\alpha_L} \times U(1)_{\alpha_R} \times U(1)_{\alpha_0} \qquad (4)$$

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*) Most of our discussions will be unaltered if the primordial gauge symmetry G_b was either the magneto-electric abelian type or nonabelian, e.g. SU(N), with fundamental matter (spin-1/2 and spin-0) belonging to $\underset{\sim}{N}$ dimensional representation of SU(N).

**) Renormalizability of the theory would demand that we add a quartic coupling and a mass term for the boson α_0. These parameters may be understood to be present in (3), though they are inessential for our discussions. In a super-symmetric context (see later), some of these parameters are not independent.

If $\alpha_{1/2}$ acquires a Dirac mass (dynamically), the global symmetry would reduce to*)

$$U(1)_{\alpha_{1/2}} \times U(1)_{\alpha_0} \qquad (5)$$

with separate conservation of fermion ($\alpha_{1/2}$) and boson (α_0)-numbers**).

We now start building composites of α's and $\bar{\alpha}$'s, in particular those which carry the same net binding charge "g"***) as the α's themselves. They are composites of the type $\alpha\bar{\alpha}\alpha$, $\alpha(\bar{\alpha}\alpha)^2$ etc. Note that in each case there are more attractive pairs of unlike charges than repulsive pairs of like charges.

We therefore expect the binding to occur, if the U(1)-force is sufficiently strong. Our dynamical assumptions are listed below:

1) We assume that the preon-binding force is sufficiently strong at some scale****) $\gg$ 1 TeV, to make composites $\alpha\bar{\alpha}\alpha$ of inverse size Λ_P.

2) We assume that the spin-1/2 and spin-0 composites of this type remain massless or acquire light masses $\ll \Lambda_p$, so that their effective interactions at momenta $< \Lambda_p$ are governed by a renormalizable interaction, while

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*) This can happen through the non-conservation of the axial current due to instanton effects.

**) Note that the model defined by the system (2) cannot be made super-symmetric since there are two two-component fermions $\alpha_{L,R}$ and only one spin-0 boson (α_0).

***) The neutral composites $\bar{\alpha}\alpha$ will eventually be identified, for example, with some of the quarks and leptons (see later).

****) The question of origin of scales in abelian or non-abelian theories is discussed later.

the spin-3/2 and spin-1 composites carrying charge "g" (if they form at all) acquire heavy masses of order Λ_p, since they cannot enter into (effective) renormalizable Lagrangians.

3) As we shall see, only composites carrying charge g will be of interest to us. We assume the existence of a dynamical saturation mechanism at the level of $\alpha\bar{\alpha}\alpha$ composites (of charge g) such that $\alpha(\alpha\bar{\alpha})^n$, $n > 1$ do not bind into light composites.

4) We assume that for the probes of low momenta $< \Lambda_p$, the composites $\alpha\bar{\alpha}\alpha$ would behave like elementary particles just like α's. For low momentum-probes, the composites $\alpha\bar{\alpha}\alpha$ would reveal only their net charge "g" and of course their spins and helicities. Furthermore their effective interactions conserve the symmetries of the basic Lagrangian (which include the conservation of charge "g" as well as the global quantum numbers N_{α_L}, N_{α_R}, and N_{α_0} – barring any dynamical breaking of these symmetries). <u>There will, however be no way to know the detailed composition of the composites $\alpha\bar{\alpha}\alpha$ in terms of pre-preons $\alpha_{L,R,0}$ and their antiparticles, so far as low momentum probes are concerned.</u>

Let us now list the distinct left and right handed spin-1/2 and spin-0 entities with charge "g" consisting of the parents $\alpha_{L,R,0}$ as well as the composites $\alpha\bar{\alpha}\alpha$ *).

*) In writing the composition of these states, $\alpha_L\alpha_L$ stands for the Lorentz scalar $\alpha_L^T C^{-1}\alpha_L$. Thus $\bar{\alpha}_R\alpha_L\alpha_L$ is a left-handed object: and $\bar{\alpha}_R\alpha_R\alpha_R$ is another. Note, in general, there are two ways of making a spin-1/2 left-handed composite with the ingredients $\bar{\alpha}_R$, α_L and α_L (with s-wave binding): (i) $\bar{\alpha}_R(\alpha_L^T C^{-1}\alpha_L)$ and (ii) $\alpha_L(\bar{\alpha}_R\alpha_L)_{\text{spin-0}}$. The second combination, due to the Pauli principle, is however proportional to the first. We thank O.W. Greenberg for making this remark.

$(\text{spin } 1/2)_L^{\text{charge "g"}}$	$(\text{spin}1/2)_R^{\text{charge "g"}}$	$(\text{spin-}0)^{\text{charge "g"}}$
$f_L^1 \equiv \alpha_L$	$f_R^1 \equiv \alpha_R$	$C_1 \equiv \alpha_0$
$f_L^2 \equiv \alpha_L\bar{\alpha}_0\alpha_0$	$f_R^2 \equiv \alpha_R\bar{\alpha}_0\alpha_0$	$C_2 \equiv \alpha_0\bar{\alpha}_0\alpha_0$
$f_L^3 \equiv \alpha_L\bar{\alpha}_L\alpha_R$	$f_R^3 \equiv \alpha_R\bar{\alpha}_R\alpha_L$	$C_3 \equiv \alpha_0\bar{\alpha}_L\alpha_R$
$f_L^4 \equiv \bar{\alpha}_R\alpha_R\alpha_R$	$f_R^4 \equiv \bar{\alpha}_L\alpha_L\alpha_L$	$C_4 \equiv \alpha_0\bar{\alpha}_R\alpha_L$
$f_L^5 \equiv \bar{\alpha}_R\alpha_0\alpha_0$	$f_R^5 \equiv \bar{\alpha}_L\alpha_0\alpha_0$	$C_5 \equiv \bar{\alpha}_0\alpha_L\alpha_L$
$f_L^6 \equiv \bar{\alpha}_R\alpha_L\alpha_L$	$f_R^6 \equiv \bar{\alpha}_L\alpha_R\alpha_R$	$C_6 \equiv \bar{\alpha}_0\alpha_R\alpha_R$

(6)

We notice that starting with just two spin-1/2 entities $\alpha_{L,R}$ and one spin-0 entity α_0 of charge "g", and including just the lowest configuration composites*) (i.e. $\alpha\bar{\alpha}\alpha$) of charge "g", we obtain for momentum-scales $< \Lambda_p$ altogether six left-handed, six right-handed plus six spin-0 entities, each of charge "g". Consistent with our assumption (4), each of these entities would behave as a point elementary particle of charge "g" for momentum-scales $< \Lambda_p$. It is, therefore, tempting to identify these six spin-1/2 left-handed (right-handed)-entities as the left (right) flavons f_L^i (f_R^i) and the six spin-0 entities as the chromons C_α in the sense discussed in the previous section**):

*) Note that in writing these composites, we have not permitted ourselves to use derivatives; in other words we have taken s-wave configuration only.

**) The reader may observe that we are encountering here a <u>new phenomenon</u> in that the preonic set $\{P\}$ of flavons and chromons includes not only the composites $\alpha\bar{\alpha}\alpha$, but also the parents $\alpha_{L,R,0}$. This situation arises, because we are seeking for all spin-1/2 and spin-0 composites, which carry charge "g" (rather than being neutral), and which are relevant at a momentum-scale $< \Lambda_p$. At these "low" momenta, the parents and the composites $\alpha\bar{\alpha}\alpha$ are on par, and therefore must be grouped together, so far as effective field theories are concerned. It is important to note that in renormalizable field theory-calculations, the finite parts of matrix elements are dominated by momenta which lie between the lowest and highest masses in the theory. Thus if Λ_p exceeds all masses in the theory, the momenta which dominate radiative graphs are less than Λ_p. The radiative loop graphs are therefore not being "stretched" to momenta where they do not apply.

$$\left\{f^{i}_{L,R}\right\}_{i=1,\,2,\,\ldots\,6} = (u,\ d,\ c,\ s,\ t,\ b)_{L,R}$$

$$\left\{C_{\alpha}\right\}_{\alpha=1,\,\ldots\,6} = (r,\ y,\ b,\ \ell\ ,\ \ell'\ ,\ \ell''\ )_{0} \qquad (7)$$

The four chromons (r, y, b, ℓ) give the quark and leptonic colours. If we have six chromons, the composites $f^{i}C^{*}$ will include the familiar quarks and leptons (for C = r, y, b, ℓ) as well as new composite fermions in each generation due to the presence of the two extra chromons*) ℓ' and ℓ''.

Since all the flavons and chromons listed above carry the same charge "g" their effective interactions mediated by the gauge particle V^{0} would be invariant under the global symmetry:

$$(G)_{global} = SU(6)_{L} \times SU(6)_{R} \times SU(6)^{C} \times U(1)_{f} \times U(1)_{C} \qquad (8)$$

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*) Note that the symbols ℓ' and ℓ'' do not necessarily imply that these are leptonic chromons just like ℓ. Whether the charge-pattern associated with ℓ' and ℓ'' and their effective low energy interactions coincides with the charge-structure of ℓ and the interaction of ℓ depends on the pattern of spontaneous symmetry breaking of $SU(6)_{C}$. One possible charge assignment leading to fractionally charged quarks (see Ref. 3) for flavons and chromons is as follows: $Q = (+\frac{1}{2}\ ,\ -\frac{1}{2})$ for (u,d) flavons; $Q = (\frac{1}{6}\ ,\ \frac{1}{6}\ ,\ \frac{1}{6}\ ,\ -1/2\ ,\ +1/2, -1/2)$ for the antichromons $(r,y,b,\ell\ ,\ \ell'\ ,\ \ell''\ )^{*}$. This corresponds to the charge formula: $Q = I_{3L} + I_{3R} + \frac{B-L}{2} + I^{C}_{3}$, where I^{C}_{3} denotes the third component of the generators of $SU(2)^{C}$ defined by the $(\ell'\ ,\ \ell'')$ doublet. The above charge-pattern would imply integer lepton-like charges for $f^{i}C^{*}$ composites with C being ℓ' or ℓ'' (just as for $C = \ell$) . In general, however, other charge-patterns are permissible especially for ℓ' and ℓ'' . In general, one may also add a term $(N_{f} - N_{C})/2$ to the electric charge formula, where N_{f} and N_{c} denote flavon and chromon numbers; such a term would assign integer charges (+1, 0) to the flavons without altering quark-lepton-charges. Finally, if Q is chosen so as to yield integer-charge quarks and if, furthermore, the term $(N_{f} - N_{c})/2$ is added to Q, all preons (flavons and chromons) would have integer charges .

Note that this symmetry is non-existent at the fundamental pre-preon level. Here $U(1)_{f}$ and $U(1)_{C}$ denote the flavon and chromon-numbers respectively. Such a global symmetry is operative despite the fact that the flavons f^{i}_{L} (likewise f^{i}_{R}'s and C_{α}'s) differ from each other in respect of the quantum numbers $N_{\alpha_{L,R,0}}$. These numbers are only global, i.e. there exist no interactions generated by these quantum numbers. If such interactions existed they will not conserve the global symmetry $SU(6)_{L} \times SU(6)_{R} \times SU(6)^{C}$.

"Neutral" Spin-1 Composites

We consider now spin-1 (and spin0) composites*) of pre-preons and/or preons, which are neutral with regard to the binding charge Q_{b} . We expect these composites to form in general with small size, i.e. large inverse size $(\Lambda_{V}) \lesssim \Lambda_{P}$. These Q_{b}-neutral spin-1 (and spin-0) composites may be viewed either as two-body preonic $P\bar{P}$-composites like $\bar{f}^{i}_{L}\ \gamma_{\mu} f^{j}_{L}$, $\bar{f}^{i}_{R}\ \gamma_{\mu}\ f^{j}_{R}$ and $C^{+}_{\alpha}\ \overleftrightarrow{\partial}_{\mu}\ C_{\beta}$ (for the spin-1 case), or as two four and six-body pre-preonic composites**) or both. Consistent with the "renormalizability condition" for small size small-mass-composites stated before, we shall assume that those spin-1 composites, which can become part of an effective renormalizable theory would be born massless; they would be the gauge particles of an effective local gauge symmetry (G_{eff}); the remaining spin-1 composites would be born heavy with masses $\sim \Lambda_{V}$. If G_{eff} operates on chiral fermions, it must, of course, be such as to be free from anomalies for the sake of renormalizability. The symmetry (G_{eff}) would be operative only at momenta $\lesssim \Lambda_{V}$: in general it may break dynamically (spontaneously) to a subgroup G_{I} at a scale $\lesssim \Lambda_{V}$: the composite gauge particles in the Coset G_{eff}/G_{I} would thereby acquire masses $\lesssim \Lambda_{V}$.

) Neutral spin-1/2 composites, which in our picture are composites of the type fC, are discussed later. Note that these include composites of the type $\alpha\bar{\alpha}$ as well as $\alpha(\overline{\alpha\bar{\alpha}\alpha})$, since in our picture α and $\alpha\bar{\alpha}\alpha$ are on par for all momenta below Λ_{P} .

**) For example $\bar{f}^{2}_{L}\ \gamma_{\mu}\ f^{2}_{L}$ may be regarded as a six-body pre-preon composite $\overline{(\alpha_{L}\bar{\alpha}_{0}\alpha_{0})}\ \gamma_{\mu}\ (\alpha_{L}\bar{\alpha}_{0}\alpha_{0})$.

Given that the global symmetry $G = SU(6)_L \times SU(6)_R \times SU(6)^C \times U(1)_f \times U(1)_C$ is not anomaly-free, we expect, following the renormalizability condition, that either the preons $\{P\} = \{f^i_{L,R}, C\}$ are accompanied by their mirror-partners*) (in this case the full global symmetry G could emerge as an effective local symmetry), or a suitable anomaly-free subgroup of G emerges as the effective <u>local</u> symmetry at momenta $\langle \Lambda_V$. The anomaly-free subgroup, which suggests itself (in the absence of mirrors**)), is:

$$G^{local}_{eff} = SU(2)^e_L \times SU(2)^{\mu}_L \times SU(2)^{\tau}_L \times SU(2)^e_R \times SU(2)^{\mu}_R \times SU(2)^{\tau}_R \times SU(6)^C \tag{9}$$

Here $SU(2)^{e,\mu,\tau}_{L,R}$ act respectively on the doublets:

$$f^e_{L,R} = \begin{pmatrix} f^1 \\ f^2 \end{pmatrix}_{L,R} \equiv \begin{pmatrix} u \\ d \end{pmatrix}_{L,R} \quad ; \quad f^{\mu}_{L,R} = \begin{pmatrix} f^3 \\ f^4 \end{pmatrix}_{L,R} \equiv \begin{pmatrix} c \\ s \end{pmatrix}_{L,R} \tag{10}$$

$$\text{and } f^{\tau}_{L,R} = \begin{pmatrix} f^5 \\ f^6 \end{pmatrix}_{L,R} \equiv \begin{pmatrix} t \\ b \end{pmatrix}_{L,R}$$

while $SU(6)^C$ acts on the sextet $(C_\alpha)_{\alpha=1,\ldots 6} = (r, y, b, \ell, \ell', \ell'')$. The choice of which pair of flavons out of the six constitute a doublet of which SU(2) ($SU(2)^e$, $SU(2)^{\mu}$ or $SU(2)^{\tau}$) is to some extent arbitrary. We are guided in making the particular choice exhibited above by the following observation: The flavons

*) The question of formation of mirrors as composites is a dynamical one. That they can in general arise naturally in a variety of ways has been mentioned elsewhere (see e.g. Ref.3).

**) Note that in the absence of mirrors, $U(1)_f$ cannot act as an effective local symmetry due to anomaly in $SU(2)_L \times U(1)_f$. $U(1)_C$ could survive as a local symmetry for preons, but not for quarks and leptons.

f^1_L and f^2_L possess the same global quantum numbers: $N_{\alpha_L} = +1$, $N_{\alpha_R} = N_{\alpha_0} = 0$; likewise f^2_L and f^3_L, both of which possess: $N_{\alpha_R} = +1$, $N_{\alpha_L} = N_{\alpha_0} = 0$; but f^5_L and f^6_L differ from each other in respect of their global quantum numbers:

$$f^5_L = \bar{\alpha}_R \alpha_0 \alpha_0 \quad (N_{\alpha_L} = 0,\ N_{\alpha_R} = -1,\ N_{\alpha_0} = +2)$$
$$f^6_L = \bar{\alpha}_R \alpha_L \alpha_L \quad (N_{\alpha_L} = +2,\ N_{\alpha_R} = -1,\ N_{\alpha_0} = 0) \tag{11}$$

Analogous situation prevails for the right-handed flavons. To summarise, it has emerged in the present model that two pairs of flavons and therefore two families are somehow more alike to each other, while the third is distinct in that transitions between members of the first pair and likewise of the second pair (i.e. $f^1_L \leftrightarrow f^2_L$ or $f^3_L \leftrightarrow f^4_L$) do not involve any change in the global quantum numbers, while those between members of the third pair (i.e. $f^5_L \leftrightarrow f^6_L$) do. Based on this observation, we wish to identify the two "like" pairs of flavons with the e and μ-families, and the unlike pair with the τ.
As we shall see, this identification, suggested by the underlying model itself, can have important phenomenological implications.

As mentioned before*), the demand of freedom from anomalies for the effective theory implies that in the absence of mirror preons, the effective local symmetry at preon-level cannot include (at least) the flavon number symmetry $U(1)_f$ as a <u>local</u> symmetry; even though it could, in principle, contain the chromon number symmetry $U(1)_C$ as a local symmetry. This is because $U(1)_C$ as well as $SU(6)_C$ operate on spin-0 chromons only and thus $SU(6)_C \times U(1)^C$ gives rise to no anomaly.

At the subsequent quark-lepton level even $U(1)_C$ cannot survive as an effective local symmetry, since quarks and leptons are chiral.
Alternative scenarios can be conceived of for this situation to emerge.

*) We note that despite the similarity between the e and μ-flavon-pairs, they still differ from each other in respect of their overall global quantum numbers with $N_{\alpha_L} = +1$, $N_{\alpha_R} = 0$, for e-flavons versus $N_{\alpha_R} = +1$, $N_{\alpha_L} = 0$ for μ-flavons. <u>This</u> distinction is, of course, lost once separate conservations of N_{α_L} and N_{α_R} are replaced by conservation of just the sum ($N_{\alpha_L} + N_{\alpha_R}$) due for example to instanton-effects.

i) Perhaps the simplest scenario may be that the composite spin-1 particles V_0^f and V_0^C coupled to $U(1)_f$ and $U(1)_C$ respectively acquire heavy masses of order Λ_p, on account of the lack of renormalizability in the presence of chiral interactions. These objects then get decoupled from the effective low energy interactions. This could happen with flavon and chromon numbers still being conserved.

ii) Alternatively, at about the same scale Λ_V, where the composite gauge particles of flavour and colour are formed, it is conceivable that both flavon and chromon numbers are violated simulataneously dynamically*) by four-particle condensates of the type $\Phi_L \sim \langle f_L^a f_L^b C_\alpha^* C_\beta^* \rangle \neq 0$ and/or $\Phi_R \sim \langle f_R^a f_R^b C_\alpha^* C_\beta^* \rangle \neq 0$, which form under the influence of the strong attractive force. The condensates $\Phi_{L,R}$ are neutral with regard to G_b; they in general transform as $\underset{\sim}{3} + 1$ of flavour $SU(2)_{L,R}$ and as $(15 + 21)$ of $SU(6)^C$, or as $(\overline{10} + 6 + 4^* + 4^* + 4^* + 4^* + 1 + 1 + 1 + 1 + 1)$ of the familiar $SU(4)^C$, or as $\{(6 + 3 + 1) + (3 + 3^*) + (3^* + 1) \times 4 + (1 \times 4)\}$ of the familiar $SU(\hat{3})^C$. If we use Φ_L, we must assume that only $SU(2)_L$-singlet, $SU(3)^C$-singlet component of Φ_L acquires a VEV; likewise for Φ_R. In this case, the residual effective local symmetry would, for example, be $G_R^{(1)} = [SU(2)_L]^3 \times [SU(2)_R]^3 \times SU(4)^C \times SU(2)^C \times U(1)_{4-2}$ **). Alternatively, the minimum of the effective potential can legitimately choose $\Phi_L = 0$, $\Phi_R \neq 0$, with Φ_R transforming as a triplet***) of $SU(2)_R$ but as a singlet of $SU(3)^{col}$. In this case, the residual effective gauge symmetry will be e.g. $G_R^{(2)} = [SU(2)_L]^3 \times U(1) \times SU(3)^C$; in either case flavon and chromon numbers will never arise as global or local symmetries in the sense that concomitant with the formation of $\alpha\bar{\alpha}\alpha$-composites, the relevant condensates violate flavon and chromon-number symmetries. The effective gauge symmetry, to begin with, would then be of the type $G_R^{(1)}$ or $G_R^{(2)}$. One of these symmetries would then breakdown dynamically through several steps, utilising preonic condensates to $U(1)_{em} \times SU(3)^C$. A detailed presentation of such breakdown is discussed elsewhere by one of us (Ref. 6).

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*) The corresponding would-be goldstone bosons, we expect, would be absorbed by the composite spin-1 bosons V_0^f and V_0^c coupled to $U(1)_f$ and $U(1)_c$, which would thereby become massive.

**) Here $U(1)_{4-2}$ deonotes the traceless generator of $SU(6)^C$ which commutes with $SU(4)^C$ and $SU(2)^C$.

***) Such a condensate could transform e.g. like $(1, 3, \overline{10})$ under $SU(2)_L \times SU(2)_R \times SU(4)^C$ and would have the desirable property of breaking left-right symmetry and B-L in one go.

We remind the reader that the generation of the effective local symmetry $G_R^{(1)}$ or $G_R^{(2)}$ together with the formation of the corresponding massless spin-1 gauge particles in our picture arises simultaneously with the formation of the composite preons themselves: in other words the corresponding global symmetries arise only as effective local symmetries at the composite preon-level. As stated before, such a situation is not in contradiction with the WW constraint[9].

The gauge particles of $[SU(2)^{e,\mu,\tau}]_{L,R}$, $SU(4)_C$ and $SU(2)_C$ which may be viewed effectively as six-body pre-preon-composites are best defined by the preonic contents of the currents, which couple to them:

$$\begin{aligned}
\left[\vec{W}_\mu^{e,\mu,\tau}\right]_{L,R} &\sim \bar{f}_{L,R}^{e,\mu,\tau} \gamma_\mu \frac{\vec{\tau}}{2} f_{L,R}^{e,\mu,\tau} \\
\left[V_\mu\right]_{SU(4)^C} &\sim \left[c_\alpha^+ \frac{(\vec{\lambda})_{\alpha\beta}}{2} \overleftrightarrow{\partial}_\mu c_\beta\right]_{\alpha,\beta = r,y,b,\ell} \\
\left[\vec{V}_\mu\right]_{SU(2)^C} &\sim \left[c_\alpha^+ \frac{(\vec{\tau})_{\alpha\beta}}{2} \overleftrightarrow{\partial}_\mu c_\beta\right]_{\alpha,\beta = \ell', \ell''}
\end{aligned} \tag{12}$$

For practical purposes, the gauge particles listed above may be "viewed" as preonic composites in the form listed above, although they may be written down as two, four and six body pre-preon composites as well.

A further comment is in order. Flavon and chromon gauge particles (including W's, Z, gluons and the photon) are "born" in the present picture only at the preonic level with inverse size of order Λ_P. Thus electric charge in this picture acquires a meaning only at the level of preons, i.e. for effective momenta $< \Lambda_P$; it cannot be defined for pre-preons. The photon as well as W's, Z and the gluons "die" as we probe them with momenta exceeding Λ_P, viz. they dissociate into their constituents-pre-preons. This in turn implies that while we can determine the electric charges of quarks and leptons in terms of preonic-charges, we must not attempt to do so in terms of pre-preonic charges; electric charge has only a "transitional" meaning*), valid at energies below Λ_P.

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*) To those familiar with Kaluza-Klein theories (although these are not directly related to the present models) such a transitional character of electric charge is fully familiar. In the original Kaluza-Klein theory with a five-dimensional space-time, there is the transition energy $\sim e/\sqrt{G_N}$ ($< 10^{19}$ GeV) below which the existence of the fifth dimension manifests itself as electric charge. Above this energy charge has no meaning and the fifth space-dimension is on par with the other three space-dimensions.

e Versus μ Versus τ

We now return to one of the most interesting features of the model, which suggests that one of the three families (identified with τ) is distinct from the other two (identified with e and μ). Following the discussion below Eqs. (10) and (11), it follows that $W^{+}_{\tau L}$ coupled to the non-diagonal current $\bar{f}^{5}_{L}\gamma_{\mu}f^{6}_{L}$ carries non-vanishing global quantum numbers; $N_{\alpha_L} = -2$, $N_{\alpha_0} = +2$, $N_{\alpha_R} = 0$; $W^{-}_{\tau L}$ carries the opposite global quantum numbers: by contrast W^{+}_{eL} and $W^{+}_{\mu L}$ carry no net global quantum numbers. An analogous situation prevails for the "right handed" gauge particles W_R's . This in turn implies that while $\vec{W}_e$ and $\vec{W}_\mu$ can mix with each other through dynamical symmetry breaking without a violation of the global quantum numbers (i.e. $[SU(2)^e \times SU(2)^\mu]_{L,R}$ can break to $[SU(2)^{e+\mu}]_{L,R}$ leaving $(\vec{W}_e - \vec{W}_\mu)/\sqrt{2}$ heavy ($> 3 \times 10^5$ GeV*), such a mixing between $\vec{W}_{e,\mu}$ and $\vec{W}_\tau$ cannot occur unless and until the global quantum numbers $N_{\alpha_{L,R,0}}$ are violated dynamically*). It is perfectly possible that the scale of dynamical breakdown of these global quantum numbers is much lower than that of $\vec{W}_e \leftrightarrow \vec{W}_\mu$ -mixing. In this case, we shall encounter the following pattern of symmetry breaking**) :

*) For a discussion of the types of condensates which could lead to e- and e-μ- family universality see Ref. 6. Note that the e-μ family universality must emerge at an energy-scale lying above $\gtrsim 3 \times 10^5$ GeV to account for the known degree of suppression of flavour-changing neutral currents involving transitions between members of the e and the μ-families (e.g. $K_L \nRightarrow \mu^+\mu^-$, $K^0 \leftrightarrow \bar{K}^0$ etc.)

**) The possibility that e, μ and τ may be associated with distinct SU(2)'s at some basic level has been raised in the context of "maximal" grand unifying symmetries like $[SU(16)]^3$ (see Pati and Salam Ref. 11), or the even smaller three family-symmetry $[SU(6)]^4$ (J.C. Pati, Ref.11). Some of its phenomenological consequences has been considered by E.Ma (Hawaii preprint, 1981) and A. Zee (unpublished, 1981, private communications). The symmetry breaking pattern[13] amounting to e-μ universality preceding the e-μ-τ universality as suggested here is new. It is amusing that, the origin of the three families with three distinct SU(2)'s (and e or μ versus τ -distinction) appear to emerge as a consequence of the underlying pre-preonic model presented here.

$$
\begin{array}{l}
SU(2)^{e}_{L} \times SU(2)^{\mu}_{L} \times SU(2)^{\tau}_{L} \\
\Big\downarrow\; M_1 > 3 \times 10^5 \text{ GeV} \\
SU(2)^{e+\mu}_{L} \times SU(2)^{\tau}_{L} \\
\Big\downarrow\; M_2 \sim 1 - 10 \text{ TeV} \\
SU(2)^{e+\mu+\tau}_{L}
\end{array}
\qquad (13)
$$

In the above, we have exhibited the pattern for the breaking of the left-handed flavour-sector; a similar pattern can occur for the right-handed flavour-sector (alternatively the right-handed flavour symmetry can break in conjunction with SU(6) or SU(4)-colour-symmetry in more than one step to U(1) x $SU(3)^C$). Focussing attention on (13), such a breaking pattern would imply that even if the right-handed gauge-particles became very heavy, there would be two kinds of gauge-particles with masses $\lesssim M_2$:

i) The familiar $W^{\pm}_{e+\mu+\tau}$ and $Z^{0}_{e+\mu+\tau}$ with masses of order 100 GeV*, which would be coupled to the sums of e, μ and τ -currents; these would lead to universal e , μ and τ -interactions, and

ii) a new set of gauge particles $W^{\pm}_{e+\mu-\tau}$ and $Z^{0}_{e+\mu-\tau}$ with masses of order 1 to 10 TeV, which would couple to charged and neutral currents of the form $(J^{e}_{L} + J^{\mu}_{L} - J^{\tau}_{L})$.

In this case, the interference of the two sets of gauge particles (e.g. $Z_{e+\mu+\tau}$ and $Z_{e+\mu-\tau}$) in processes of the type

$$
\begin{array}{l}
e^-e^+ \to e^-e^+ ,\ \mu^-\mu^+ ,\ \tau^-\tau^+ \\
\bar{p}p \to \text{"X"} + (e^-e^+) \text{ vs. } (\bar{\mu}\mu) \text{ vs. } (\bar{\tau}\tau) \text{ etc.}
\end{array}
\qquad (14)
$$

would exhibit dramatic departures from e-μ-τ -universality for centre of mass momenta approaching and exceeding masses as low as 1 to 10 TeV. High intensity high energy e^-e^+ and $\bar{p}p$-machines would be needed in the 1-10 TeV

*) The masses of these particles arise through the dynamical breaking of standard electroweak symmetry $SU(2)^{e+\mu+\tau}_{L} \times U(1)$ to $U(1)^{em}$ by a scale of order 300 GeV (see Ref. 6).

range for a test of these ideas*) .

Observation of any such departures from universality would establish three distinct SU(2)'s at an underlying level with a breaking pattern of the type (11). This in itself will be a strong hint for compositeness of e, μ and τ .

MODEL II: SUPERSYMMETRY AND EMERGENCE OF FLAVOUR AND COLOUR THROUGH THE BREAKING OF SUPERSYMMETRY

Following the observation that within our approach to minimality, fundamental matter must consist of spin-1/2 fermions <u>and</u> spin-0 bosons carrying the same charge "g" (or belonging to the same representation $\underline{N}$ of the underlying symmetry group), we are tempted to believe that the basic theory is supersymmetric. Before building such a pre-preonic theory, however, it is instructive to observe one special feature of the flavon-chromon preonic model in its simplest version consisting of just spin-1/2 flavons and spin-0 chromons coupled universally to some gauge fields.

In this model, as stated before, one needs two left-handed and two right-handed flavons plus four spin-0 chromons to build a single family of quarks and leptons. Note that the fermionic degrees of freedom (2 + 2) carried by the flavons precisely matches the complex bosonic degrees of freedom (4) carried by the chromons. Barring the possibility that this is merely a coincidence, it appears especially attractive to view flavons and chromons as chiral supersymmetric partners of an underlying theory, e.g.

$$\Phi_{1+} = \binom{u_L}{r} , \ \Phi_{2+} = \binom{d_L}{y} , \ \Phi_{1-} = \binom{u_R}{b} , \ \Phi_{2-} = \binom{d_R}{\ell} \qquad (14)$$

*) In principle the presence of $W^{+}_{e+\mu+\tau}$ can be felt through corresponding charged current interference-experiments, though this may be harder. Note that the possible presence of these new sets of gauge particles with masses $\sim$ 1 to 10 TeV coupling to ($J_e + J_\mu - J_\tau$)-currents would have negligible effects on the life time or decay-characteristics of τ or on $e^-e^+ \rightarrow \tau^- \tau^+$ - asymmetry parameter at PETRA-PEP energies.

While one can now write down a supersymmetric Lagrangian*) involving the coupling of these superfields to local U(1), or U(1) x U(1), or SU(N) gauge fields, assigning the same charge to all of them**), it is quite clear that unless and until supersymmetry is broken, one cannot define flavour and colour as distinct commuting symmetries***). It is only after supersymmetry is broken, with the gauginos becoming relatively heavy compared to the matter fields - that one can define separate flavour and colour symmetries.

We may have the following scenario: Starting with supersymmetric chiral multiplets of prepreons coupled to some gauge fields, one may find that the dynamics permits of the emergence of supersymmetric preonic composite multiplets with inverse size Λ_p . Supersymmetry may break for energies $\Lambda_s \lesssim \Lambda_p$. At this stage, flavour and colour quantum numbers are born - synonymous with fermions and bosons contained in the primary and composite supermultiplets, parting their supersymmetric company. At the same time colour and flavour gauge particles (i.e. W's and gluons) can form as composites of preons (or pre-preons) with inverse size Λ_s defining an effective low energy gauge symmetry of the type $SU(2)_L \times SU(2)_R \times SU(4)^C$ or its subgroups.

This idea of the emergence of flavour and colour being synonymous with the breaking of supersymmetry was first suggested in Ref. 12.

To make the idea concerete, we start with two pre-preonic chiral left and right-handed supermultiplets.

$$\Phi_+ = \left(\frac{\alpha_L}{\alpha_0}\right)^{"g"} \quad , \quad \Phi_- = \left(\frac{\alpha_R}{\alpha'_0}\right)^{"g"} \qquad (15)$$

which carry the same charge "g" or constitutes the same fundamental representation with respect to a local gauge group G. As was noted in Ref. (12), the field representation of a composite field in supersymmetric theories is particularly attractive. This is because any product-field created by multiplying any number of + (or -) type of chiral superfields leads just to a + (or -) type of composite

*) Such a Lagrangian may be regarded as an effective Lagrangian only, if preons are composites. This we assume later.

**) For an SU(N) theory, each of u_L and u_R is an N-plet; similarly for the other preons.

***) The Yukawa coupling of the gaugino (or gauginos) prevents such an identification.

superfields with a $\bar{\Phi}_+$ behaving like a Φ_- and a $\bar{\Phi}_-$ like a Φ_+ in such a product[13]; i.e.

$$\Phi_{i\pm}\Phi_{j\pm} = \Phi_{k\pm}\,,\ \Phi_{i+}\bar{\Phi}_{j-} = \Phi_{\ell+} \text{ etc.}$$

where + (-) types of superfields consist just of left-handed (right-handed) spin-1/2 plus spin-0 fields. Thus chiral spin-1/2 and spin-0 super-preons, coupled supersymmetrically in this manner do not give rise to any but spin-1/2 and spin-0 composites. No higher spins result.

Spin-1 composites can, of course, be constructed by multiplying superfields of opposite chiralities. Thus a product superfield like $\Phi_+\Phi_-$ or $\Phi_+\bar{\Phi}_+$ or $\Phi_+\bar{\Phi}_+\Phi_+$ gives rise to a general superfield Φ consisting of spin-0, spin-1/2 as well as spin-1 objects. Such general superfields Φ can be decomposed by applying projection operators on them:

$$E_+ = -1/(4\partial^2)\ (D_-D_-)\ (D_+D_+)$$

$$E_- = -1/(4\partial^2)\ (D_+D_+)\ (D_-D_-)$$

$$E_1 = 1 - E_+ - E$$

where $D_\pm = (1 \pm \gamma_5)/2\ (\partial/\partial\bar{\theta} - \frac{i}{2}\ \not{\partial}\theta)$,

$$\text{and } \Phi(x,\Theta) = (E_- + E_+ + E_1)\ \Phi\ (x,\Theta) = \Phi_- + \Phi_+ + \Phi_1 \qquad (16)$$

The superfield Φ_1 contains spin-0, spin-1/2 and spin-1 components. This is in fact the superfield which (in the Wess-Zumino gauge) can be used to describe gauge bosons and gauginos, if the internal symmetry quantum numbers permit.

After these introductory remarks, consider the two chiral pre-preons Φ_+ and Φ_- each carrying the same charge g with respect to a local gauge symmetry U(1) or the same representation N with respect to a local SU(N) gauge group: (the U(1) can be replaced by a dual magneto electric theory[3,4] in its supersymmetric version[14] described by electric and magnetic type charges g and h, related by $gh/4\pi = n/2$).

The pre-preons Φ_+ and Φ_- interact through the intermediacy of the gauge superfield V. One can expect the formation of composites of the type $\Phi\bar{\Phi}\Phi$ with inverse size Λ_p carrying the same charge "g" (or

representation N) as the basic fields Φ_+ analogous to model I*). It is amusing that limiting oneself to upto three particle composites and using chiral as well as nonchiral combinations (the nonchiral combinations being subject to chiral projections through $E_\pm$), one obtains - including the pre-preons $\Phi_\pm$ - just six (+) and six (-) chiral superfields; each consisting of one spin-1/2 two component (left or right-handed) plus a spin-0 field with charge "g". These are:

$$\begin{array}{ll}
\text{(I)} & \left\{\begin{array}{l}\Phi_+ \\ \Phi_+\bar{\Phi}_-\Phi_+\end{array}\right. ,\quad \begin{array}{l}\Phi_- \\ \Phi_-\bar{\Phi}_+\Phi_-\end{array} \\
\text{(II)} & \left\{\begin{array}{l}E_\pm\ \Phi_+\bar{\Phi}_+\Phi_+ \\ E_\pm\ \Phi_+\bar{\Phi}_+\Phi_-\end{array}\right. \\
\text{(III)} & \left\{\begin{array}{l}E_\pm\ \Phi_-\bar{\Phi}_-\Phi_+ \\ E_\pm\ \Phi_-\bar{\Phi}_-\Phi_-\end{array}\right.
\end{array} \qquad (17)$$

In the chiral multiplets shown above, one can identify - subsequent to supersymmetry breaking - the six left-handed fermions with six left-flavons, the six right-handed fermions with six right-flavons and the twelve spin-0 bosons with twelve chromons. Note that the supersymmetric system yields four new chromons per family (i.e. for each set of 2 flavons (left and right)). This suggests that within the supersymmetric approach (if indeed three families have their origin at the preonic level rather than at the composite quark-lepton level), the colour symmetry subsequent to supersymmetry breaking, may start off being SU(12) or $SU(4)^C_e \times SU(4)^C_\mu \times SU(4)^C_\tau$.

One remarks is in order. To preserve locality of field operators representing composites, one should multiply $E_\pm$ by ∂^2. In terms of the constituent fields, some of the terms would then involve derivatives for the "nonchiral" composites, in contrast to the chiral composites like $\Phi_+\bar{\Phi}_-\Phi_+$. Which type of composites represent physical objects of light masses (light relative

*) If spin-1 composites (like those arising from $\Phi_+\bar{\Phi}_+\Phi_+$) carry charge "g", they cannot in general act as gauge fields: (gauge fields must belong to an adjoint representation of a symmetry group and for U(1) they must be neutral). We, therefore, assume, consistent with the renormalizability-condition mentioned before, that such composites are formed with a heavy mass $\sim\Lambda_P$.

to Λ_p) is, of course, a dynamical question*). If the formation of "nonchiral" composites with light masses is inhibited, one may need to use, in addition to the chiral set I (see Eq. (17)) 5 and 7 particle chiral composites, i.e. $\bar{\Phi}_+ (\bar{\Phi}_- \hat{\Phi}_+)^n$ and $\hat{\Phi}_-(\bar{\Phi}_+ \hat{\Phi}_-)^n$ with n = 2 and 3 to build a preonic system with 4 flavons plus eight chromons. Once again, the question of why saturation should take place for n = 3, in this case, is left unanswered at present.

We now discuss the problem of supersymmetry breaking. Given the present state of the art, we should seek for a spontaneous breaking of supersymmetry at the tree level either through the Fayet-Illiopoulos mechanism (for the abelian case) or through the O'Raifeartaigh mechanism; in the latter case we need to introduce new Higgs superfields (see below) with new coupling parameters. In accordance with our desire for minimality in basic fields and parameters as well as uniqueness for the basic Lagrangian, we may expect these Higgs fields and their appropriate interactions to be generated dynamically at a composite level (say of preons) - i.e. supersymmetry breaks dynamically. We are aware that at present this attitude appears to be incompatible with certain theoretical arguments[15]. It appears to us that these arguments are not sufficiently general and they need not apply especially if the matter fields belong to a complex representation of SU(N) gauge group, or if supersymmetry is locally realised.

Irrespective of this, to fix ideas, introduce, as an example, the O'Raifeartaigh-Witten[16,17] mechanism into the fundamental (pre-preonic) Lagrangian to break supersymmetry spontaneously at the tree level, though our discussions will remain unaltered if this mechanism is induced effectively at the composite-preon level without being fed in through the pre-preonic Lagrangian. We may, of course, still entertain the possibility that the scale Λ_s of supersymmetry breaking is less than or of the order of the scale Λ_p denoting the inverse size of composite preons, since Λ_p, in the simplest version of an underlying model, is the scale of the primordial force**). In this sense,

*) Relevant in this context are t'Hooft's anomaly-matching conditions. As is well known, for supersymmetric theories chiral and energy-momentum trace-anomalies are tied with each other. We shall, however, not pursue this here.

**) In a theory with just one input scale, we would, of course, expect Λ_p and Λ_s to be related at least nonperturbatively (see remarks below).

one can still use only supersymmetric composites of pre-preons to build preons.

The suggestion of Witten (incorporating the O'Raifeartaigh mechanism has the merit that with one input scale Λ_s (the scale of supersymmetry breaking), it permits the generation of a higher scale $M \approx \Lambda_s \exp\left[\text{constant}/g_b^2\right]$ non-perturbatively, where $\left[\text{constant}/g_b^2\right] \gg 1$. There emerges also radiatively a lower scale[18] $m \sim (\frac{\alpha_b}{2\pi}) (\Lambda_s^2/M)$, where α_b is the relevant gauge coupling constant. Such a situation is clearly advantageous in an approach towards minimality like ours, which emphasises a minimum of input scales (ideally, just one). The other side of the coin, however, is that these theories - particularly the Higgs sector - are baroque.

To show what is needed, consider a pre-preon theory in which the primordial binding force is an SU(3) gauge force*) and the pre-preons (Φ_+'s) are SU(3)-triplets. Following recent work by a number of authors[18] introduce two SU(3) octet chiral superfields**) (A_+) and Z_+ and one singlet X_+.

The part of the superspace potential involving X, Z and A -fields, i.e.

$$W = \lambda_1 T\gamma (ZA^2) + \lambda_2 X(T\gamma A^2 - \Lambda_s^2) \tag{18}$$

leads to supersymmetry breaking at the tree level. The magnitude of $\langle \phi_A \rangle$ is determined ($\sim \Lambda_s$), but $\langle \phi_X \rangle$ and $\langle \phi_Z \rangle$ though related to each other are undetermined at the tree level. One computes (following Huq[19] and Witten[17]) the one-loop radiative corrections to the potential. Provided the gauge

*) This choice for the primordial force (SU(3)) is dictated by our desire to utilise the O'Raifeartaigh mechanism for breaking supersymmetry: which for an SU(n) internal symmetry requires n to be odd. We thank J. Strathdee for this remark.

**) If the gauge symmetry was abelian like $U(1)_g$ or $U(1)_g \times U(1)_h$, one would need two multiplets A and A' carrying opposite charges (e.g. (0,h) and (0,-h) for the case of $U(1)_g \times U(1)_h$-symmetry). For the second case, $U(1)_g$ is the gauge group providing the main binding force and $U(1)_h$ is an auxiliary gauge group, which will eventually be broken spontaneously. Such a model - like most super-symmetric models - gets fairly elaborate. The consequences of this model are being examined by Zhian.

contributions ($\propto - g_b^2$) dominate over the scalar-contribution ($\propto \lambda_1$), these radiative corrections lead naturally in a supersymmetric theory to Witten's upside-down hierarchy-mechanism, i.e. the determination of the maximal scale (M) of the theory, which characterises the upper limit of applicability of the perturbative calculation: $M \approx \Lambda_s \exp\left[c/g_b^2\right] \gg \Lambda_s$. On the one hand, the scale M represents the VEV of X and Z; on the other hand it may represent the scale Λ_p of the binding force. In the extreme case M may be as high as the Planck mass $\approx 10^{19}$ GeV with $M = M_{planck} = \Lambda_p \gg \Lambda_s$. Alternatively, M may be distinct, lying above the scale Λ_p, i.e. $M_{planck} \gtrsim M \gg \Lambda_p \gtrsim \Lambda_s$. It seems premature to fix on the relative magnitudes of the scales, until one has a clearer picture of the origin of gravity*) and the breaking of supersymmetry.

Following Dimopoulos and Raby and Polichinshi and Susskind[18], we argue that while the components of the field A feel supersymmetry breaking directly and their scalar components acquire masses $\sim$ M, the effective supersymmetry breaking scale for other fields (induced radiatively) is in general given by $\frac{\alpha_b}{2\pi}(\Lambda^2/M)$. Scalar components of matter fields and gauginos acquire masses of this order**).

We may envisage still lower scales generated by further radiative corrections. This will not be discussed further, since the situation here is similar to that discussed in Ref. 18 (see for example Dimopoulos and Raby) with SU(3) replacing SU(5). The primordial SU(3) gauge symmetry breaks down spontaneously in our case to a conserved SU(2) x U(1)***) which can now provide the essential binding force.

*) That the graviton may also be a composite of pre-preons has been discussed in Ref. 4. Other references on somewhat similar ideas may be found there.

**) If supersymmetry could break dynamically (for whatever reasons), one can envisage a more general pattern of supersymmetry breaking than that realised within the O'Raifeartaigh mechanism.

***) This SU(2) x U(1) is of course not the electroweak symmetry. Note that, with this descent, we would expect the generation of topological U(1)-monopoles

The following diagram gives the stages we envision in this theory:

$$\underset{(M)}{\text{Pre-preons}} \longrightarrow \underset{(\Lambda_p)}{\text{Preons}} \longrightarrow \underset{(\Lambda_s)}{\text{Supersymmetry breaking}} \longrightarrow$$

$\rightarrow$ Emergence of flavour and colour and of gauge particles for an effective symmetry like $SU(2)_L \times SU(2)_R \times SU(4)^C$

$\rightarrow$ Quarks and Leptons $(\Lambda_{q,\ell})$

Since the Λ_s-stage preceeds the emergence of $SU(4)^C$ and since $SU(4)^C$ must break spontaneously so that leptoquarks acquire masses $\gtrsim 3 \times 10^5$ GeV[1], we would expect $\Lambda_s > 3 \times 10^5$ GeV*). With the radiatively generated scale $\frac{\alpha_b}{2\pi}(\Lambda_s^2/M)$ in the range of 1 - 100 GeV, the heavy scale M may be expected to vary quadratically with Λ_s from 10^8 GeV upward with Λ_p, in general, being equal to M or lying intermediately between Λ_s and M. The extreme situation could be $M = \Lambda_p$ = Planck-mass $\approx 10^{19}$ GeV with supersymmetry breaking around $10^{10} - 10^{12}$ GeV.

Model III: We conclude this section by noting an alternative origin of flavons and chromons.

While in Model II we have emphasised that flavons and chromons have their origin as supersymmetric partners, one can envision an alternative scenario in which flavons and chromons arise (from a pre-preonic theory) as Fermi and Bose-components of different superfields; the bosonic partners of the flavons and perhaps also the fermionic partners of the chromons acquire relatively heavy masses and get decoupled from the low energy theory, while the flavons and chromons remain light or massless after supersymmetry breaking. In this picture one would need at least 8 chiral superfields at the preonic level

*) Note that the formation of the flavour symmetry $\left[SU(2)_L^e \times SU(2)_L^\mu \times SU(2)_L^\tau\right] \times (L \rightarrow R)$, which allows for family distinctions (see text), would also require a breaking scale $\gtrsim 3 \times 10^5$ GeV signifying the scale of $e-\mu-\tau$ - unification. This also implies, in the present picture, that $\Lambda_s > 3 \times 10^5$ GeV.

as matter multiplets, four of them being flavonic and four chromonic. The particle content of the 8 superfields are as follows:

$$\Phi_{1+}=\left(\frac{u_L}{\varphi_u}\right),\ \Phi_{2+}=\left(\frac{d_L}{\varphi_d}\right),\ \Phi_{1-}=\left(\frac{u_R}{\varphi_u'}\right),\ \Phi_{2-}=\left(\frac{d_R}{\varphi_d'}\right)$$
$$\xi_{1+}=\left(\frac{\chi^c_{1L}}{C_1}\right),\ \xi_{2+}=\left(\frac{\chi^c_{2L}}{C_2}\right),\ \xi_{1-}=\left(\frac{\chi^c_{1R}}{C_1'}\right),\ \xi_{2-}=\left(\frac{\chi^c_{2R}}{C_2'}\right) \quad (19)$$

Each of these superfields of course possesses an index, which is suppressed, which denotes its coupling to the primordial gauge force. The superscript C on χ has the connotation of colour rather than "charge conjugate." Note, with these superfields, one can already define a global or local $[SU(2)_L \times SU(2)_R]$-flavour symmetry, where $SU(2)_L$ treats (u_L, d_L) and (φ_u, φ_d) as doublets; likewise $SU(2)_R$. On the colour-side, one can define at this stage (i.e. prior to supersymmetry-breaking) only* $SU(2)^C_L \times SU(2)^C_R$. The flavour and colour symmetries are part of a global $U(4)_L \times U(4)_R$ where $U(4)_L$ and $U(4)_R$ act on the + and − superfields respectively; in line with our previous approach we expect only a suitable anomaly-free subgroup of this global symmetry to materialise as the effective gauge symmetry at the composite preonic level.

For the full $SU(4)^{colour}$ (rather than $SU(2)^C_L \times SU(2)^C_R$) to emergy as the effective local symmetry in the limit of unbroken supersymmetry at the preonic level, together with $SU(2)_L \times SU(2)_R$ flavour symmetry, one would need 4 additional chiral superfields (i.e. altogether 12 rather than 8) with the content:

$$\xi_{3+}=\left(\frac{\chi^c_{3L}}{C_3}\right),\ \xi_{4+}=\left(\frac{\chi^c_{4L}}{C_4}\right),\ \xi_{3-}=\left(\frac{\chi^c_{3R}}{C_3'}\right),\ \xi_{4-}=\left(\frac{\chi^c_{4R}}{C_4'}\right) \quad (20)$$

With these, one can realize a full chiral $SU(4)^C_L \times SU(4)^C_R$-symmetry together with $[SU(2)_L \times SU(2)_R]$-flavour at the preonic level priot to supersymmetry-breaking. We would expect as before only the anomaly subgroup – i.e. $[SU(2)_L \times SU(2)_R]_{flavour} \times SU(4)^{Col}_{L+R}$ to emerge as the effective gauge symmetry to preserve renormalizability. Since $SU(4)^C$ can now co-exist with supersymmetry, one can permit the scale Λ_s of supersymmetry-breaking to be even lower than 3×10^5 GeV, if needed. The details of the pattern of supersymmetry-breaking for the 8 and 12-superfield models** will be considered elsewhere.

*) It is conceivable that subsequent to supersymmetry breaking, with χ-fields being superheavy compared to C-fields, $(C_1, C_2, C_1', \text{ and } C_2')$ could define a full SU(4)-colour.

**) After this preprint was ready, we received a preprint by R. Barbieri (Pisa preprint, August, 82), who also considers this twelve superfield-model. Depending upon the pattern of supersymmetry-breaking, there can be the possibility of generating several families in this model, as noted by Barbieri.

IV. ENERGY SCALES IN PARTICLE PHYSICS AND THEIR POSSIBLE ORIGIN

Our quest for elementarity suggests that there are a minimum of four, but very likely many more, energy-scales in particle physics representing characteristically different physical phenomena. They are:

a) The Planck mass $M_p \approx 10^{19}$ GeV characterising the strength of the gravitational interaction as well as the inverse size of the graviton, if it is a composite[4).

b) $\Lambda_{W_L} \approx (1/2)$ TeV characterising the mass-scale for spontaneous breaking of chiral symmetry as well as electroweak gauge symmetry.

c) $\Lambda_C \approx 100 - 300$ MeV, signifying the energy scale where QCD-gauge interactions are effectively strong.

d) The scale Λ_s of supersymmetry breaking, which in one extreme limit may approach Planck mass M_p and, in the other the scale of electro-weak-breaking Λ_{W_L}. In general, $M_p \gtrsim \Lambda_s \gtrsim \Lambda_{W_L}$.

In addition to these four, one expects many more scales of physical significance; this is especially the case if one envisages several layers of elementarity – yet to be unravelled – within quarks and leptons. To mention at least a few pertinent ones, they are:

e) M_U signifying the scale of grand unification*), which may be as high as $\approx 10^{15}$ GeV.

f) Λ_p, signifying the inverse sizes of preons – viewed as composites of pre-preons ($M_p \gtrsim \Lambda_p \gtrsim 3 \times 10^5$ GeV).

g) $\Lambda_{q,l} \gtrsim 1$ TeV, signifying the inverse sizes of quarks and leptons. (Considerations based on dynamical symmetry breaking through preons suggest[6) $\Lambda_{q,l} \sim 10$ TeV.)

*) We stress that the approach of grand unification is not necessarily orthogonal to the preonic approach in that grand unification through e.g. SU(16), SO(10) or SU(5) could emerge as an effective gauge theory at a composite level with the parameters of the associated composite Higgs being determined (at least in principle) by the underlying theory. (See in particular the second paper in Ref. 3).

h) $\Lambda_{e-\mu} \gtrsim 3 \times 10^5$ GeV signifying the scale above which $e-\mu$ family-distinction would manifest itself and $e-\mu$ universality lost.

i) $\Lambda_{W_R} >$ (1 - few) TeV, signifying the scale above which left-symmetry could begin to manifest with the appearance of new gauge particles coupled to V + A - flavour - currents, and

j) A possible succession of scales $\Lambda^n_{HC} > {}^{n-1}_{HC} > \ldots > \Lambda^1_{HC} \sim$ 1 TeV characterising the momentum regimes where the respective nonabelian hypercolour gauge interactions become effectively strong. In a preonic context, such hypercolour gauge interactions may arise as residual effects of the primordial preonic or pre-preonic force.* Note that in our picture SU(3)-colour gauge force is one such residual force. These hypercolour interactions with differing scales, on the one hand, provide a hierarchy in sizes of the composites, and on the other, a hierarchy in the scales of vacuum expectation values of preonic or pre-preonic condensates or equivalently of composite Higgs.

Clearly not all these scales can represent fundamental parameters. Ideally, only one scale may be fundamental with the others being induced radiatively. It would seem that an induced proliferation in scales can arise in a variety of ways:

i) Within a supersymmetric context, one may regard the scale of supersymmetry breaking Λ_s to be an input; a higher scale (M) and a lower scale ($\mathfrak{m}$) are induced radiatively leading to a geometric hierarchy[18,17] of the type $M\mathfrak{m} \sim (\alpha g/\pi)\Lambda_S^2$. One could identify M, for example, with the Planck mass M_P and $\mathfrak{m}$ with one of the lower scales ranging between Λ_{W_R} and Λ_{W_L}.

ii) Scales lower than $\mathfrak{m}$ could arise through further radiative corrections. In particular, this could account for the observed hierarchy in fermion-masses with the fermions in the μ-family having masses of order $\sqrt{\alpha}$ relative to those of the τ-family**) and likewise for fermions of the e versus μ-family.

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* For example, in a pre-preon-model, which gives rise to 8 composite chromons (see Ch. III), the effective colour-gauge symmetry at a momentum-scale >> 1 TeV may be $SU(8)^{Col}$, which could break dynamically through chromonic condensates to $SU(4)_{HC} \times SU(3)^C \times U(1)_{B-L}$. The $SU(4)_{HC}$-force will naturally be stronger than $SU(3)^C$-force at a scale of 1 TeV due to renormalization. The use of this possibility is stressed in Ref. 6.

** An explicit realization of this possibility is recently demonstrated in Ref. 20.

iii) Assuming that effective nonabelian gauge forces can be induced at the composite level as residual effects of the primoridal pre-preon or pre-pre-preon force, one can identify these residual forces with the known flavour-colour as well as a set of unknown hypercolour gauge forces. These residual forces could define a succession of new scales, which are of course related to, and can in principle be derived from, the scale of the primoridal force.

iv) Lastly, the dynamics of the underlying primoridal force (QPD) may be quite peculiar, as peculiar perhaps as QCD is relative to QED. This may give rise, non-perturbatively, to its own peculiar β-function, which may provide a succession of scales, and thereby a succession of sizes of composites.

To illustrate the possible scenarios, consider a primordial gauge force with an effective coupling constant $\alpha_h \sim 1/10$ (say) in the infrared ($Q \to 0$), which is not asymptotically free. The gauge-force may be an SU(2)-force, whose asymptotic freedom is lost due to the presence of too many fermions and/or scalars, or alternatively, it may be an abelian U(1) or a dual magneto-electric U(1) x U(1)-type of force. Now, perturbatively, the coupling constant should grow indefinitely, albeit logarithmically, as momentum Q increases away from zero. It is conceivable that non-perturbatively the theory (in order to remain physically sensible) stops such an indefinite growth - i.e. the β-function ($\beta = \beta(t)$) reaches a maximum, which is positive, and then goes through a zero as t increases.

This signifies a fixed point, provided $\beta(t)$ crosses the t-axis. Imagine, instead of crossing, the β-function reaches a minimum on the t-axis itself (i.e. has a double zero) and for higher t, begins to rise again. Imagine further that there is a succession with the β-function, reaching maxima and minima a number of times with minima all occurring on or above the t-axis before β finally goes through zero (say at Planck-mass). Then it is easy to see that the values of momenta = Λ_{m_1}, Λ_{m_2} ... which corresponds to the minima of the β-function will represent quasi-stationary points for the rising coupling constant $g^2 = g^2(t)$. The Λ_{mi}'s represent the succession of scales we have in mind, and these correspond to sizes of composites, whose constitutents are held together by the attractive primordial force.

Assuming that the appropriate effective nonabelian forces are generated in the manner described in this paper, the first two as well as the third mechanism may actually be realized in the present state of the field-theoretic art. The fourth mechanism, however, - dependent as it is on non-perturbative phenomena - must at present be regarded as highly speculative. But even if only the first three mechanisms are operative - and these could coexist - it is clear that the theory may exhibit a multitude of scales starting with just one input fundamental scale.

V. FINITENESS, SUPERSYMMETRIC YANG-MILLS THEORIES WITH PRE-PREONS AND COMPOSITE SUPERGRAVITY

Since we are contemplating Planck mass as the upper energy limit of validity of the pre-preonic theory, we may inquire, what in an aesthetic context of supersymmetry-theories, the ultimate pre-preons may be? If one imposes on the theory the requirement that it should be <u>finite</u> (i.e. no ultra-violet infinities) and also possess a mass scale, there appears a nearly unique candidate. This would be an N = 2 non-Abelian (e.g. SU(2)) gauge theory with one matter N = 2 <u>massive</u> multiplet in the adjoint representation, which has its origin in the N = 4 supersymmetric Yang-Mills theory in the manner specified below. Finiteness implies that there is no cut-off energy in the theory.

The particle content of the model is then exactly that of the unique N = 4 gauge theory*) and so is the interaction-term. In N = 2 language, the content is an SU(2)-triplet gauge-multiplet consisting of one spin one, two two-component spin-1/2, and one complex scalar-field plus SU(2)-triplet matter-multiplet consisting of one left and one right spinor along with two complex scalars. The interaction-terms are specified to be precisely those of the N = 4 theory (with just one coupling parameter). The only difference from the N = 4-theory is that the Lagrangian contains an explicit mass term for the N = 2 matter fields. It can be shown[22] that such a theory is finite to all orders just like N = 4 massless Yang-Mills theory. The advantage of this theory, however, is that it contains a mass scale, and is thus immediately relevant to physics.

We now observe that if we choose the pre-preons to be given by the set of 16 states (Φ_α^A, $A=1,\dots 16$, $\alpha=1,\dots n^2-1$) comprised among the N = 4 Yang-Mills supersymmetric multiplet (i.e. two helicity states each associated with one J = 1 and four J = 1/2 objects, plus six J = 0-states) each of these states being an adjoint (n^2-1) of an internal Yang-Mills symmetry SU(n), we would generate 256 = (16 x 16) composite SU(n)-singlet preonic states $\sum_\alpha \Phi_\alpha^A \Phi^{B,\alpha}$ through the SU(n)-binding force.

*) For a general discussion of N = 2 and N = 4 supersymmetric Yang-Mills theories, derived from spontaneous compactification of 6 and 10 dimensions to 4, see e.g. J. Scherk (Ref. 21), other references may be found here.

These 256 states precisely represent the objects comprised in the N = 8 supergravity multiplet (i.e. two helicity states each associated with one J = 2, eight J = 3/2, twenty-eight J = 1 and fifty-six J = 1/2 plus seventy J = 0 states).

These may be the preons, of which quarks and leptons are made, as conjectured by Ellis, Gaillard, Maiani and Zumino[23]. These authors suggest that the hidden SU(8) Cremmer-Julia gauge-symmetry in this theory, mediated by composite gauge-fields (made out of the seventy scalars) may break down to an SU(5) x $[SU(3)]_{family}$ symmetry, with the emergence of three families of chiral massless quarks and leptons.

Now the emergence of three families of massless quarks and leptons using these supergravity-preons as well as the breaking of SU(8) to SU(5) x SU(3)- has been questioned by Derendinger, Ferrara and Savoy[22].* Even if one does not use this particular preonic multiplet to make up quarks and leptons, there is the possibility in the pre-preonic model we have presented, of composing preons of the type considered in this paper (and subsequently composing quarks and leptons) directly from the N = 4 Yang-Mills pre-preonic multiplet Φ_α^A.

For example, one may break the N = 4 multiplet first down to the N = 2 supersymmetric multiplet with the massive "matter" N = 2 multiplet consisting of one SU(n)-adjoint, left-handed chiral (Ψ_+) plus one right-handed chiral (Ψ_-) N = 1 supermultiplet in the manner described earlier. With these as the starting pre-preons, one may compose, as in section III, the sets of preons $\Psi_+\overline{\Psi}_-$ $\overline{\Psi}_+$, $\overline{\Psi}_-$ $\overline{\Psi}_+\overline{\Psi}_-$, ... through the intermediacy of the N = 2 SU(n) gauge-forces.

To conclude, it appears attractive to view N = 8 supergravity theory as an effective composite theory having its origin in the N = 4 supersymmetric Yang-Mills theory of pre-preons.**). In such a composite formulation of supergravity, with its starting point in a finite pre-preonic (N = 4 supersymmetric

*) The possibility of SU(8) breaking down to SU(4) x $SU(4)_{flavour}$ may equally well be entertained (see Transactions of the Royal Society, Ref. 4, page 149).

**) After this paper was written, we have come across a preprint by M. Grisaru and H. Schitzer (Brandeis preprint, "Bound States in N = 8 Supergravity and N = 4 Supersymmetric Yang-Mills Theories," 1982), in which an analogous compositeness of N = 8 supergravitons is motivated, from the point of view of a Regge-pole analysis.

Yang-Mills theory), the problems associated with quantum-gravity-infinities take on a different complexion. There are no infinities at or beyond the Planck scale, when the composites dissociate only the finite pre-preonic framework remains. But, in addition to these composites, so far as quarks and leptons are concerned, they may well be composed from the pre-preons of the N = 4 supersymmetric Yang-Mills theories, through a preonic chain, which differs from the composite preonic chain based on the N = 8 supergravity multiplet. We must, however, point out one arbitrariness inherent in any presently available formulation of the N = 4 supersymmetric Yang-Mills pre-preonic theories. This is the arbitrariness inherent in the choice of the non-Abelian SU(n) Yang-Mills group. The internal symmetry (e.g. SU(n) must be non-Abelian in order to guarantee finiteness; but which n? Is it SU(2), or SU(3), ... ? Ideally, we may have liked the internal symmetry to have emerged uniquely, for example, from a compactification of a higher dimensional space-time theory.

One further merit of assuming that the N = 4 supersymmetric theory is the basic pre-preonic theory lies in the magnetic-electric duality which this theory is conjectured to possess [24]. As an alternative, or in addition, to the SU(N) binding force suggested above, it may be that the dual magneto-electric force helps bind pre-preons to make preons[*].

To summarise, it appears to us that the elegance, finiteness and uniqueness of the supersymmetric N = 4 Yang-Mills theory (with masses as explained above), makes it worth pursuing in the context of a search for a fundamental theory of pre-preons.

We thank Qaiser Shafi and John Strathdee for many helpful discussions.

*) As stressed by Nahm and Rossi, no renormalisation of the coupling constant g in the N = 4 supersymmetric Yang-Mills theory, removes any renormalisation-ambiguity in the Dirac relation $\frac{gh}{4\pi} = jh/2$, where h is the monopole charge of the topological monopoles.

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