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A NEW MAGNETIC PREON MODEL AND AN SU(5) GRAND UNIFIED THEORY

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We propose and develop a new magnetic preon model and extract from it via preon diagram an $SU(5)$ grand unified theory, which features higher fermion representations, mirrors, higher Higgs representations, several Higgs quintets, and a massive neutrino. We build preons out of scalar pre-preons only. A composite picture for the graviton is proposed. Experimental signatures are briefly discussed.

1. Introduction

Recent years have witnessed a resurgence of interest in composite models[1]. A number of models with interesting implications have been proposed[2]. Notable among these are the rishon model of Harari, and of Shupe[3], with dynamics provided by Harari and Seiberg[4–5] and the Pati-Salam model[6], with dynamics provided by Pati[7], and elaborated by Pati, Salam and Strathdee[8]. Pati's dynamics is via an Abelian force with both an electric and magnetic component[9] with the Lagrangian ala Zwanziger[10], which, while formally doubling the degrees of freedom of the Abelian force mediant, has the advantage of being local and having very simple Feyman rules. (For an aternative formulation, see Ref. 11).

One physical advantage (simultaneously a technical setback) of the magnetic preon model (we reserve this name for the Pati-Salam model made complete and axplicit by Pari's dynamical proposal) is strong-coupling $\left(\frac{eg}{2\pi} = 1\right)$, hence one possibility of more point-like constituents, with binding radii much smaller than Compton wavelength of the composites.

The second advantage is the economy of degrees of freedom. Minimally, there are seven preons plus one mediant, altogether eight particles. This is to be compared with the rishon model with $8 + 8$ massless mediants and $2 \times 3 \times 3$ rishons, altogether 34 particles.

The third feature is the possibility of generation of spin entirely by Saha's mechanism[12] as proposed by Pati, Salam and Strathdee[8] and Freund[13].

This, in many respects, is a highly appealing picture. Moreover, as pointed out by Pati, Salam and Strathdee[9] and Pati[14] there is likely to exist a connection between preon models and grand unified theories, such as the $SU(16)$ *GUT* of Pati and Salam[15]. In such a picture, *all the GUT particles* (fermions, vector bosons Higgs) *can be composite*[8,14] paralleling, in a different context and model, the *pique of audacity* of Ellis, Gaillard and Zumino[16].

2. *The model*

We present here a model which is a variant of Pati's magnetic preon model with explicit quantum number assignments and which will be shown to lead to an $SU(5)$ grand unified theory (possibly as a part of a larger group). The equivalence will not be shown by a dynamical calculation, but by exhibiting preon diagrams for vertices governing the interaction of composites and showing that they are precisely those of an $SU(5)$ grand unified theory. A crucial ingredient in this demonstration will be the Abelian nature of the interpreon interaction, which guarantees that any preon line goes unchanged through a preon diagram, making preon diagrams in this theory very simple and easy to analyze.

Without further ado, let us specify the particle content of the model. There are seven preons $(c_1, c_2, c_3, f_1, f_2, \xi, l)$ with electric charges $e(-1/3, -1/3, -1/3, 1, 0, 0, 0,)$ and magnetic charges $g(3, 3, 3, 3, 3, -6)$ with $eg/2\pi = 1$ (Dirac's quantization condition). Note that f_2 and ξ have the same electric and magnetic charge, we shall assume that they have substantially different mass. If preons have further substructure (pre-preons) we can perhaps think of ξ as a radical excitation of f_2, but this is not a prerequisite for any of the further developments.

The spin assignments are $s = (1, 1, 1, 1, 1/2, 1/2, 1/2)$ the explanation for this seemingly odd assignment is likely to be that the quintet $\psi_\alpha = (c_1, c_2, c_3, f_1, f_2)$ is a composite of the type $\Phi_\alpha s$, with $e_\alpha = e(-2/3, -2/3, -2/3, 2/3, -1/3)$, $g_\alpha = 0$, $e_s = \frac{1}{3} e$, $g_s = 3g$, $s\Phi_\alpha = s = 0$.

Note that in general

$$\vec{s}_{ij} = -\frac{1}{4\pi}(e_i g_j - e_j g_i)\,\hat{u}_{ij} \tag{1}$$

where $\hat{u}_{ij}$ is the unit vector from i'th dyon to j'th dyon[12].

At the end of the paper we also discuss how the pre-preon Φ_α, s, and L (with $e_l = 0$, $g_l = 3g$, $s_l = 0$) are to be composited to yield (ψ_α, ξ, l) and thus provide an explicit model of total dynamical spin generation.

We see that composites shall be organized as »multiples« of quintets $\psi_\alpha = (c_a, f_l)$ and antiquintets $\overline{\psi}_\alpha = (\overline{c}_a, \bar{f}_l)$ with enough ξ's and l's to make the composites magnetically neutral (we assume exact mass degeneracy for Φ_α) and thus global flavour (quantum number labelling quintets) is broken (only by electric effects) which should ultimately be reflected in spontaneous breakdown of symmetry in *GUT* at the composite level.

We shall furthermore assume that preon mases are at least several orders of magnitude above the unification mass, possibly of the order of Planck's mass. Indeed, for such an arrangement this is simultaneously the compositeness scale, and the locality of the composite *GUT* will preserved at least till unification scale, a requirement necesary for the *GUT* to make sense. This will also generate enough baryon asymmetry[17].

A sthe global flavour-symmetry is explicitly, though slightly, broken by electric charges, there are no problems with the masslessness of particles other than gluons (colour symmetry is exact at preon level!)[18], an gluons are not likely even to exist as free asymptotic particles (a requirement necessary for the theorem in Ref. 18 to hold) but only as confined glue. Moreover a subtlety overlooked in Ref. 18 may invalidate that theorem[19].

Before we proceed, we conjecture in a manner akin to Ref. 16, that all particles not protected by local symmetry — renormalizability will acquire explicit mass terms of the order of preon mass. We dub this the generalized survival hypothesis (*GSH*). As in Ref. 16, the scheme, of course, is not complete before this hypothesis is proved. By the Appelquist-Carrazone decoupling theorem[20], these particles are decoupled at energies up to (and even somewhat above) unification scale and at such energies they can be ignored.

To compute the spins of the composite, let us remind themselves of Eq. (1), for each pair of preons and concentrate on magnetic neutrals:

$$\psi_s^a = \psi^a \, l\xi. \tag{2}$$

We take these states to be linear in spatial arrangement in order to balance the magnetic forces. Summing dynamic and intrinsic spin, we generate two quintets of spin $\frac{1}{2}$ + some odd spin $\frac{1}{2}$ states + one spin quintet. According to *GSH*, everything but two spin $\frac{1}{2}$ quintets is ultraheavy (i. e., have mass of the order of preon mass).

The states

$$W_{\alpha\beta} = \overline{\psi}_s \, \psi_\alpha \tag{3}$$

form two 24-plets and two singlets (we have spin zero and spin one states) and again odd states, which are ultraheavy and decouple according to *GSH*.

The states

$$H^a = \psi^a \, \tilde{\xi} \tag{4}$$

form a quintet of spin zero, a quintet of spin one plus odd states. The spin one quintet cannot couple in a renormalizable manner, so it is effectively decoupled and ultraheavy according to *GSH*. One might think that this scenario could be escaped if the effective symmetry were $U(6)$ with vector bosons $W^{\mu}_{\alpha\beta}$, $(\psi^{\alpha}\,\bar{\xi})_{\mu}$, $(\bar{\psi}^{\alpha}\,\xi)_{\mu}$, $(\bar{\xi}\,\xi)_{\mu}$, but we shall assume no mass degeneracy between ψ^{α} and ξ and thus such a symmetry must be broken explicitly, not spontaneously, (and that at scales much above the $SU(5)$ unifications scale, in fact probably at preon mass scale — this again is consistent with *GSH*).

The states

$$\psi^{\alpha\beta}_{10} = \psi^{[\alpha,}\, l\, \psi^{\beta]} \tag{5}$$

and

$$\psi^{\alpha s}_{15} = \psi^{\{\alpha,}\, l\, \psi^{\beta\}} \tag{6}$$

form two spin decimets, two spin $\frac{1}{2}$ pentadecimets + odd states.

There are also higher representations and we shall dwell on those later. The particle content hitherto uncovered is very suggestive of an $SU(5)$ *GTU* (renormalizability does not protect the singlet vector boson from gaining explicit ultraheavy mass) with exotic fermions (colour sextet, flavour triplet, charge two) states. Indeed the 74 vector can be taken as $SU(5)$ vector bosons, the spin zero quintet and 24 of Higgs give a pattern of symmetry breaking in the minimal Higgs scheme of Georgi and Glashow (the 1 of Higgs will gain ultraheavy mass and decouple).

One of the spin $\frac{1}{2}$ quintets would be the quintet of Georgi and Glashow, and the most plausible interpretation of the second spin-$\frac{1}{2}$ quintet is that it is the next family, and the third could be an excited radial state — such a scenario would predict an even number of families. The scenario is plausible on the grounds that spin splittings are usually smaller than radial splittings for heavy particles and would explain the one between these two and the tau-lepton — without invoking any exotic binding potentals.

Again, one of the decimets could be the one of Georgi and Glashow, enabling te pairing of helicities as in the $SU(5)$ *GUT* of those authors. The pairing of helicities of the 15 and a higher multiplet (40) will occur as for 5 and 10, by the Higgs effect. This pairing will be explained somewhat later, when we discuss the vertices of the composite theory.

3. *Preon diagrams*

So far, the quantum numbers (particles) hitherto uncovered do not go beyond a mere intimation of an $SU(5)$ *GUT* at the composite level. But we can make a much stronger statement by looking at possible preon diagrams and see what vertices of the effective field theory could be present.

Before we do this, we should add that, strictly speaking, this effective field theory cannot be a local field theory, as the composites are not pointlike particles, yet if the size of the composite is much below unification scale, the theory will be local to a good approximation at least all the way up to unification scale. If this were not so, the dynamic content of a formal $SU(5)$ GUT would be empty, as the theory would become highly nonlocal before unification. In this respect, the scenario is akin to that of Ellis, Gaillard and Zumino[16]; in that the sufficiently small size of the composite is guaranteed by the sufficiently large mass of the constituents ($m_{preon} \sim m_{Planck}$).

Now let us inspect the preon diagram in Fig. 1. At a vertex, a preon and *its* antipreon annihilate (the interaction is Abelian). Everywhere else, preons lines just go through, unchanged, possible connected with lines where the vector mediant of the magnetic preon theory is exchanged.

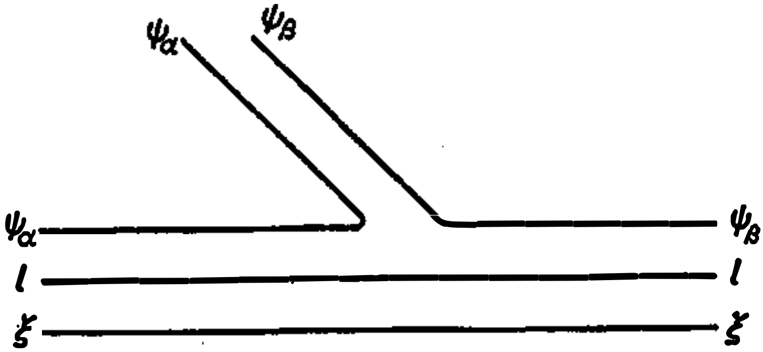


Fig. 1. The 5 — 5 — vector 24 vertex.

The vector mediant of magnetic preon theory is *not* the photon,indeed the photon is a composite (massless) vector boson, a combination of vector bosons of vector 24. We shall call the massless vector mediant of magnetic preon theory the *luxon* — for obvious reasons. The distinction between photon and luxon seems strange from the point of view of electric charge assignment — indeed we see that charges with respect to luxon interactions are commensurate with the charges corresponding to photon coupling (there is no reason why the *overall* strength of the photon coupling should be the same as luxon coupling). Yet there is a deep reason behind this, which we shall discuss later.

Clearly, the preon diagram of Fig. 1 displays the 5 — 5 — vector 24 coupling (the vector 1 decouples, as discussed above, at energies below Planck's energy).

The preon diagram of Fig. 2. displays the 10 — 10 — vector 24 and 15 — 15 — — vector 24 coupling. Fig. 3 displays the 5 — 10 — Higgs 5 coupling.

The 10 — 10 — Higgs 5 coupling is absent, as these would be an unmatched ξ and absence of such coupling is guaranteed to all orders in $SU(5)$ couplings by chiral invariance imposed on the 10 which is simultaneous with the absence of the Lagrangian u-quark mass. u quark mass, however, can be generated by instanton effects[21]. c and t quark masses must also be generated nonperturbatively, or else our scheme may have to be modified or even fail. The 15 is paired via the 5 Higgs

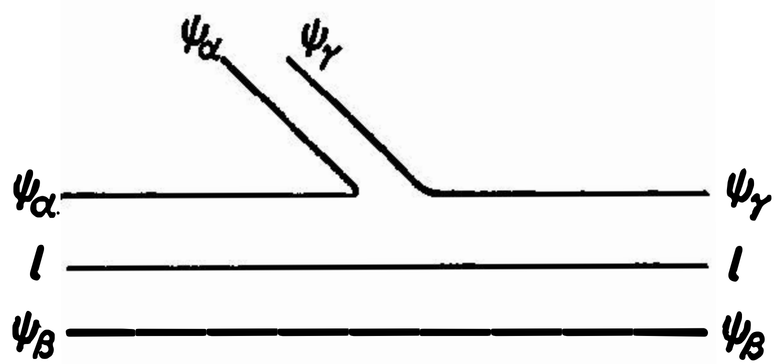


Fig. 2. The 10 — 10 — vector 24 and 15 — 15 — vector 24 vertices.

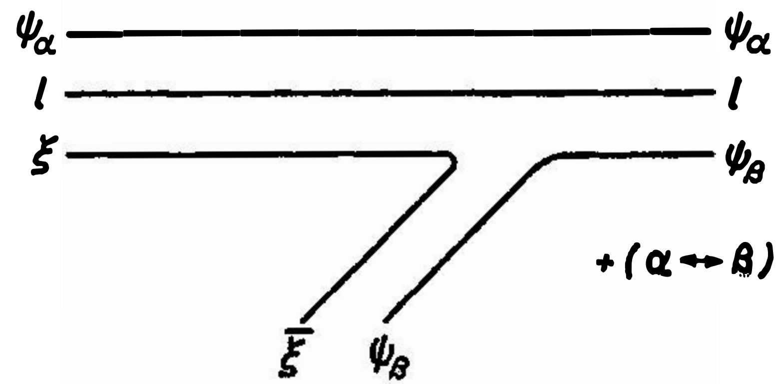
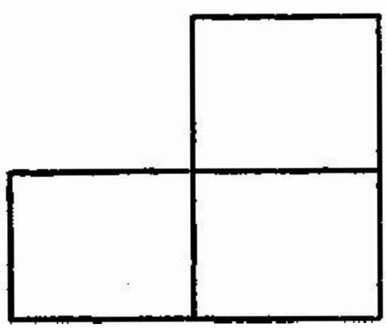


Fig. 3. The 5 — 10 — Higgs 5 vertex.

with a 40 (preon content $\psi_\beta \, \psi_s \, \psi_\gamma \, \bar{\xi} \, l$, Young tableaux:



and this is also where the fermion masses in this sector come from). There are also higher fermion representations, and we shall dwell on these systematically elsewhere.

Some of the vector boson self-couplings and Higgs-Higgs and Higgs-vector boson couplings are displayed in Fig. 4 — we invite the reader to reconstruct the remaining ones.

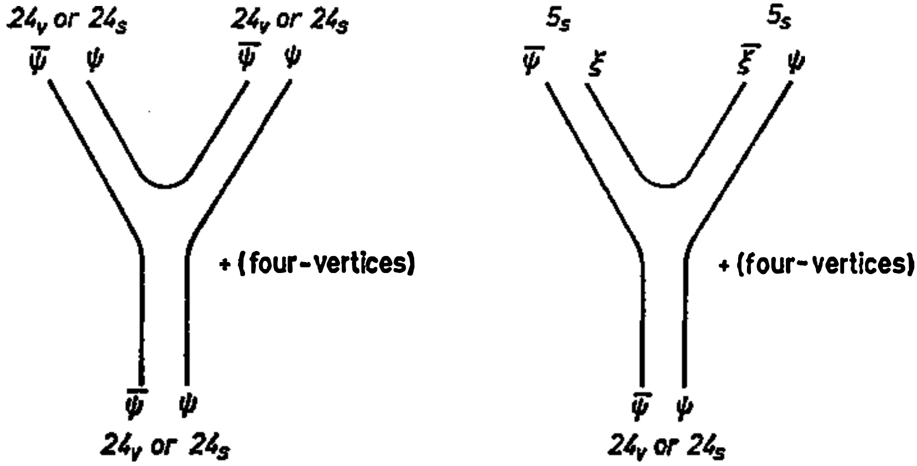


Fig. 4. Some spin 0 — spin — 1 vertices.

We cannot prove, of course, that the couplings are in such proportion as to reproduce, directly, the $SU(5)$ GUT described by vertices displayed above, yet this must be so if we invoke renormalizability of the composite interactions (Veltman's conjecture).

4. *Higgs effect, parity violation*

Let us note that the Higgs effect operant here gives masses to particles with helicity assignments $5_R - 10_L$ *as well as their mirrors* $5_L - 10_R$. The unequal strength of the vertices $5_H - 5_R - 10_L$ and $5_H - 5_L - 10_R$ guarantees unequal mass for the mirrors. Its origin is parity nonconservation of the preon theory, as it is a magnetic monopole theory. At the composite level, *Van der Waals forces* have parity violation suppressed by a factor μ/M where μ is the composite mass and M the compositeness scale[7] but this is not so for the *vertices* above, since the luxon can emanate from the magnetic vertex at the place where a preon and its antipreon annihilate, and it can be connected to an electric vertex which can be placed anywhere, and the particles in general are not electric neutrals! For this picture to make sense, we need extremely small or zero mirror mixing. Mirror mixing can be forbidden, as in the case of $SU(16)$ mirrors of Pati, Salam and Strathede[15], by imposing asymmetry on the composite Lagrangian. But whether this obtains from the preon model, and if yes, why, in a complex issue to be addressed elsewhere. Needless, to say, virtually the same augmentation can be repeated for vertices $5_H - 15_L - 40_R$ and $5_H - 15_R - 40_L$ etc.

These will clearly also be Higgs field with preon content $\psi - \bar\psi - \psi - \bar\xi$ which is two quintets, one 45 and one 70. The 45 is precisely what is needed for the Georgi-Jarlskog fermion mass generation mechanism[22], and the two quintets together with the quintet $\psi\,\xi$ form three quintets sufficient for soft CP violation and nonrestoration of symmetry at high temperature and a possible resolution of the monopole problem[24].

The origin of the Higgs effect is seen to be in the possibility that the vacuum is the condensate of preon degrees of freedom — luxonic electric charge conservation will then guarantee that only neutral members of the scalar 24 and 5 can develop an expectation value, a pattern of symmetry breaking that is the same as in the Georgi-Glashow *GUT*. This will also certainly hold for higher Higgs multiplets.

It is possible that the solution of the hierarchy problem of *GUTS* lies in a preonic explanation of the Higgs field, the scenario being that the overlap between f_2 and ξ $\langle 0|f_0 \bar{\xi}|0\rangle$ must certainly be considerably smaller than for a preon and its own antipreon, say $\langle 0|\bar{c}_a c_a|0\rangle$. In fact such an overlap would be zero were it not for some mixing between f_2 and ξ, which is possible on the grounds that the dynamic quantum numbers (luxonic charges) are the same for the two particles. That such a mixing can indeed be so tiny as to produce a solution to the hierarchy problem in its full ferocity in a conjecture whose credibility is to be tested by detailed dynamical calculations.

The Higgs mechanism operant here will guarantee the neutrino a mass. Indeed the vertex 5 Higgs — 5_R — 1_L $((\xi\, l\, \xi)_L)$ is present. We invite the reader to draw the relevant preon diagram.

The photon is clearly the same as in Georgi — Glashow's theory $A_\mu^{\gamma\nu} \sim -$ $- 1/3\, c_a^* c_a + f_1^* f_1$ and thus the photonic charges are commensurate with luxonic ones. If this were not se we would not have exact quantization of observable electric charge. Indeed Fig. 5 displays a contribution to photonic charge which would spoil quantization of (electric) photonic charge if the luxonic and photonic charges were not commensurate.

States such as $\bar{f}_2 \gamma_\mu \gamma_5 \gamma_2$, $\bar{\xi}\xi$, $\bar{\xi}\gamma_\mu \xi$, $\bar{l}\, l$, $\bar{l}\gamma_\mu l$, will hopefully be ultraheavy according to the generalized survival hypothesis.

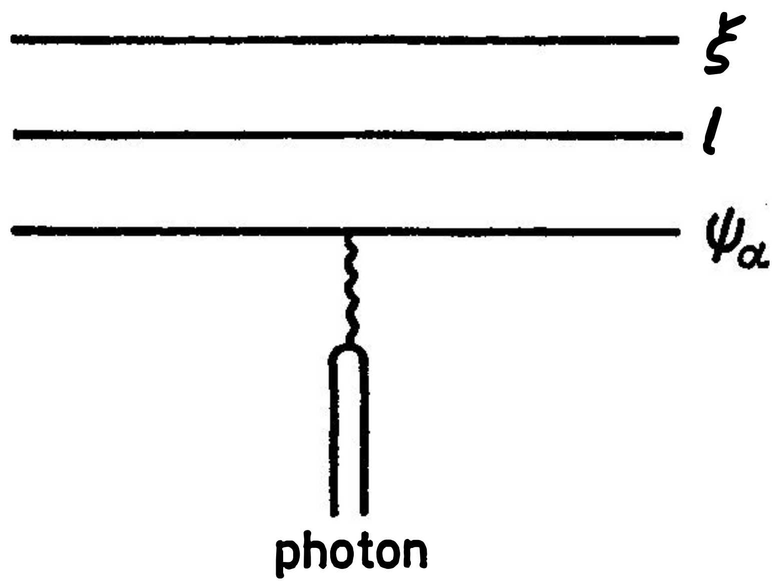
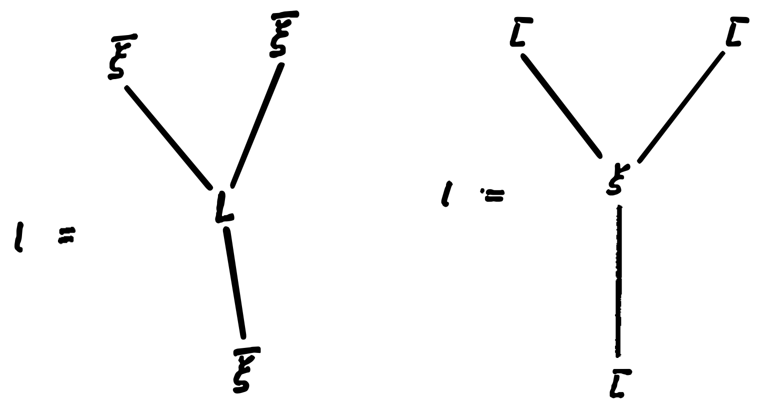


Fig. 5. Nonleading contribution to photonic charge.

5. *Pre-preons, the graviton, experimental signatures*

We have seen that we can build the quintet ψ_α from a scalar pre-preon quintet Φ_α ($g = 0$, $e_\alpha = (-2/3, -2/3, -2/3 -2/3, -1/3)$, $s = 0$) and a scalar pre-preon s ($g = 3$, $e = 1/3$, $s = 0$). Further we can take ξ to be an excited radial of f_2. To build l solely out of scalar pre-preons, introduce a scalar pre-preon L ($g = 3$, $e = 0$, $s = 0$) and take



whichever state is lighter. In the course of generating the preons (ψ_α, ξ, l) from the pre-preons (Φ_α, s, L) there will be generated other states, which hopefully lie higher in mass. The number of relevant pre-preons and preons is the same, but in the process we have generated all particles from scalar particles, thus providing a realistic realization of the Pari-Salam-Strathdee[8] and Freund[13] conjecture.

Calling $m_\alpha s_\alpha = (\Phi_\alpha, s, l)$ we have a natural proposal for the graviton

$$g_{\mu\nu} = \eta_{\mu\nu} + \partial_\mu s^*_\alpha \partial_\nu s_\alpha + (\mu \Leftrightarrow \nu) \tag{7}$$

a la Ref. 23, but with their $g_{\mu\nu}$ replaced by $h_{\mu\nu}$, which we feel is more natural, since the gravitational field is $h_{\mu\nu}$, not $g_{\mu\nu}$.

Note that gravity does not have to be renormalizable, as for $\varkappa \sim m_\gamma \sim 10^{19}$ GeV, its lagrangian is scaled by a power of the preon mass (compositeness scale), and also a compositeness scale, gravity becomes nonlocal (this could also provide elimination of singularities). Once we could prove that the graviton as defined above is massless, Einstein's dynamics would follow from the Boulware-Deser theorem[26] for wavelengths long compared to $1/\varkappa$.

The pre-preons Φ_α, all magnetically neutral and with fractional electric charge, are natural candidates for Fairbank et al. events[27] (see Pati et al.[28]). They could be the unsynthesized left-overs from the big bang.

As a conclusion, note that our proposal illustrated here, namely that all $SU(5)$ composites are built out strings of 5's and 5*'s (also singlets to provide suitable magnetic binding) parallels in entirety the motivation that led from the eightfold way to quarks and thus endows the idea of preons with the same degree of motivation as that of quarks. The full implications of this will be discussed elsewhere, as well as the philosophy of how global flavour becomes local at the composite level (though spontaneously broken) by the generation of correct vertices via preon diagrams and the demand of renormalizability, a phenomenon illustrated dramatically in our model.

The chief experimental signature of our model are exotic colours and flavours, say a colour sextet and a flavour triplet in the 15. The direct signature for a flavour triplet in the 15 will be a *stable spin* $\frac{1}{2}$ *lepton with electric* charge 2, hopefully below 250 GeV[29,30].

The next signature at mirrors, similar to those of Pati, Salamand Strathdee[15], characterised by larger masses, again below 250 GeV[29], and $V + A$ weak interactions.

The existence of particles described above may be testable in the near future.

It would be interesting to see whether (and if yes, to what extent) *new representations especially in the fermion sector modify the predictions for proton decay* (after all, their Casimir factors are so much bigger!).

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Added note

For an analysis of ultraviolet infinity subtraction in monopole theory, see Ref. 31.

For the solution of the infrared problem and radiation effects in monopole theory, see Ref. 32.

Another avenue fo evading the Weinberg-Witten theorem might be if the gluon develops an effective mass. See Ref. 33.

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NOVI MODEL MAGNETSKIH PREONA I SU (5) VELIKO-UNIFICIRANA TEORIJA

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Predlažemo i razvijamo novi model magnetskih preona i iz njega izvlačimo preko preonskih grafova *SU* (5) veliko-unificiranu teoriju, koja ima više fermionske reprezentacije, zrcala, više Higgsove reprezentacije, nekoliko Higgsovih kvinteta i masivni neutrino. Gradimo preone samo iz skalarnih pre-preona. Predlaže se kompozitna slika za graviton. Kratko se razmatraju eksperimentalne signature.