Preon Trinity - A Schematic Model of Leptons, Quarks and Heavy Vector Bosons

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Abstract. – Quarks, leptons and heavy vector bosons are suggested to be composed of stable spin-1/2 preons, existing in three flavours, combined according to simple rules. Straightforward consequences of an SU(3) preon-flavour symmetry are the conservation of three lepton numbers, oscillations and decays between some neutrinos, and the mixing of the d and s quarks, as well as of the vector fields W^± and B^±. We find a relation between the Cabibbo and Weinberg mixing angles, and predict new (heavy) leptons, quarks and vector bosons, some of which might be observable at the Fermilab Tevatron and the future CERN LHC. A heavy neutrino might even be visible in existing data from the CERN LEP facility.

Introduction. – The phenomenological success of the standard model of quarks and leptons, and their observed patterns, indicate that there exist a more fundamental basis. Here we present a simple preon model where leptons, quarks and heavy vector bosons are composite, and where many of the ad hoc ingredients of the standard model are clear-cut consequences of this inner structure. We limit the present discussion to straightforward, qualitative consequences of the model, and leave a more quantitative analysis, requiring extra assumptions, to future publications.

Although there is currently no direct experimental evidence for (or against) preons, there are quite a few phenomenological, and logical, circumstances that point at compositeness, some of which have been known for long:

• There are “too many” leptons and quarks, but still a pattern among them. Historically, such patterns have led to ideas about compositeness, with the quark model as a modern example, and the periodic system as an older one.

• The least elegant (mathematical) features of the standard model are due to the weak gauge bosons being massive (and unstable and of different charges). They might be preon-antipreon states, in analogy to the nuclear force being “leaked” by quark-antiquark states. If so, there is no fundamental weak force, nor a Higgs mechanism. The photon-Z^0 mixing is equivalent to the photon-ρ^0 mixing in the vector-dominance model.
Table I – The “supersymmetric” preon scheme.

| charge          | $+e/3$ | $-2e/3$ | $+e/3$ |
|-----------------|--------|---------|--------|
| spin-1/2 preons | $\alpha$ | $\beta$ | $\delta$ |
| spin-0 (anti-)dipreons | $(\bar{\alpha}\bar{\delta})$ | $(\bar{\alpha}\delta)$ | $(\bar{\alpha}\bar{\beta})$ |

- An overlooked hint is that most leptons and quarks are unstable, which in our view disqualifies them as fundamental particles. Historically, decays of “elementary” particles have sooner or later been interpreted as processes among more fundamental objects.
- There are mixings or oscillations, among some quarks, among the vector fields $W^0$ and $B^0$ of the weak interaction, and among some neutrinos. This reminds about the chemical mixing of isotopes and the quantum-mechanical one of $K^0$ and $\bar{K}^0$ mesons, both being due to compositeness.
- The conservation (exact or approximate) of lepton numbers, baryon number and weak isospin, are not yet properly understood. When strong isospin and strangeness were introduced for hadrons, on similar grounds, the explanation later turned out to be in terms of compositeness (quarks).

Early preon models focused on explaining the lightest quarks ($u$ and $d$) and leptons ($e$ and $\nu_e$) with as few preons as possible. This means either a minimal number of (two) different preons, e.g., the “rishons” \[3\], or a minimal number of (two) preons inside a quark or lepton, e.g., the “haplons” \[4\]. Following these ideas we now present a preon model for all leptons and quarks, addressing some of the less understood cornerstones of the standard model. Examples are lepton-number conservation, the Cabibbo-Kobayashi-Maskawa (CKM) mixings \[5,6\] and the “photonic” behaviour of the $Z^0$ boson. We have been much inspired by other models:

- The original quark model \[7,8\], prescribing that the hadrons known in the early 1960s can be explained in terms of three quark flavours, with an (approximate) $SU(3)$ symmetry.
- The rishon and haplon models, where the lightest quarks and leptons contain, respectively, three spin-1/2, or one spin-1/2 and one spin-0 preon each.
- Diquark models (reviewed in \[9\]), often prescribing that quarks pair up in total spin 0.
- Supersymmetry, where spin-1/2 objects have spin-0 relatives, even if only phenomenologically, e.g., as a quark-diquark “supersymmetry” \[10\].

A trinity of preons. – A preon model for six leptons and six quarks must have at least five different preons in the sense of the haplon model, i.e., three with spin 1/2 and two with spin 0, or vice versa. A symmetric scheme should have three of each, giving nine leptons and nine quarks. The spin-1/2 and spin-0 preons can be arranged as partners of identical charges. We suggest that the spin-0 ones are not fundamental, but tightly bound “dipreon” pairs, kept together by spin-dependent forces. Calling the preons $\alpha$, $\beta$ and $\delta$, with electric charges $+e/3$, $-2e/3$ and $+e/3$ (by choice; there is an ambiguity in the names preon and antipreon), we get the simple, symmetric scheme in Table I. Each preon has a “supersymmetric” partner, which is the anti-dipreon formed by the other two (anti)preons.

The preons are conjectured to have the following properties:

- Mass: One of the preons, say $\delta$, must be much heavier than the other two, since only six leptons, six quarks and three heavy vector bosons have been seen so far. Curiously enough, the two dipoles with a $\delta$ must not be superheavy. Rather, it seems as if $(\alpha\beta)$, the partner of $\delta$, is somewhat heavier than $(\alpha\delta)$ and $(\beta\delta)$, which, in turn, might be a clue to the underlying...
preon dynamics.

- **Spin and electric charge:** These are just implemented on the preon level, although an unambiguous definition of spin (and mass) requires a free particle. Maybe the mass difference between $\alpha$ and $\delta$ is related to different, and strong, magnetic charges, coupled to spin and electric charge.

- **QCD colour:** Preons (and anti-dipreons) are $3^*_c$ representations of the $SU(3)_c$ of normal QCD, so that leptons and vector bosons become colour singlets and quarks colour triplets.

- **Stability and preon flavour:** We assume that preons are stable. Hence, a weak decay is merely a reshuffling of preons into particles with a lower total mass. The preon-flavour $SU(3)$ symmetry is similar to the one of the original quark model. Preons are $3^f$ and dipreons $3^*_f$.

- **“Hypercolour”?** Some preon models rely on a QCD-like force that binds preons into leptons and quarks, although its group symmetry might be more complicated than $SU(3)$. We will not restrict the model to any specific preon dynamics at this “schematic” stage.

**Leptons.** - Leptons are preon-dipreon systems in colour singlet ($3^*_c \otimes 3_c = 1_c \oplus 8_c$), as in Table II, where each cell contains the lepton built by a preon to the left and a dipreon from the top line. The following conclusions can be drawn:

- The known leptons are reproduced, although with an ambiguity in the scheme; the “$e$” and “$\tau$” charge can be interchanged.

- There are three new (superheavy) leptons, all containing an “isolated” $\delta$. Two of these are neutrinos, which must hence be heavier than half the $Z^0$ mass (and unstable). There is no other clear-cut mass-ordering, although the mass seems to increase along all diagonals from upper left to lower right.

- The three lepton numbers are conserved in all known leptonic processes (except neutrino oscillations - see below), due to the conservation of preon flavour, and assuming that dipreons do not split up. Muon decay, $\mu^- \rightarrow \nu_\mu + e^- + \bar{\nu}_e$, is a typical example: $\bar{\alpha}(\bar{\alpha}\delta) \rightarrow \bar{\beta}(\bar{\alpha}\bar{\delta}) + \beta(\beta\delta) + \bar{\alpha}(\bar{\beta}\bar{\delta})$. The dipreon goes into a $\nu_\mu$, and the preon into a $W^- = \beta\bar{\alpha}$, which then decays to $e^-\bar{\nu}_e$. A dipreon split-up would violate energy conservation, and lepton number is here equivalent to “dipreon number”. Hence there is no fourth lepton number for $\kappa$, $\nu_{\kappa1,2}$. Rather, their decays must violate also the normal lepton-number conservation, e.g., $\kappa^+ \rightarrow \mu^+ + \nu_\kappa + \nu_\tau$.

- There is a fair chance that at least one of $\nu_{\kappa1}$ and $\nu_{\kappa2}$ is lighter than the top quark, since one of them is in the same “cell” as the top (see Table III). In particular, $\nu_{\kappa2}$ can then be produced in $e^+e^-$ reactions even at CERN LEP energies (up to 209 GeV), and hence might be visible in existing data. The production channel would be $e^+e^- \rightarrow \ell_e + \nu_{\kappa2}$ or $\nu_\mu + \nu_{\kappa2}$, exploiting that $\nu_e$, $\nu_\mu$, and $\nu_{\kappa2}$ contain the same preons. The best chance to discover $\nu_{\kappa2}$ is through its decay channels $\nu_{\kappa2} \rightarrow \mu^+ + W^-$, $e^- + W^+$, or $\nu_e/\bar{\nu}_\mu + \gamma$ (and similar for $\bar{\nu}_{\kappa2}$). The experimental signatures for $\nu_{\kappa2}$ would therefore be a fast $\mu$ or $e$ plus two hadronic jets (probably from an on-shell $W$), or a single high-energy $\gamma$. It is noteworthy that our model has no channels like $e^+e^- \rightarrow \ell_{\text{light}} + \ell_{\text{heavy}}$, with charged leptons.
Table III – Quarks as preon-anti-dipreon states.

|       | (βδ) | (αδ) | (αβδ) |
|-------|------|------|-------|
| α     | u    | s    | c     |
| β     | d    | X    | b     |
| δ     | t/h  | g    | h/t   |

- There is no “family” subscheme. The SU(3) flavour structure resembles the baryon octet ($3_f \otimes \bar{3}_f = 8_f \oplus 1_f$) in the quark model. The singlet is a mixture of the three neutrinos on the main diagonal, while the other two combinations are the lepton versions of $\Sigma^0$ and $\Lambda^0$ in the quark model.

- The scheme contains $e^-$, $\tau^-$ and $\mu^+$ on equal footing. It is noteworthy that the neutrino (negative) helicity is carried by negatively charged preons ($\alpha$ in $\nu_e$ and $\nu_\tau$; $\beta$ in $\nu_\mu$; $\delta$ in $\nu_{\kappa 1}$ and $\nu_{\kappa 2}$), and opposite for antineutrinos.

- The neutrinos $\nu_e$, $\bar{\nu}_\mu$ and $\nu_{\kappa 2}$ can mix into mass eigenstates, as they have identical net preon flavours: $\nu_e = \alpha(\beta\delta)$, $\bar{\nu}_\mu = \beta(\alpha\delta)$ and $\nu_{\kappa 2} = \delta(\alpha\beta)$. The ambiguous shift of columns in Table II would involve $\nu_\tau$ in the mixing instead of $\nu_e$. A realistic set of mass eigenstates, leading to oscillations, is $|\nu_1| = \cos\theta_P|\nu_{e/\tau}| - \sin\theta_P|\bar{\nu}_\mu|$, $|\nu_2| = \sin\theta_P|\nu_{e/\tau}| + \cos\theta_P|\bar{\nu}_\mu|$ and $|\nu_3| = |\nu_{\kappa 2}|$. There should also be decays, like $\nu_2 \rightarrow \nu_1 + \gamma$, or $\nu_2 \rightarrow \nu_1 + \phi$, where $\phi$ is a light scalar, such as a Goldstone boson $\phi$, or a scalar ($\beta\beta$ or $(\alpha\alpha)$). The situation is hence theoretically complex, with decays and oscillations, maybe involving both wrong-helicity (= “sterile”?) and normal components (see also [12]). We will therefore study the neutrino sector in some detail elsewhere, taking into account the bulk of data from solar and atmospheric neutrinos. Such an analysis will require additional assumptions, outside the definition of our preon model, e.g., about the mixing angle, the oscillation and decay lengths (and channels) and the whereabouts of wrong-helicity neutrinos.

- Mixings of charged leptons, and decays like $\mu \rightarrow e + \gamma$, cannot occur.

Quarks. – Quarks are bound states of a preon and an anti-dipreon in colour triplet ($3_c^* \otimes \bar{3}_c^* = 3_c \oplus 6_c^*$), as shown in Table III. The following list of quark properties takes up several features that do not exist for leptons:

- All known quarks are reproduced with their quantum numbers. There are a few ambiguities in the scheme, e.g., with $t$ and $h$ interchanged.

- Quarks are not as fundamental here as leptons. There is no obvious “hypercolour” that groups the quarks into overall singlets, and preons in quarks might be just dynamically bound, more like in a resonance than in a “real” particle. A hint is that the lone preon is in a colour-singlet configuration with one of the antipreons inside the anti-dipreon.

- There are three new quarks, but only two of these ($g$ and $h$, for “gross” and “heavy”) contain an isolated $\delta$, while the third ($X$) does not. On the other hand, the top quark is, conveniently, among the superheavies, indicating that “superheavy” in our model means a few hundred GeV. That would make the CERN LHC and the Fermilab Tevatron ideal for discovering new leptons, quarks and heavy vector bosons, with existing CERN LEP data as a thrilling possibility, as noted above.

- The quarks have no family grouping either. The flavour-SU(3) decomposition is into a sextet and an antitriplet ($3_f \otimes \bar{3}_f = 6_f \oplus \bar{3}_f^*$). The $3_f^*$ contains the three quarks on the main diagonal, while the $6_f$ contains the off-diagonal ones. A sextet assignment for the known quarks has been suggested by Davidson et al. [13], and speculated to be due to compositeness.
The $X$ quark with charge $-4e/3$ might pose a problem, but also opens up for some new opportunities. Neglecting the possibility that a “light” $X$ has escaped discovery, we can imagine two reasons for its “non-existence”:

a) The system $X = \beta + (\bar{\alpha}\delta)$ might be unbound. It has the strongest internal electric repulsion of all quarks and leptons, due to the charge $-2e/3$ of both preon and anti-dipreon. Quarks are probably smaller than 0.001 fm, and the internal electric forces are substantial.

b) $X$ might be the discovered top quark. This cannot be easily dismissed, since the top charge is not known. The top quark was found through its presumed decay channels $t \rightarrow b + \ell^+ + \nu$ and $t \rightarrow b + u + \bar{d}$, where a few $b$ decays have been “tagged” by a charged muon. The situation is complex, because an event contains the decay of a $t\bar{t}$ pair into leptons and hadrons. Comparable channels for $X$ would be $X \rightarrow \bar{b} + \ell^+ + \nu$ and $X \rightarrow b + q_1 + q_2$, so that the full $XX$ decay would give the same leptons and jets as a $t\bar{t}$ decay, although with another $b/\ell$ matching. Hopefully, this issue will be settled soon at the Tevatron \cite{14}. Also Chang et al. \cite{15} suggest that the top charge is $-4e/3$, after a “standard-model” data analysis.

Quark decays are more complicated than lepton decays, not the least because they can be studied in detail only in hadronic decays. Assuming that dipreons do not readily break up into two preons, a quark decay can go through four types of processes:

(a) Preons annihilate or change place with preons in another quark in the same hadron. Some of these decays violate lepton-number conservation, an “invisible” example being $D^0 \rightarrow \bar{\nu}_\tau + \nu_e$ through $[\alpha(\bar{\alpha}\beta)][\bar{\alpha}(\beta\delta)] \rightarrow \alpha(\bar{\alpha}\beta) + \alpha(\beta\delta)$.

(b) The dipreon ends up in a lighter quark, e.g., beta decay $d \rightarrow u + e^- + \bar{\nu}_e$ through $\beta(\bar{\beta}\delta) \rightarrow \alpha(\bar{\alpha}\bar{\beta}) + \beta(\beta\delta) + \bar{\alpha}(\beta\delta)$. This is similar to a charged-lepton decay.

(c) The dipreon ends up in a lighter lepton. This does not conserve lepton numbers, and involves a dipreon exchange instead of a preon-antipreon exchange. An example is $b \rightarrow \bar{\nu}_\tau + e^- + u$ through $\beta(\bar{\alpha}\beta) \rightarrow \alpha(\bar{\alpha}\beta) + \beta(\beta\delta) + \bar{\alpha}(\beta\delta)$. Such decays are associated with the smallest CKM mixings, reflecting that dipreon exchange is suppressed. A problem here is that a $c$ quark must decay to $s$, $u$ or $d$ through such channels, e.g., $c \rightarrow \bar{\nu}_\tau + s + \mu^+$.

(d) A preon annihilates an antipreon in the same quark, resulting in another preon-antipreon pair inside a lighter quark. Such transitions can occur between quarks with identical net preon flavours, such as $d$ and $s$. Hence $s \leftrightarrow d$ goes through $\alpha\bar{\alpha} \leftrightarrow \beta\bar{\beta}$. This, in turn, leads to a quantum-mechanical (Cabibbo) mixing of the two quarks into two mass eigenstates. Such a mixing is important also for the $Z^0$ (see below). In terms of wave functions and the notions of the Cabibbo theory, the mass eigenstates are

$$|d'\rangle = \cos \theta_C|\beta(\bar{\beta}\delta)\rangle + \sin \theta_C|\alpha(\bar{\alpha}\bar{\beta})\rangle \quad (1)$$

$$|s'\rangle = \cos \theta_C|\alpha(\bar{\alpha}\delta)\rangle - \sin \theta_C|\beta(\bar{\beta}\delta)\rangle. \quad (2)$$

In the $(d')$ ground-state $\beta\bar{\beta}$ dominates over $\alpha\bar{\alpha}$ by roughly a factor four, which might be due to a stronger electric attraction in the $\beta\bar{\beta}$ system. In the quark model $\bar{u}u$ and $\bar{d}d$ have the same weight in the lightest mesons ($\pi^0$ and $\rho^0$), because a meson is much more extended than a quark, and hence electric forces are less important there.

- As within some other preon models the normal hydrogen atom here contains as many antipreons as preons. The proton has the preon flavour of $e^+ + 2(\alpha\delta)$, and decays, e.g., through $p \rightarrow e^+ + 2\bar{\nu}_e + 2\nu_\tau$. This requires a complicated rearrangement of three preons into three antipreons and three neutrinos.

**Heavy vector bosons.** – There are nine preon-antipreon states in the shape of vector bosons, as in Table IV. The following observations can be made:
Table IV – Heavy vector bosons as preon-antipreon states.

|   | $\bar{\alpha}$ | $\bar{\beta}$ | $\bar{\delta}$ |
|---|----------------|----------------|----------------|
| $\alpha$ | $Z^+$, $Z^0$ | $W^+$ | $Z^0$ |
| $\beta$ | $W^-$ | $Z^0$, $Z^+$ | $W^-$ |
| $\delta$ | $Z^+$ | $W^+$ | $Z''$, $Z'$ |

- The scheme is similar to the vector meson octet in the quark model ($\rho$, $\omega$, $\phi$, $K^*$). Both carry a “leakage force”; the weak and nuclear ones, and both $Z^0$ and $\rho^0$ “mix” with the photon through their constituents. There is hence a “vector meson dominance” of the photon also in the preon sector.
- $W$ decays are split-ups into other preon states, like $W^- \rightarrow e^- + \bar{\nu}_e$ through $\beta\bar{\alpha} \rightarrow \beta(\beta\bar{\delta}) + \bar{\alpha}(\bar{\beta}\bar{\delta})$. Such channels dominate also $Z^0$ decay, but there are, in addition, annihilation channels inside $Z^0$, e.g., $\beta\bar{\beta} \rightarrow \gamma^* \rightarrow \ell\bar{\ell}$.
- Weak isospin and the Weinberg mixing appear in the model for the same reason as the Cabibbo and neutrino mixings, i.e., as consequences of preon-flavour $SU(3)$, which mixes states with identical net preon flavours into mass eigenstates. The weak $SU(2)$ isotriplet wave function is supposed to be $W(0) = (|\alpha\bar{\alpha}⟩ - |\beta\bar{\beta}⟩)/\sqrt{2}$, while the isosinglet is $|B(0)⟩ = (|\alpha\bar{\alpha}⟩ + |\beta\bar{\beta}⟩)/\sqrt{2}$.

$$|Z^0⟩ = -\frac{1}{\sqrt{2}}(\cos θ_W + \sin θ_W)|β\bar{β}⟩ + \frac{1}{\sqrt{2}}(\cos θ_W - \sin θ_W)|α\bar{α}⟩.$$  \hspace{1cm} (3)

Suppose that the $β\bar{β} ↔ α\bar{α}$ admixture depends only on the $β$ and $α$ electric charges. Then we expect the admixture (up to a sign set by convention in the definitions of the Cabibbo and Weinberg angles) to be the same in the ground-states $|d⟩$ and $|Z^0⟩$:

$$\cos θ_W - \sin θ_W = \sqrt{2}\sin θ_C.$$  \hspace{1cm} (4)

With $\sin^2 θ_W = 0.23117 ± 0.00016$ and $\sin θ_C = 0.2225 ± 0.0035$ \cite{16} the $lhs = 0.396 ± 0.001$ and the $rhs = 0.315 ± 0.005$. This is a fair agreement considering the rough assumptions.

- The nearest orthogonal partner of the $Z^0$ is a heavier $Z'$. One cannot profit from the analogy with the vector mesons $\rho^0$ and $\omega$, and predict that $Z'$ will be near $Z^0$ in mass, since the unequal $β\bar{β} ↔ α\bar{α}$ admixture differs from the quark situation in vector mesons. In addition, $Z'$ might have a superheavy $δ\bar{δ}$ component, in analogy with scalar mesons, where the $s\bar{s}$ component makes the $η$ much heavier than the $π^0$.

- Scalar counterparts to the vector bosons are expected in many preon models \cite{1}. It is not known if these are even heavier than the vector bosons, or have an extra weak coupling to other particles.

Conclusions and outlook. – Our model, as defined by the preon schemes of Tables I-IV, provides a qualitative understanding of several phenomena that are not normally addressed by preon models, nor explained within the standard model. It can hence serve as a basis for a deeper analysis of the many disjoint ingredients of the latter. In addition, the model predicts several new leptons and quarks, which might be discovered in the near future, maybe even in existing data from the (closed) CERN LEP facility.

However, many problems remain to be solved: The model still lacks a dynamics, so that masses, reaction rates, etc., cannot yet be reproduced or predicted. In this respect we are worse off than the original quark model, which had at least a phenomenological mass formula for
baryons. Also, it is not yet clear if all phenomenologically successful aspects of the electroweak theory can be explained by preons. More work is obviously needed before a quantitative theory may emerge. This will include making extra assumptions, in addition to the mere “observations” made here, and analysing the data in the light of these. We will continue our efforts with a deeper analysis of the neutrino sector, in order to find oscillation and decay patterns. A thorough analysis of existing CERN LEP data would also be desirable, in search of decay products of a heavy neutrino, along the lines predicted by our model.

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