Vol. B11 (1980) ACTA PHYSICA POLONICA No 6

TOWARDS A DYNAMICAL PREON MODEL

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(Received January 24, 1980)

We discuss further the recently proposed "primordial" quantum chromodynamics, where a massive Fermi-Bose couple of two colour triplets δ and χ of spin 1/2 and 0, respectively, and of equal charge $-1/3$ interacts with a colour octet of massless vector gluons. The "preons" δ and χ form bound states $\nu_e = \delta\bar{\chi}$, $e = \delta(\chi\chi)_P$ (colour singlets) and $u = \bar{\delta}\bar{\chi}$, $d = \bar{\delta}(\chi\chi)_P$ (colour triplets). Other preon bound states also exist and are briefly reviewed.

A theoretical search for possible sub-elementary constituents of leptons and quarks [1, 2], though a little bold, seems to be a natural thing to do at the present stage of particle physics development. Especially, a dynamical theory of such constituents would certainly be welcome.

As an attempt towards such a theory, we made in a recent paper [3] the conjecture that leptons and quarks of the lowest generation, ν_e, e and u, d, are bound states of massive "preons" forming two colour triplets δ and χ of spin 1/2 and 0, respectively, and of equal charge $-1/3$. We assumed tentatively that the underlying dynamics of strong binding forces is the "primordial" quantum chromodynamics, where the coloured preons δ and χ interact with a colour octet of massless vector gluons (in the gauge-invariant way). Such a model implies obviously the colour conservation as well as the separate conservation of δ number (i.e. $N_\delta - N_{\bar{\delta}}$) and χ number (i.e. $N_\chi - N_{\bar{\chi}}$), the latter owing to the δ-number conservation and charge conservation. The baryonic number (i.e. $\frac{1}{3}(N_q - N_{\bar{q}})$) is, however, not absolutely conserved, allowing for the proton decay $p \rightarrow \bar{e}\bar{\nu}_e\bar{\nu}_e$. Note that in the case of full supersymmetry δ and χ preons would interact also with a colour octet of massless spin-1/2 "gluinos" [4], so that our primordial quantum chromodynamics is not a supersymmetric QCD but rather the usual QCD applied on the sub-elementary level to a Fermi-Bose couple of δ and χ preons.

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In this model it was natural to formulate the hypothesis that

$$\nu_e = (\delta\bar{\chi})_S \text{ colour singlet,}$$

$$e = [\delta(\chi\chi)_P]_S \text{ colour singlet,}$$

$$u = (\bar{\delta}\bar{\chi})_S \text{ colour triplet,}$$

$$d = [\bar{\delta}(\chi\chi)_P]_S \text{ colour triplet} \tag{1}$$

and

$$W^- = [\chi(\chi\chi)_P]_S \text{ colour singlet,}$$

$$Z = \text{a linear combination of colour singlets } (\delta\bar{\delta})_{\uparrow\uparrow S} \text{ and } (\chi\bar{\chi})_P, \tag{2}$$

the photon being an orthogonal combination or, alternatively, an elementary particle like the gluons (in the second case the orthogonal combination might represent a second neutral weak vector boson). The spin-0 colour singlets $(\delta\bar{\delta})_{\uparrow\downarrow S}$ and $(\chi\bar{\chi})_S$ were related to two neutral Higgs bosons (note that the spin-0 colour singlets $[(\delta\delta)_{\uparrow\downarrow S}\chi]_S$ and $(\chi\chi\chi)_S$ with charge -1 are forbidden by the Fermi or Bose statistics, respectively).

Another assignment of e, d and W^- to preon bound states might be

$$e = [\delta(\delta\delta)_{\uparrow\downarrow P}]_S \text{ colour singlet,}$$

$$d = (\bar{\delta}\delta\delta)_{\downarrow\uparrow\uparrow S} \text{ colour triplet} \tag{3}$$

and

$$W^- = [(\delta\delta)_{\uparrow\uparrow S}\chi]_S \text{ colour singlet.} \tag{4}$$

We shall exclude this possibility, however, because it seems likely that

$$[\delta(\delta\delta)_{\uparrow\downarrow P}]_S \rightarrow (\delta\delta\delta)_{\uparrow\uparrow\uparrow S}\gamma, \tag{5}$$

where $(\delta\delta\delta)_{\uparrow\uparrow\uparrow S}$ is a spin-3/2 colour singlet having presumably a lower mass than the orbital-excited spin-1/2 colour singlet $[\delta(\delta\delta)_{\uparrow\downarrow P}]_S$ (note that the nonexcited spin-1/2 colour singlet $(\delta\delta\delta)_{\downarrow\uparrow\uparrow S}$ is forbidden by the Fermi statistics).

We can see that in this model there is an analogy between lepton and quark electroweak (or only weak) interactions mediated by electroweak (or weak) bosons composed of preons, and hadron strong interactions mediated by mesons composed of quark (which in turn are, however, composed of preons). In both cases real agents of interactions are coloured gluons binding preons into electroweak (or weak) bosons and quarks into mesons. In this sense, the primordial quantum chromodynamics is intended to be a really fundamental theory of *both* interactions. We would like to stress that the interpretation of preon bound states given by Eqs. (1) and (2) enables us to construct (consistently with the primordial quantum chromodynamics) an *effective* SU(2) × U(1) electroweak symmetry group of the standard model (if the photon is composite). However, we cannot say yet to which extent this group really follows from our preon model. In order to answer this question one should learn to calculate effective interactions (mediated by colour-singlet bound states) from the primordial quantum chromodynamics. They correspond to the composite-line interaction diagrams resembling here the so-called dual diagrams of the quark model.

One can try to approximate two-body preon interactions by a Coulomb-like potential $V = -\alpha/r$, where $\alpha = (4/3)\alpha_S$ or $\alpha = (2/3)\alpha_S$ in a colour-singlet or colour-triplet state, respectively. Then it turns out that carrying out relativistic two-body calculations for a system of one Dirac and one Klein–Gordon particle and taking the critical value $\alpha_S = 3/2$ and equal preon masses $m_\delta = m_\chi$, one gets for the neutrino ν_e the zero mass exactly [5], and for the u quark the mass $m_u = m_\delta\sqrt{3}$, which is very large if $m_\delta = m_\chi$ is such. This large mass corresponds, however, to an abstract free u quark. As to the electron, it is not clear yet if one can obtain its small mass when one takes a very large mass for δ and χ (in order to provide that the electron be very point-like as observed experimentally). An answer to this crucial question would require performing relativistic three-body calculations for a system of one Dirac and two Klein–Gordon particles. The following arguments may suggest, however, that the electron mass should come out small indeed: since for the zero mass of ν_e one has effectively $m_{\nu_e} \sim 2m_\delta - B \sim 0$, for the mass of e one gets $m_e \sim 3m_\delta - (B+B/2) \sim 0$. Similarly, $m_u \sim 2m_\delta - B/2 \sim m_\delta$ and $m_d \sim 3m_\delta - 2B/2 \sim m_\delta$ are of the same order of magnitude but very large (for free quarks). Note that the ratio $B : B/2 = 2 : 1$ of colour-singlet binding to colour-triplet binding works very well here. Generally, due to this argument, bare masses of all colour-singlet bound states come out ~ 0. The large (but not very large) masses of $W^\pm$ and Z may, therefore, follow from an additional mechanism as an *effective* Higgs mechanism connected with the vertices

$$W^+W^- \to (\chi\bar{\chi})_S(\chi\bar{\chi})_S \tag{6}$$

and

$$ZZ \to (\delta\bar{\delta})_{\uparrow\downarrow S}(\delta\bar{\delta})_{\uparrow\downarrow S} \quad \text{or} \quad (\chi\bar{\chi})_S(\chi\bar{\chi})_S, \tag{7}$$

where

$$\langle(\delta\bar{\delta})_{\uparrow\downarrow S}\rangle_{\text{vac}} \neq 0, \quad \langle(\chi\bar{\chi})_S\rangle_{\text{vac}} \neq 0. \tag{8}$$

Obviously, such a mechanism contributes also to other bound-state masses. Similarly the masses of all colour-triplet states come out $\sim m_\delta$.

Let us remark that in this model the neutrino ν_e, being composed of charged constituents, possesses an electromagnetic structure (as it was discussed in Ref. [6]). This is not the case for the model of Ref. [2], where the neutrino consists of neutral building blocks.

It is evident in the present model that leptons, quarks and W bosons should have their "supersymmetry-like" partners whose preon content can be obtained by the subsituation $\delta \rightleftarrows \chi$. They are given in Table I, where all "non-exotic" (i.e. two-fold and three-fold), orbital-nonexcited preon bound states are constructed for δ and χ preons. Note that there appears a fourth class of composite particles, the colour-triplet weak bosons

TABLE I

Non-exotic (i.e. two-fold and three-fold), orbital-nonexcited bound states of δ and χ preons[a]

Q \ J	0	1/2	1	3/2
	Leptons (colour singlets) and their $\delta \rightleftarrows \chi$ partners			
0	no	$\nu_e = (\delta\bar{\chi})_S$	no	orb.-exc.
−1	orb.-exc.	$e = [\delta(\chi\chi)_P]_S$	$[(\delta\delta)_{\uparrow\uparrow S}\chi]_S \to e\nu_e$	$[\delta(\chi\chi)_P]_S \to e\gamma$
	Quarks (colour triplets) and their $\delta \rightleftarrows \chi$ partners			
2/3	no	$u = (\bar{\delta}\bar{\chi})_S$	no	orb.-exc.
−1/3	orb.-exc.	$d = [\bar{\delta}(\chi\chi)_P]_S$[b]	$[(\delta\delta)\bar{\chi}]_{\uparrow\uparrow S} \overset{?}{\to} \bar{u}\bar{d}$	$[\bar{\delta}(\chi\chi)_P]_S \to d\gamma$
	Colour-singlet weak bosons and their $\delta \rightleftarrows \chi$ partners			
0	H's $\sim (\delta\bar{\delta})_{\uparrow\downarrow S}, (\chi\bar{\chi})_S$[c]	no[d]	$\gamma, Z \sim (\delta\bar{\delta})_{\uparrow\uparrow S}, (\chi\bar{\chi})_P$[c]	no
−1	orb.-exc.	spin-orb.-exc.[e]	$W^- \sim [\chi(\chi\chi)_P]_S$	$(\delta\delta\delta)_{\uparrow\uparrow\uparrow S} \to e\nu_e\nu_e$
	Colour-triplet weak bosons and their $\delta \rightleftarrows \chi$ partners			
2/3	no	no	$(\delta\delta)_{\uparrow\uparrow S} \to u\bar{\nu}_e, d\bar{e}$; $(\bar{\chi}\bar{\chi})_P \to u\nu_e$	no
−1/3	orb.-exc.[f]	$(\bar{\delta}\delta\delta)_{\downarrow\uparrow\uparrow S}$[f] $\to d\nu_e\nu_e$	$[\bar{\chi}(\chi\chi)_P]_S$[f] $\to d\nu_e$	$(\bar{\delta}\delta\delta)_{\uparrow\uparrow\uparrow S}$[f] $\to (\bar{\delta}\delta\delta)_{\downarrow\uparrow\uparrow S}\gamma$

[a] The conclusions presented in this table would still be true if the model were supersymmetric, i.e. δ and χ preons were coupled not only to spin-1 gluons but also to spin-1/2 "gluinos". [b] It is assumed that effectively $m_d < m_\delta$ to avoid the decay $d \to \bar{\nu}_e\chi$ within hadrons. [c] One of $(\chi\bar{\chi})_S$ and $(\chi\bar{\chi})_P$ is orbital-excited. [d] Thus there are no "photino" and other "nuinos". [e] $[\delta(\delta\delta)_{\uparrow\downarrow P}]_S \to (\delta\delta\delta)_{\uparrow\uparrow\uparrow S}\gamma$. [f] These states may not be bound, immediately rearranging into $\delta(\delta\bar{\delta})$ or $\chi(\chi\bar{\chi})$.

and their supersymmetry-like partners. Note also that in our model there are no "scalar leptons" and "scalar quarks" as well as no spin-1/2 partners of the photon and Z boson called "nuinos" (in particular, no "photino") [7].

The proton decay proceeds in this model through the following chain of virtual processes:

$$p = (uud) \to u[(\delta\bar{\delta})_{\uparrow\uparrow S}\chi]_S \to [\bar{\delta}(\bar{\delta}\bar{\delta})_{\uparrow\downarrow P}]_S \to [(\overline{\delta\delta})_{\uparrow\uparrow S}\bar{\chi}]_S\nu_e \to \bar{e}\bar{\nu}_e\bar{\nu}_e, \tag{9}$$

where two spin-1 and one spin-1/2 intermediate bound states participate. If the indicated steps correspond to semi-weak processes, we can write for the proton lifetime the formula

$$\frac{1}{\tau_p} \sim \frac{m_p^5}{96\pi^3} \frac{(m_W^2 G_F/\sqrt{2})^2}{m_{\delta\delta\chi}^4} \frac{1}{m_{\delta\delta\delta}^2} \frac{(m_W^2 G_F/\sqrt{2})^2}{m_{\delta\delta\bar{\chi}}^4} |\psi(0,0)|^2, \tag{10}$$

where $m_p^2 G_F = 1.02 \times 10^{-5}$ while $\psi(0, 0)$ denotes the proton internal wave function at the zero separation of u, u and d constituent quarks. Hence

$$\frac{1}{\tau_p} \sim \frac{m_W^8 m_p^2}{m_{\delta\delta\chi}^4 m_{\delta\delta\delta}^2 m_{\delta\delta\bar{\chi}}^4} \sec^{-1} \tag{11}$$

if $|\psi(0, 0)|^2 \sim m_p^6$. Here $m_{\delta\delta\bar{\chi}}$ ($\sim m_\delta \sim m_\chi$) is very large (of the colour-triplet mass scale), whilst perhaps $m_{\delta\delta\delta} \sim m_{\delta\delta\chi}$ ($\sim m_W \simeq 75$ GeV) and are essentially of the colour-singlet mass scale. Then

$$\frac{1}{\tau_p} \sim 10^{11} \left(\frac{\text{GeV}}{m_{\delta\delta\bar{\chi}}}\right)^4 \text{year}^{-1}. \tag{12}$$

Thus $\tau_p > 10^{29} - 10^{33}$ years if $m_{\delta\delta\bar{\chi}} > 10^{10} - 10^{11}$ GeV (as is known, the present experimental lower bound for τ_p is 10^{31} years). However, it might as well be $m_{\delta\delta\bar{\chi}} \sim 10^{19}$ GeV if $m_\delta \sim m_\chi \sim$ Planck mass.

Besides the non-exotic preon bound states discussed above, there may exist also some "exotic" bound states involving more δ's and/or χ's, and being, therefore, an analogy of the exotic quark bound states, as for example $q\bar{q}q\bar{q}$ or $qqqq\bar{q}$. Some interesting examples of such exotic states are spin-1/2 colour singlets $[\bar{\delta}\chi(\chi\chi)_P]_S$ and $\{\delta[(\chi\chi)_P(\chi\chi)_P]_P\}_S$ of charge 0 and −1, respectively. Through a rearrangement they may transit virtually (and decay if their masses allow) into $\bar{\nu}_P(\chi\bar{\chi})_P$ and $\bar{\nu}_e W^-$, in analogy with the hypothetic baryonium $[(qq)(\bar{q}\bar{q})]$ which transits virtually (and decays) into two mesons $(q\bar{q})(q\bar{q})$. Their weak-decay modes would be $e\bar{e}\bar{\nu}_e$ (or $\nu_e\bar{\nu}_e\bar{\nu}_e$) and $e\bar{\nu}_e\bar{\nu}_e$, respectively. The former might decay electromagnetically into $\bar{\nu}_e\gamma$.

In conclusion, we would like to repeat the crucial question asked in Ref. [3], why at the presently available energies do leptons not display any strong interactions, whilst hadrons, also being colour singlets, do. A related question is, why are leptons (and quarks) very point-like, while hadrons are considerably extended, or, in other words, why are preons in leptons (and in quarks) effectively heavy, whilst quarks in hadrons are effectively light. In Ref. [3] we made the conjecture that these differences between leptons and hadrons are connected with the difference in the asymptotic freedom of preons (within leptons) and quarks (within hadrons). The latter difference is caused, in fact, by the quartic self-coupling of spin-0 χ preons present in the primordial quantum chromodynamics and *effectively* absent from the usual quark-gluon dynamics (i.e. the "effective" quantum chromodynamics).

Such self-coupling, $\frac{1}{2}\lambda(\chi^+\chi)^2$, spoils the asymptotic freedom of the primordial quantum chromodynamics, leading (in the collaboration with gluon couplings) in the next-to-lowest order to the following renormalization-group equation for the running coupling constant

$\bar{\lambda}(t)$ [8]:

$$\frac{d}{dt}\frac{\bar{\lambda}}{\bar{g}^2} = \bar{g}^2\left[A\left(\frac{\bar{\lambda}}{\bar{g}^2}\right)^2 + B\frac{\bar{\lambda}}{\bar{g}^2} + C\right], \qquad \bar{\lambda}(0) = \lambda \tag{13}$$

where $2t = \ln(Q^2/\mu^2)$ and (in our case)

$$A = \frac{7}{8\pi^2}, \qquad B = -\frac{8}{8\pi^2} + b = \frac{2\frac{1}{6}}{8\pi^2}, \qquad C = \frac{2\frac{1}{6}}{8\pi^2}, \tag{14}$$

while the running coupling constant $\bar{g}(t)$ $(\bar{\alpha}_S(t) = \bar{g}^2(t)/4\pi)$ is given (on our case) by formulae

$$\bar{g}^2 = \frac{g^2}{1+bg^2t}, \qquad b = \frac{1}{8\pi^2}(11-\tfrac{2}{3}-\tfrac{1}{6}) = \frac{10\frac{1}{6}}{8\pi^2}. \tag{15}$$

Since here $4AC-B^2 > 0$, Eq. (13) gives us the rising solution with t,

$$\frac{\bar{\lambda}}{\bar{g}^2} = -\frac{B}{2A} + \frac{\sqrt{4AC-B^2}}{2A}\tan\left(\frac{\sqrt{4AC-B^2}}{2b}\ln\left|\frac{g^2}{\bar{g}^2}\right| + \arctan\frac{2A\lambda+Bg^2}{g^2\sqrt{4AC-B^2}}\right), \tag{16}$$

even if a posteriori $\lambda = 0$. Eq. (13) and its solution (16) are valid, of course, only in such ranges of t where $\bar{g}^2(t)$ and $\bar{\lambda}(t)$ are small enough. Formally, however, $\bar{\lambda} = \pm\infty$ at the points $t_n \mp 0$ for which the argument of the tangent in Eq. (16) is equal to $(2n+1)\pi/2 \mp 0$ with integer n. Note that $t_n > 0$ for $n \geqslant 0$ and $t_n < 0$ for $n < 0$, where $t_n \to \infty$ and $-1/bg^2$ at $n \to +\infty$ and $-\infty$, respectively. As follows from Eqs. (13) and (15) [8]

$$\frac{d\bar{\lambda}}{dt} = A\bar{\lambda}^2 + (B-b)\bar{\lambda}\bar{g}^2 + C\bar{g}^4, \tag{17}$$

where $[(B-b)^2-4AC]\bar{g}^4 > 0$, so we can see that $\bar{\lambda}(t)$ rises with t from $-\infty$ and to $+\infty$ in the ranges $t_{n-1} < t < t_n^{(1)}$ and $t_n^{(2)} < t < t_n$, respectively, where the points $t_n^{(1)}$ and $t_n^{(2)}$ satisfy the equalities

$$\bar{\lambda}(t_n^{(1,2)}) = \frac{-(B-b) \mp \sqrt{(B-b)^2-4AC}}{2A}\,\bar{g}^2(t_n^{(1,2)}), \tag{18}$$

the coefficient on the right-hand side being equal to $(8 \mp \sqrt{3\frac{1}{3}})/14$. In the ranges $t_n^{(1)} < t < t_n^{(2)}$, $\bar{\lambda}(t)$ decreases. Note that the solution $\bar{\lambda} \equiv \bar{\lambda}(\bar{g}^2)$, Eq. (16), displays the "damped periodicity" with respect to the argument of the tangent,

$$\bar{\lambda}\left[\bar{g}^2\exp\left(-\frac{2\pi nb}{\sqrt{4AC-B^2}}\right)\right] = \bar{\lambda}(\bar{g}^2)\exp\left(-\frac{2\pi nb}{\sqrt{4AC-B^2}}\right), \tag{19}$$

where $n = 0, \pm 1, \pm 2, \ldots$, while the values $\bar{\lambda} = \pm\infty$ are formally assumed periodically at the points $(2n+1)\pi\,2 \mp 0$.

The static Fourier transform of $\bar{\lambda}(t)$,

$$\tilde{\bar{\lambda}}(r) = \frac{1}{(2\pi)^3}\int d^3\vec{Q}\bar{\lambda}(t)e^{i\vec{Q}\cdot\vec{r}} = \bar{\lambda}\left[\tfrac{1}{2}\ln\left(-\frac{\nabla^2}{\mu^2}\right)\right]\delta^3(\vec{r}) \tag{20}$$

(here $Q^2 = \vec{Q}^2$ and $Q \to Q-i\varepsilon$), if formally calculated by using Eq. (16), takes the form

$$\tilde{\bar{\lambda}}(r) = -\frac{1}{\pi b}\sum_n \frac{Q_n^2}{r}\cos Q_n r, \tag{21}$$

where $Q_n^2 = \mu^2 \exp(2t_n)$ and $n = 0, \pm 1, \pm 2, \ldots$ Note that $r\tilde{\bar{\lambda}}(r) \to -\infty$ at $r \to 0$ because $\sum_n Q_n^2 = \infty$. In fact,

$$Q_n^2 = \Lambda^2 \exp\left(2\beta \exp\frac{2\pi nb}{\sqrt{4AC-B^2}}\right), \tag{22}$$

where

$$\Lambda^2 = \mu^2 \exp\left(-\frac{2}{bg^2}\right),$$

$$\beta = \frac{1}{bg^2}\exp\left[\frac{2b}{\sqrt{4AC-B^2}}\left(\frac{\pi}{2}-\arctan\frac{2A\lambda+Bg^2}{g^2\sqrt{4AC-B^2}}\right)\right]. \tag{23}$$

Since $\beta > 0$, one gets $Q_n^2 \to \infty$ and Λ^2 at $n \to +\infty$ and $-\infty$, respectively. The parameter Λ here is the same as that appearing in formula

$$\bar{g}^2 = \frac{2}{b\ln(Q^2/\Lambda^2)}, \tag{24}$$

which follows from Eqs. (15) and (23) (and implies formally that $\bar{g}^2 \to \infty$ at $Q^2 \to \Lambda^2+0$).

Since the simplest δ–χ and χ–χ interactions are proportional to $\bar{g}^2$ or $\bar{g}^2\bar{\lambda}$ and $\bar{g}^2$ or $\bar{\lambda}$, respectively, the terms with $\bar{\lambda}$ spoil the asymptotic freedom of δ–χ and χ–χ interactions.

At any rate, we can say that if *the same* fundamental forces have to be responsible for preon binding in leptons (and quarks) and for quark binding in hadrons, the above--mentioned differences between leptons and hadrons must be related to the difference in the content of leptons and hadrons.

Another crucial question concerns, of course, the higher generations of leptons and quarks. One can try to imagine hopefully that they are in a sense (perhaps neither radial nor orbital) excited states of the lowest generation [9]. An alternative, very "non-economical" possibility would be the existence of separate generations of δ_N and χ_N preons ($N = 1, 2, 3, \ldots$) for separate generations of ν_N and e_N leptons and u_N and d_N quarks (with a Cabibbo-like intergeneration mixing in the case of quarks). Then, at any rate, the zero mass can be provided for neutrinos ν_N of all generations. But there seems to be trouble with the composite intermediate bosons, universal for all generations of fermions.

The author would like to thank Professor Abdus Salam, the International Atomic Energy Agency and UNESCO for hospitality at the International Centre for Theoretical Physics, Trieste.

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