MAGNETISM AS THE ORIGIN OF PREON BINDING

Jogesh C. PATI [1]
The Institute of Physics, Bhubaneswar, Orissa, India
and The International Centre for Theoretical Physics, 34100 Trieste, Italy

Received 29 April 1980
Revised manuscript received 27 October 1980

It is argued that ordinary "electric"-type forces – abelian or nonabelian – arising within the grand unification hypothesis are inadequate to bind preons to make quarks and leptons unless we proliferate preons. It is therefore suggested that the preons carry electric and magnetic charges and that their binding force is magnetic. Quarks and leptons are magnetically neutral. Possible consistency of this suggestion with the known phenomena and possible origin of magnetic charges are discussed.

The idea that quarks and leptons have *one* origin and that their forces – weak, electromagnetic as well as strong – are aspects of a single force serves to remove a certain degree of arbitrariness from particle physics [1,2]. But the arbitrariness persists now in another form due to the vast proliferation of quarks and leptons and correspondingly of the gauge spin-1 as well as spin-0 quanta, which appear to be needed to describe reality in the context of a gauge unification. Such a proliferation runs counter to one's intuitive notion of elementarity.

To resolve this dilemma it was suggested in 1974 that quarks and leptons may define only a stage in one's quest for elementarity [3–5] [‡1]. The fundamental entities may more appropriately correspond to the truly fundamental "*attributes*" (charges) exhibited (or yet to be exhibited) by nature. The fields carrying these fundamental attributes are named "*preons*". Quarks and leptons of number *mn* exhibiting *m* flavors and *n* colors [‡2] may be viewed within this picture as composites of a set of preons consisting, for example, of *m* elementary "*flavons*" (f_i) plus *n* elementary "*chromons*" ($\mathcal{C}_\alpha$). The flavons carry only flavor but no color, while the chromons carry only color but no flavor. If both flavons and chromons carry spin-1/2 (rather than flavons carrying spin-1/2 and chromons carrying spin-0 for example), one needs to include a third kind of spin-1/2 attribute (or attributes) in the preon set, which for convenience we shall call "*spinons*" (ζ_ν); these serve to give spin-1/2 to quarks and leptons [‡3], but may in general serve additional purposes, which we shall mention. The quarks and leptons are in the simplest case composites of one flavon, one chromon and one spinon plus the "sea". We see that within this picture, the number of elementary preons needs be no more than $(m + n + 1)$, which for the cases of interest is considerably smaller than the number *mn* of quarks and leptons. For example,

[1] Permanent address: Department of Physics, University of Maryland, College Park, MD 20742, USA.

[‡1] Several authors have worked on composite models of quarks and leptons with an emphasis on classification rather than gauge unification of forces [4]. Harari and Shupe [5] have recently proposed the most economical model of all, but with a number of dynamical assumptions, whose bases are not clear.

[‡2] For simplicity let us proceed with the notion that lepton number is the fourth color [1]. In this case the composite structure is as follows: $(q_u)_{r,y,b} = u + (r, y \text{ or } b) + \zeta$, while $\nu = u + \ell + \zeta$ etc. Within the preon idea leptons may however differ from quarks by more than one attribute. For example, we may have $\nu = u + \ell + \zeta'$ where $\zeta' \neq \zeta$. Such variants will be considered elsewhere.

[‡3] With the spinon present the flavons and chromons can carry integer spin 0 or 1.

 0 031–9163/81/0000–0000/$ 02.50 © North-Holland Publishing Company

for six flavors and four colors, $m + n + 1 = 6 + 4 + 1 = 11$, while $mn = 24$. Now if the spinons are assigned to play the role of a family quantum number, then only 9 preons, consisting of two flavors (u, d) + four chromons (r, y, b, ℓ) + three spinons ($\zeta_e, \zeta_\mu, \zeta_\tau$) will suffice. Alternatively and perhaps more attractively, if the μ and τ families are viewed to differ from the e-family only in respect of an "excitation quantum number" or degeneracy quantum number, which is lifted by some "fine or hyperfine" interaction, then only seven preons consisting of (u, d, r, y, b, ℓ and ζ) suffice to describe the 24 quarks and leptons of 3 families and even more, if they are to be discovered.

For this reason, the preon idea appears to be attractive. But can it be sustained dynamically? The single most important problem which confronts the preon hypothesis is this: What is the nature and what is the origin of the force which binds the preons to make quarks and leptons? This note is addressed to elucidating the nature of this problem and suggesting a possible resolution.

Our first observation is that ordinary "electric"-type forces [‡4] – abelian or nonabelian – arising within the grand unification hypothesis are inadequate to bind preons to make quarks and leptons unless we proliferate preons much *beyond* the level depicted above. In arriving at this observation, we shall follow the conventional perturbative renormalization group approach [6] for the evolution of all effective gauge coupling constants down to such momenta where they are small (i.e. $g_i^2/4\pi < 0.3$ say).

The argument goes as follows: Since quarks and leptons are so pointlike – their sizes are shorter than 10^{-16} cm as evidenced (especially for leptons) by the $(g-2)$ experiments – it follows that the preon binding force F_b must be strong or superstrong at short distances $r \leqslant 10^{-17}$–10^{-18} cm corresponding to running momenta $Q \gtrsim 1$ to 10 TeV. (Recall for comparison that the chromodynamic forces generated by the $SU(3)_{color}$ symmetry are strong ($\alpha_c > 1$) only at distances of order 1 fm, which correspond to the sizes of the known hadrons.) This says that the symmetry-generating preon binding force must lie outside of the familiar $SU(2) \times U(1) \times SU(3)_{col}$ symmetry.

‡4 By "electric"-type forces we mean forces whose effective coupling constants are of order $\alpha \approx 1/137$ at the unification point M. For evolutions of these coupling constants see Georgi et al. [6].

Now consistent with our desire to adhere to the grand unification hypothesis, we shall assume that the preon binding force F_b derives its origin either intrinsically or though the spontaneous breakdown of a grand unifying symmetry G. Thus either the basic symmetry G is of the form $\mathcal{G}_k \times \mathcal{G}_b$ with $\mathcal{G}_k$ generating the known electroweak–strong forces and $\mathcal{G}_b$ generating the preon binding forces (in this case $\mathcal{G}_k$ and $\mathcal{G}_b$ are related to each other by discrete symmetry so as to permit a single gauge coupling constant); or the unifying symmetry G breaks spontaneously as follows:

$$G \xrightarrow{\text{SSB}} \mathcal{G}_k \times \mathcal{G}_b \times [\text{possible U(1) factors}]. \tag{1}$$

In the second case $\mathcal{G}_k$ need not be related to $\mathcal{G}_b$ by discrete symmetry. But in either case $\mathcal{G}_k$ contains the familiar $SU(2)_L \times U(1)_{ew} \times SU(3)_{color}$ symmetry and therefore the number of attributes (N_k) on which $\mathcal{G}_k$ operates needs to be *at least* 5. This corresponds to having two flavons (u, d) plus three chromons (r, y, b). To incorporate leptonic chromon ℓ and possibly also the spinon ζ, N_k may need to be at least 7; but for the present we shall take conservatively $N_k \geqslant 5$.

Now consider the size of $\mathcal{G}_b$. On the one hand the effective coupling constant $\bar{g}_b$ of the binding symmetry $\mathcal{G}_b$ is equal to the effective coupling constant $\bar{g}_c$ of the familiar SU(3)-color symmetry (up to embedding factors [7] like $1/\sqrt{2}$ or $1/\sqrt{3}$ etc.) at the unification mass scale $M \geqslant 10^4$ GeV. On the other hand, $\bar{\alpha}_b \equiv \bar{g}_b^2/4\pi$ needs to exceed unity at a momentum scale $\mu_b \gtrsim 1$ to 10 TeV, where the chromodynamic coupling constant $\bar{\alpha}_c \ll 1$. It therefore follows (assuming that the embedding factor mentioned above is unity) that $\mathcal{G}_b$ is much larger than SU(3) [‡5]. Using renormalization group equations for variations of the coupling constants $\bar{\alpha}_b$ and $\bar{\alpha}_c$, one may verify that $\mathcal{G}_b$ minimally is SU(5) [‡6] and correspondingly the dimension N_b of the space on which $\mathcal{G}_b$ operates is minimally 5.

Now the preons $\{\mathcal{P}_i\}$ which bind to make quarks

‡5 This incidentally excludes the possibility that $\mathcal{G}_b$ is abelian.

‡6 One may have considered the possibility that $\mathcal{G}_b$ is SU(4). But then the physical requirement of making quarks and leptons to be singlets of $\mathcal{G}_b$ (so that they do not exhibit undue strong interactions) would imply that they are four-preon composites. With each preon carrying spin-1/2, however, this will not lead to spin-1/2 for quarks and leptons in any case. In other words $\mathcal{G}_b$ = SU(n) implies n must be odd.

and leptons must be nontrivial with respect to *both* $\mathcal{G}_k$ and $\mathcal{G}_b$. Since each of $\mathcal{G}_k$ and $\mathcal{G}_b$ requires for their operations a space, which is *minimally* five dimensional, it follows that the number of preons $N_{\mathcal{P}}$ needed (under the hypothesis alluded to above) is minimally $N_k \times N_b \geqslant 25$:

$$N_{\mathcal{P}} \geqslant N_k \times N_b \geqslant 5 \times 5 = 25 . \tag{2}$$

We may consider relaxing the assumption that the embedding factor is unity. This would permit the ratio $[\bar{g}_b(\mu)/\bar{g}_c(\mu)]_{\mu=M}$ to be a number like $\sqrt{2}$ or $\sqrt{3}$ for example. In turn this can result in a reduction in the size of $\mathcal{G}_b$. But simultaneously such a step necessitates an increase in the size of $\mathcal{G}_k$ or effectively of the number N_k with the result that the minimal number of preons needed $N_{\mathcal{P}} \geqslant N_k \times N_b$ is not reduced below 21 [‡7].

This number 25 (or 21) representing the minimal number of preons needed already exceeds or is close to the number of quarks and leptons which we need at present, which is 24 [‡8]. And if we include, more desirably, the leptonic chromon ℓ and the spinon ζ in the preonic degrees of freedom, the number of preons needed would increase to 35 (or 27).

Such a proliferation of preons defeats from the start the very purpose for which they were introduced – economy. In turn, this poses a serious dilemma. On the one hand giving up the preon idea altogether and living with the quark–lepton system as elementary runs counter to one's notion of elementarity and is thus unpalatable. On the other hand giving up the grand unification hypothesis is not aesthetically appealing.

Noting this impasse, we are led to suggest that the preons carry not only electric but also magnetic charges [‡9] and that their binding force is magnetic in nature. The two types of charges are related to each other by the familiar Dirac-like quantization conditions [8,9] [‡10] for charge–monopole or dyon systems, which imply that the magnetic coupling strength $\alpha_m \equiv g_m^2/4\pi$ is $O(1/\alpha_e) \approx O(137)$ and thus is superstrong. In other words, the magnetic force can arise through an abelian U(1) component within the unification hypothesis (as remarked further at the end) and yet it can be superstrong. This is what gives it the power to bind preons into systems of small size without requiring a proliferation. Quarks and leptons do not exhibit this superstrong force because they are magnetically neutral (see remarks below).

We shall first discuss the consistency of this idea with presently known phenomena from a qualitative point of view and later indicate the possible origin of this magnetic force.

(1) Since the electric fine structure constant $\alpha_e = e^2/4\pi$ varying with running momentum remains small, $\approx 10^{-2}$, almost everywhere (at least up to momenta $\approx 10^{14}$ GeV and therefore up to distances $\approx 10^{-28}$ cm), the magnetic "fine-structure" constant $\alpha_m \equiv g_m^2/4\pi$ related to α_e by the reciprocity relations is superstrong even at distances as short as 10^{-28} cm (if not at $r \to 0$). It is this strong short-distance component of the magnetic force, which makes quarks and leptons so point-like with sizes $r_0 \ll 10^{-16}$ cm. Their precise size would depend upon the dynamics of the superstrong force, which we are not yet equipped to handle. For our purposes we shall take r_0 to be as short as perhaps $1/M_{\text{planck}} \approx 10^{-33}$ cm but as large as perhaps 10^{-18} cm (i.e. $r_0 < 10^{-18}$ cm).

(2) Quarks and leptons do not exhibit even a trace of the superstrong interactions of their constituents because they are magnetically neutral composites of preons and their sizes are small compared to the distances $R \gtrsim 10^{-16}$ cm which are probed by present high-energy experiments. The Van der Waals-like magnetic forces measured at separation $R \gtrsim 10^{-16}$ cm $\gg r_0$ are expected to be highly damped despite the superstrong character of magnetic charges because $(r_0/R)^N < 10^{-14}$ for $r_0 < 10^{-18}$ cm, $R > 10^{-16}$ cm and [10] $N \approx 7$.

(3) We mention in passing that had we assumed, following Schwinger [9], that quarks (rather than preons)

‡7 This and other examples will be presented in a longer article.

‡8 To be precise we presently need 21 four-component + 3 two-component quark–lepton entities assuming that the top flavor will be discovered.

‡9 This is not to say that *all* preons must carry both types of charges. For example some of them may carry only magnetic but not electric charges.

‡10 For our purposes it is immaterial whether the quantization conditions for charge–monopole systems $e_i g_j/4\pi = \frac{1}{2} n_{ij}\hbar$ and for dyons $(e_i g_j - e_j g_i)/4\pi = \frac{1}{2} N_{ij}\hbar$ are governed by integral values or only even integral values for n_{ij} and N_{ij}.

carry magnetic charges, we would not understand why they interact so weakly at short distances as revealed by deep inelastic ep scattering.

(4) Due to their composite nature, we expect corrections [‡11] to the low-energy parameter $(g-2)$ of the muon and the electron of order $(m/M_0)^2$ or $(mm_{\mathcal{P}}/M_0^2)$, where m denotes the mass of the composite muon (or the electron), $m_{\mathcal{P}}$ the constituent mass of the preon and $M_0 \equiv 1/r_0 > 10$ TeV. We regard the bare as well as the constituent mass of the preons to be rather light $\ll M_0$. Thus if $m_{\mathcal{P}} \approx 100$ GeV and $M_0 > 3 \times 10^5$ GeV, $\Delta(g-2)_\mu < 10^{-10}$. A similar remark applies to the P and T violations for quarks and leptons which would be severely damped by powers of $(1/M_0)$ in spite of large P and T violations for preons carrying electric and magnetic charges.

(5) We have not yet fully resolved the saturation problem except to note that magnetic neutrality [‡12] of the composites amounting to maximum attraction among the constituents must play an important role in this regard.

What can be the possible origin of magnetic charges of preons? The origin could perhaps be topological [11,12]. Spontaneous breaking of the nonabelian preonic local symmetry G_p to lower symmetries may generate monopoles or dyons. Such a picture would be attractive if in particular it could generate spin-1/2 monopoles (in addition to spin-0 and spin-1) and assign electric and magnetic forces to the originally introduced spin-1/2 fields as well as to their topological counterparts. In this case half or at least some of the preons may be topological.

There is a second alternative, which is the simplest of all in respect of its gauge structure. Assume that the basic lagrangian of the preons is generated simply by the abelian symmetry $U(1)_e \times U(1)_m$. The $U(1)_e$ generates "electric" and $U(1)_m$ the "magnetic" interactions of preons. Subject to subsidiary conditions, the theory generates only one photon coupled to electric as well as magnetic charges [‡13]. The charges are constrained by the Dirac quantisation condition. The preons are assigned electric and magnetic charges subject to some guide lines such as magnetic neutrality of the quarks and leptons and their known electric charges [‡14]. *In this model the basic fields are only the spin-1/2 preons and the spin-1 photon.* The strong magnetic force binds preons to make spin-1/2 quarks and leptons (as discussed before) with inverse size $M_0 \equiv 1/r_0$ much greater than the masses of the quarks and leptons. Simultaneously it makes spin-1 and spin-0 composites of an even number of preons (including antipreons), which also have very small sizes like the quarks and leptons. The spin-0 and spin-1 fields carry charges and interact with quarks and leptons as well as among themselves. The use of a recently suggested "theorem" [14] would then suggest that their effective interactions at momenta $\ll M_0$ must be renormalizable [‡15] and therefore generated from a local symmetry with nonabelian Yang–Mills components, which is broken spontaneously. The spin-0 composites will now play the role of Higgs fields [‡16]. Such an effective interaction would be applicable at momenta $\ll M_0$. It is amusing that if this picture can be sustained, the apparent proliferated quark–lepton gauge structure $G_{(q,\ell)}$ with the associated spin-1/2, spin-1 as well as spin-0 quanta may have its origin in the simplest interaction of all: electromagnetism defined by the abelian symmetry [‡17]

‡11 I thank S. Brodsky and L. Susskind for discussions on this point.

‡12 As an illustration for the system of seven preons (u, d, r, y, b, ℓ, ζ), one possible magnetic charge assignment is $Q_m = g_m(+1, +1, +3, +3, +3, +3, -4)$. This makes the fcζ combinations magnetically neutral, but all other three-preon composites and also $\mathcal{P}\mathcal{P}\bar{\mathcal{P}}$ or $\mathcal{P}\bar{\mathcal{P}}\bar{\mathcal{P}}$ composites magnetically charged. The corresponding electric charge assignment (following ref. [1]) is $Q_e = |e|(+1/2, -1/2, 1/6, 1/6, 1/6, -1/2, 0)$. Other variants will be considered elsewhere.

‡13 The formalism may follow that of Zwanziger [13].

‡14 See for example remarks in footnote 12. We believe that eventually the freedom of charge assignments for the abelian symmetries will be restricted due to self-consistency of the starting abelian symmetry with the nonabelian effective quark–lepton symmetry, which it genetrates.

‡15 The renormalizability "theorem" [14] would also suggest that spin-3/2 and higher-spin composites should either not exist with masses lower than M_0 or should have effective interactions damped by powers of $(1/M_0)$.

‡16 It is conceivable that the expectation values of these magnetically bound spin-0 composites exhibit a hierarchy due to the magnetic attraction being different in different channels. In this picture the magnetically charged spin-1/2 composites can play the role of technifermions with magnetism serving as the technicolor force.

‡17 Note that the photon defined by $G_{\mathcal{P}}$ will have to be a part of the set of gauge fields of $G_{(q,1)}$ for consistency.

Footnote continued on next page

$G_{\mathcal{P}} = \mathrm{U}(1)_e \times \mathrm{U}(1)_m$.

To conclude, the idea of magnetic binding of preons and its origin needs to be further developed. What we have argued here is that within the unification context, electric binding of preons is inadequate and a magnetic-type binding [‡18] might be desirable.

I would like to thank Abdus Salam for enlightening discussions and encouragement. For helpful and critical comments I am most grateful to S. Mishra, R. Mohapatra, T. Pradhan, B. Sakita, J. Strathdee, J. Sucher, V. Teplitz and C.H. Woo. I have also benefited from discussions with S. Brodsky and L. Susskind on the question of compositeness. This work developed in the summer of 1979 during my stay at the Institute of Physics, Bhubaneswar, Orissa, India [‡19]. I am grateful to T. Pradhan and all members of the Institute for the warm hospitality offered to me during my stay. This research is supported in part by the National Science Foundation and in part by the John Simon Guggenheim Memorial Fellowship.

Footnote continued from preceding page

In such a picture there would be a natural reason why electric charge may be absolutely conserved and correspondingly why the photon may remain truly massless, despite spontaneous symmetry breaking. The reason is that the photon is now responsible for the very existence of the composite Higgs particles, which trigger spontaneous symmetry breaking.

‡18 Needless to say, one may of course replace magnetic binding by binding through any hidden abelian U(1) force generated by a presumably massless quantum A'. The requirements are that the preons carry this primary abelian charge, the associated force be superstrong at short distances $r_0 \ll 10^{-14}$ cm and that normal matter be neutral with respect to this primary abelian charge. Like magnetism this would provide the necessary binding of preons without requiring a proliferation.

‡19 Originally it was planned that this would appear as a joint paper with A. Salam, with the inclusion of more formal developments. See citation by Salam [15].

References

[1] J.C. Pati and A. Salam, Phys. Rev. D8 (1973) 1240; Phys. Rev. Lett. 31 (1973) 661; Phys. Rev. D10 (1974) 275; Phys. Lett. 58B (1975) 333.
[2] H. Georgi and S.L. Glashow, Phys. Rev. Lett. 32 (1974) 438.
[3] J.C. Pati and A. Salam, Phys. Rev. D10 (1974) 275; Proc. EPS Intern. Conf. on High energy physics (Palermo, 1975), ed. A. Zichichi, p. 171; J.C. Pati, A. Salam and J. Strathdee, Phys. Lett. 59B (1975) 265.
[4] K. Matumoto, Prog. Theor. Phys. 52 (1974) 1973; O.W. Greenberg, Phys. Rev. Lett. 35 (1975) 1120; H.J. Lipkin, Proc. EPS Conf. (Palermo, 1975), ed. A. Zichichi, p. 609; J.D. Bjorken, C.H. Woo and W. Krolikowski, all unpublished; E. Nowak, J. Sucher and C.H. Woo, Phys. Rev. D16 (1977) 2874; H. Terezawa, preprint, Univ. of Tokyo, INS-Rep-351 (September 1979); a list of other references may be found here.
[5] H. Harari, Phys. Lett. 86B (1979) 83; M.A. Shupe, Phys. Lett. 86B (1979) 87.
[6] H. Georgi, H. Quinn and S. Weinberg, Phys. Rev. Lett. 33 (1974) 451.
[7] See V. Elias, J.C. Pati and A. Salam, Phys. Rev. Lett. 40 (1978) 920.
[8] P.A.M. Dirac, Proc. R. Soc. London A133 (1931) 60; Phys. Rev. 74 (1948) 817.
[9] J. Schwinger, Phys. Rev. 144 (1966) 1087; D12 (1975) 3105; Science 165 (1969) 757; D. Zwanziger, Phys. Rev. 176 (1968) 1489; R.A. Brandt, F. Neri and D. Zwanziger, Phys. Rev. Lett. 40 (1978) 147.
[10] G. Feinberg and J. Sucher, Phys. Rev. D2 (1970) 2395; D20 (1979) 1717.
[11] G. 't Hooft, Nucl. Phys. B79 (1974) 276; A.M. Polyakov, JETP Lett. 20 (1974) 194.
[12] See M. Daniel, G. Lazarides and Q. Shafi, CERN preprint TH-2800; C. Montonen and D. Olive, Phys. Lett. 72B (1977) 117; P. Goddard, J. Nuyts and D. Olive, Nucl. Phys. B125 (1977) 1.
[13] D. Zwanziger, Phys. Rev. D3 (1971) 880.
[14] M. Veltman, G. 't Hooft, K. Wilson, G. Parisi and L. Susskind, all unpublished; J. Ellis, M.K. Gaillard, L. Maiani and B. Zumino, preprint Lapp, Annecy TH-15 and CERN TH-2841.
[15] A. Salam, Talk, in: Proc. EPS Conf. (Geneva, July 1979); Nobel Award talk (1979), ICTP, Trieste preprint IC/80/28 (ref. 73).