Ref.TH.3089-CERN

COMPOSITENESS AND A LEFT-RIGHT SYMMETRIC ELECTROWEAK MODEL WITHOUT BROKEN GAUGE INTERACTIONS

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ABSTRACT

We present a composite model of quarks and leptons satisfying 't Hooft's anomaly conditions, where the electroweak interactions are left-right symmetric and are not associated with broken local flavour symmetries. The scales of left- and right-handed weak interactions are associated with the scale Λ_H of hypercolour interactions responsible for preon binding. Understanding the small neutrino (ν_e) mass requires the existence of a Goldstone boson - the Majoron - related to spontaneous breaking of global lepton number. Universality of weak interactions implies $m_{\nu e} \approx$ $\approx 5 \div 25$ eV and a heavy Majorana lepton, $m_N \approx 10 \div 60$ GeV. The model predicts lifetimes for neutrinoless double β interactions ($\sim 10^{22\pm2}$ years) detectable in the next round of experiments and charged pseudo-Goldstone bosons with masses in the range $5 \div 50$ GeV.

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*) On sabbatical leave from City College of New York. Work supported by National Science Foundation and Alexander von Humboldt Foundation. Also at the University of Munich.

**) Present address. Work partially supported by the Swiss National Science Foundation.

Ref.TH-3089-CERN
19 May 1981

Obvious candidates for composite states, being necessarily hypercolour singlets, are:

$$F_\alpha^u \varphi_{ci}^\alpha \equiv u_i \quad , \quad F_\alpha^d \varphi_{ci}^\alpha \equiv d_i \tag{3}$$
$$F_\alpha^u \varphi_e^\alpha \equiv \nu \quad , \quad F_\alpha^d \varphi_e^\alpha \equiv e$$

With electromagnetism switched off, the basic Lagrangian has a global $SU(2)_L \times \times SU(2)_R \times U(1)_F$ symmetry acting on the fermions*), giving, a priori, the possibility of also explicitly gauging the weak group $SU(2)_L \times SU(2)_D$ [or $SU(2)_L \times \times U(1)$]. In this case, this same gauge group needs to be broken down to a vectorial subgroup [$U(1)_{em}$] at a scale essentially comparable to Λ_H; If the condensate responsible for this breaking has the right quantum numbers to couple to the fermion bilinears, nothing will prevent quarks and leptons from getting a mass of order Λ_H. On the other hand, if the condensate, or any polynomial of it, does not couple to fermion bilinears, the physical quarks and leptons will always remain massless.

We are thus led to consider the possibility that the weak group is not gauged at all. This will demand explaining the observed weak interactions as effective four-fermion residual interactions of the binding hypercolour dynamics. On the other hand, this point of view allows us to understand the light composite fermion spectrum as a consequence of some chiral subgroup of $SU(2)_L \times SU(2)_R$ remaining unbroken in the eventual condensation process. Making this assumption about the condensate, we note that the composites f's in (3) are precisely right to match the 't Hooft anomaly condition for the surviving chiral group, since the $SU(4)_H$ index $\alpha = 1,\ldots,4$ of the fundamental fermions is traded by the index, carried by the scalars, of a global $SU(4)$ [in the absence of $SU(3) \times U(1)$ interactions]**). A small mass can then be given to the fermions by having in the basic Lagrangian a gauge invariant mass term:

$$\delta\mathcal{L}_m = m_u \bar{F}_L^u F_R^u + m_d \bar{F}_L^d F_R^d + h.c. \tag{4}$$

with the parameters m_u and m_d explicitly controlling the breaking of the relevant chiral symmetry.

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*) The over-all axial $U(1)$ is broken by hypercolour anomalies.

**) This argument can clearly be extended to include three generations of fermions by increasing the number of scalars to 12 and the hypercolour group to $SU(12)$, with $F \subset \{12\}$ and $\varphi \subset \{\overline{12}\}$. Whether this extension is phenomenologically viable remains to be seen.

3. Before discussing the phenomenological consequences of the model, we have to make an assumption as to the way the hypercolour force breaks its global symmetry group through a condensation process. Striking differences may appear relative to QCD due to the difference in N [from $SU(3)_c$ to $SU(4)_H$] and to the presence of fundamental stongly interacting scalars. We will indeed assume that such is the case, e.g., that our condensate will break parity.

With only hypercolour forces switched on, the theory has a group of global symmetry:

$$\mathcal{G}_g \equiv SU(4)_\varphi \times U(1)_\varphi \times SU(2)_L \times SU(2)_R \times U(1)_F \tag{5}$$

with an obvious meaning of the symbols, C and P being also exactly conserved. In the presence of the strong and electromagnetic couplings, and with the mass term $\delta\mathcal{L}_m$, this symmetry is reduced to:

$$U(1)_F \times U(1)_{\varphi_c} \times U(1)_{\varphi_\ell} \tag{6}$$

Renormalizability and gauge invariance actually allow the introduction of <u>only</u> one extra term in the Lagrangian of the form

$$\lambda \; \varepsilon_{\alpha\beta\gamma\delta} \, \varepsilon^{ijk} \, \varphi^\alpha_{ci} \, \varphi^\beta_{cj} \, \varphi^\gamma_{ck} \, \varphi^\delta_\ell$$

thus reducing (6) down to $U(1)_F \times U(1)_{\varphi_c - 3\varphi_\ell}$.

In any case, however, at the level of the composites (3), the $U(1)$ global symmetries are effectively the baryon and lepton number conservations, since in (6) the linear combination $U(1)_{F-\varphi_c-\varphi_\ell}$ does not act on any of the composite fields.

Amongst other things, the dynamical breaking of the group $\mathcal{G}_g$ will especially have to explain:

i) the correct phenomenological structure of the weak interactions as the manifestation of an effective low energy Hamiltonian between fermion composites;
ii) the smallness of the neutrino mass, which would normally acquire a Dirac mass of the same order (m_i) of the charged fermions.

We assume that dynamical symmetry breaking takes place as a two step process such that:

i) <u>only</u> violation of parity occurs first at the scale Λ_H, for example through the formation of quadrilinear fermion condensates

$$\sigma_L \equiv (\bar{F}_{L\alpha}\gamma_\mu \mathbb{1} F_{L\alpha})(\bar{F}_{L\beta}\gamma_\mu \mathbb{1} F_{L\beta})$$
$$\sigma_R \equiv (\bar{F}_{R\alpha}\gamma_\mu \mathbb{1} F_{R\alpha})(\bar{F}_{R\beta}\gamma_\mu \mathbb{1} F_{R\beta}) \tag{7}$$

appropriate for the purpose of introducing the left-right asymmetry in the effective weak interactions, if we take $\langle\sigma_R\rangle \neq 0$ and $\langle\sigma_L\rangle = 0$;

ii) at a mass scale M somewhat lower than Λ_H, one also has, as an eventual result of the residual forces between the composite quarks and leptons f's:

$$\langle \nu_R^T C^{-1} \nu_R \rangle \simeq M^3 \tag{8}$$

giving a Majorana mass to the right-handed neutrino, $m_{\nu R} \simeq M^3/\Lambda^2$, and lowering $m_{\nu L}$ by the standard procedure[8] (see below).

Using the following notation for the composites (for both helicity states):

$$f_\alpha^a : \begin{cases} f_i^1 = u_i \quad , \quad f_i^2 = d_i \quad (i=1,2,3) \\ f_4^1 = \nu \quad , \quad f_4^2 = e \end{cases} \tag{9}$$

point ii) amounts to the statement that the effective potential, symmetric under $\mathcal{G}_g$, in $\Delta_{R\alpha\beta}^{ab} \equiv f_{R\alpha}^a C^{-1} f_{R\beta}^b$ gives rise to the vacuum expectation value (v.e.v.) $\langle\Delta_{R44}^{11}\rangle \simeq M^3$. This v.e.v. indeed characterizes a possible critical orbit of the over-all group $\mathcal{G}_g$, which is in this way broken down to:

$$\mathcal{G}_g' \equiv SU(3)_c \times SU(2)_L \times U(1)_{(F-2T_{3R})} \times U(1)_{\varphi_c} \times U(1)_{(F-\varphi_e)} \tag{10}$$

The chiral factor $SU(2)_L$ is enough to guarantee the masslessness of the fermion composites at this stage. As for the real global group with all other interactions and mass terms switched on, one has the breaking:

$$U(1)_F \times U(1)_{\varphi_c} \times U(1)_{\varphi_e} \rightarrow U(1)_{F-\varphi_e} \times U(1)_{\varphi_c} \tag{11}$$

Unlike the condensation of σ_R which does not break any of the global symmetries of the model, the neutrino condensate gives rise to one exactly massless Goldstone boson and to eight pseudo-Goldstone bosons. It is clear from (8) that the true Goldstone boson corresponds to the breakdown of lepton number and can be identified with the Majoron recently discussed[6]. Although the Majoron gives rise to long range forces, it is known to be consistent with existing data. It may, in fact, be helpful in relaxing the constraints on neutrino masses implied by cosmological considerations.

As far as the pseudo-Goldstone bosons are concerned, they are of two types, as one readily sees by comparing the full group $\mathcal{G}_g$ in (5) with the one in (6):

i) the ones which are colour triplets $(\Delta_{i4} \oplus \Delta^*_{i4})$ and acquire masses $m^2(\Delta_{i4}) \simeq \simeq \alpha_s/\pi\ \Lambda_H^2$;

ii) the electrically charged colour singlets $\Delta^{\pm}_{44}$ whose masses are expected to be of order $m^2(\Delta^{\pm}_{44}) \simeq \alpha/\pi\ \Lambda_H^2$.

If we take $\Lambda_H \simeq 100 \div 500$ GeV, we get*):

$$m(\Delta_{i4}) \sim 10 \div 50\ \text{GeV} \quad , \quad m(\Delta^{\pm}_{44}) \simeq 5 \div 25\ \text{GeV}$$

4. The following essential question must now be faced: is the low energy residual interaction between the fermion composites in this model consistent with the observed pattern of weak interactions? To discuss this problem, we first ignore the effects of the neutrino condensate (for example, having $M < \Lambda_H/2$, as we shall see). The full $\mathcal{G}_g$ is thus operative with only left-right symmetry being broken by $\langle\sigma_R\rangle$. Strong, electromagnetic interactions and mass terms are also neglected.

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*) We defer a discussion of their detailed experimental signature to a future publication.

At energies well below Λ_H, four-Fermi interactions between the composite fermions are induced by the hypercolour SU(4) force. In the approximation where $\mathcal{G}_g$ is exact, the most general four-Fermi effective Hamiltonian consistent with $\mathcal{G}_g$ can be cast into the form:

$$
\begin{aligned}
\mathcal{H}^{(4-F)} = \frac{1}{\Lambda_H^2} \Big[& \xi_L^V \, \vec{J}_{\mu L} \vec{J}_{\mu L} + \xi_L^S \, J_{\mu L} J_{\mu L} + \\
& + \xi_R^V \, \vec{J}_{\mu R} \vec{J}_{\mu R} + \xi_R^S \, J_{\mu R} J_{\mu R} + \\
& \xi_{LR} \, J_{\mu L} J_{\mu R} + \xi'_{LR} \left(\vec{J} \cdot \vec{J}^{+} + J J^{+} \right) \Big]
\end{aligned}
\tag{12}
$$

where

$$
\left(\vec{J}_{\mu L} , J_{\mu L} \right) = \sum_{\alpha} \bar{f}_{L\alpha} \gamma_\mu \left(\vec{\tau}, \mathbb{1} \right) f_{L\alpha} \quad , \; L \to R
$$

$$
\left(\vec{J} , J \right) = \sum_{\alpha} \bar{f}_{L\alpha} \left(\vec{\tau}, \mathbb{1} \right) f_{R\alpha}
$$

Here full use has been made of the Fierz re-arrangement.

Before spontaneous breakdown of left-right symmetry, it is:

$$
\xi_L^V = \xi_R^V \qquad , \; \xi_L^S = \xi_R^S
$$

and, furthermore, all ξ's are expected to be of order unity. After breakdown, ($\langle \sigma_R \rangle \neq 0$), these relationships are no longer valid. All ξ's acquire a dependence on $\langle \sigma_R \rangle / \Lambda_H^6$ as the effect of an infinite number of effective interactions of arbitrary dimension collapsing into the form (12) when $\langle \sigma_R \rangle \neq 0$. We identify

$$\left.\frac{\xi^{v}_{L}}{\Lambda_H^2}\right|_{\langle\sigma_R\rangle\neq 0}$$

with $4G_F/\sqrt{2}$ to get the correct strength for charged weak interactions. The ξ's other than ξ^v_L will have to be relatively small to describe the standard phenomenology. Being unable to make specific calculations, we can, for example, make the guess that the various corresponding mass scales $(\Lambda_H/\sqrt{\xi})|_{\langle\sigma_R\rangle} \neq 0$ are within an order of magnitude. As to the value of Λ_H itself, depending on the value of ξ^v_L after parity breaking, it can perhaps be in the range $100 \div 500$ GeV.

An analysis of the available neutral and charged current data shows that these same data are consistent with Eq. (12) if all the ξ's are at the 10% level relative to ξ^v_L *). (For some of the ξ's, such as ξ_{LR}, the limits are even weaker.) These values are certainly consistent with our presumption that all effective mass scales are within an order of magnitude relative to Λ_H. In turn, this implies significant deviations from the prediction of the standard model in low energy neutral and charged current weak interactions, testable in the next round of experiments. Finally, we would like to point out that to accommodate the neutrino neutral current data in theories with global weak isospin, one must add a piece to the neutral current arising out of the neutrino charge radius[11]. We also adopt this point of view and emphasize that in subcomponent models for the neutrino mass there is no reason for this contribution to be small.

So far in this section, we have ignored the effects of the neutrino condensate. In its presence, Eq. (12) is modified to the extent that the full symmetry $\mathcal{G}_g$ is broken down to $\mathcal{G}'_g$. In particular, this introduces quark-lepton asymmetry and, therefore, violation of universality. Explicitly, the source of such a breakdown can be traced to the existence of induced non-renormalizable $\mathcal{G}_g$ invariant terms of the following type:

$$\mathcal{L}_{eff} = \frac{1}{\Lambda_H^8}\left(f^{a^T}_{R\alpha} C^{-1} f^{b}_{R\beta}\right)\left(f^{a^T}_{R\gamma} C^{-1} f^{b}_{R\delta}\right)^{*}\left(\bar{f}_{L\alpha}\gamma_\mu\vec{\tau} f_{L\gamma}\right)\left(\bar{f}_{L\beta}\gamma_\mu\vec{\tau} f_{L\delta}\right) \tag{13}$$

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*) We have used the analysis of Langacker et al.[9] for neutral current data and the analysis in the book by Marshak et al.[10] for charged current data.

For the purposes that we are going to discuss, this term is dominant, being one of minimal dimensionality. From Eq. (13), $\mathcal{L}_{eff}$ leads to corrections to the four-Fermi leptonic weak Hamiltonian of the form:

$$\mathcal{L}^{(4\text{-}F)}_{lept} \simeq \frac{1}{\Lambda_H^2}\left(\frac{M}{\Lambda_H}\right)^6 (\bar{f}_{L4}\gamma_\mu \vec{\tau} f_{L4})(\bar{f}_{L4}\gamma_\mu \vec{\tau} f_{L4}) \tag{14}$$

Thus, departure from universality between β decay and μ decay is of order $(M/\Lambda_H)^6$. Since experimentally such departures are supposed to be $\lesssim 0.8\%$, we expect:

$$M/\Lambda_H \lesssim 0.45 \tag{15}$$

We see that universality constrains the value of M and will therefore lead to limits on $m_{\nu e}$ and m_N. We get:

$$m_N \simeq \frac{M^3}{\Lambda_H^2} \lesssim 10 \div 60 \text{ GeV} \tag{16}$$

and

$$m_{\nu_e} \simeq \frac{m_e^2}{m_N} \gtrsim 5 \div 25 \text{ eV} \tag{17}$$

These numbers are phenomenologically quite interesting, since they also predict lifetimes for neutrinoless double β transitions close to the present lower limit. To make these bounds more precise, one needs knowledge of some coupling parameters which are dictated by hypercolour dynamics. However, if we accept the above numbers in (16) and (17), we can estimate the contribution to $(\beta\beta)_{0\nu}$ transition amplitudes. For example, the right-handed heavy Majorana lepton N would contribute an effective η parameter[12)] to $0^+ \to 2^+$ transitions, such as in $Ge^{76} \to Se^{76}$:

$$\eta \simeq \left(\frac{\xi_R^V}{\xi_L^V}\right)^2\Bigg|_{\langle\sigma_R\rangle\neq 0} \cdot \frac{1}{m_N} \cdot f_{NN} \cdot p_{N^*}^{1/2}\,(1600 \text{ GeV}) \tag{18}$$

where P_{N^*} is the probability for N^* excitation in a nucleus and f_{NN} is the probability of overlap between nucleon wave functions. Taking reasonable values for P_{N^*} and f_{NN} ($P_{N^*} \simeq 10^{-2}$, $f_{NN} \simeq 10^{-2}$), and, for example, $\xi_R^v/\xi_L^v \simeq 1/30$, we obtain

$$\eta \simeq 2\cdot 10^{-4} \div 3\cdot 10^{-5} \tag{19}$$

This would lead to:

$$T_{1/2}^{(\beta\beta)_{0\nu}} \simeq \frac{1.1 \cdot 10^{14\pm 2}}{\eta^2}\ \text{years} \simeq \frac{1}{4}\left(10^{22\pm 2} \div 10^{23\pm 2}\right)\text{years} \tag{20}$$

Thus, the next round of experiments on $(\beta\beta)_{0\nu}$ decay could throw light on the validity of our model.

5. To summarize, we have presented a composite model of light fermions, left-right symmetric to start with, where the scale of weak interactions is related to the scale Λ_H of a new strong interaction responsible for the binding of quarks and leptons. No breakdown of any local symmetry is contemplated. Our investigation into a possible dynamics for the model has led to several phenomenologically interesting consequences, even at low energy relative to Λ_H. These features make the model amenable to experimental verifications. We have also indicated a possible way of extending the model to include families. Other possibilities are envisageable. This is currently under investigation.

ACKNOWLEDGMENTS

Two of the authors, (R.N.M. and A.M.), would like to thank Professor R. Gatto and Professor H. Ruegg for their hospitality at the University of Geneva where the work was started, and the Swiss National Foundation for support.

1. The simplest composite model[1)] of quarks and leptons (f's) one can think of is the one in which the f's are made from a fundamental fermion F and a fundamental scalar φ with some splitting of the standard interactions carried by F and φ [2)]. An interesting question in such models is the origin and nature of the weak interactions of the composite fermions (f's). There are a priori two alternatives:

i) the observed weak interactions of composites are the broken gauge interactions carried by the fundamental preons; or

ii) they are associated with the global symmetry $\mathcal{G}_g$ of the theory.

Along the second line of thinking, two kinds of possibilities have been suggested. The first one is where, due to some as yet unknown mechanism (which, however, has to circumvent a no-go theorem[3)]), the global symmetry turns into a local symmetry and is subsequently broken dynamically. The second possibility, recently discussed by Abbott and Farhi[4)], is to consider the induced four-fermion interactions between composites, respecting the global symmetry $\mathcal{G}_g$, and describe with them the observed weak interactions of the f's. The scale of weak interactions, $G_F^{-1/2}$, is then essentially associated with the scale Λ_H, where the fundamental binding interaction operating on the preons becomes strong.

The model of Abbott and Farhi[4)] is intrinsically left-right asymmetric, with only left-handed quarks and leptons being composites of a scalar carrying global $SU(2)_W$ quantum numbers and of a fermion possessing local $SU(3)_c \otimes U(1)_{em}$ interactions. One may think, however, that a situation in which for instance the right-handed electron is elementary while the left-handed part is composite, is unsatisfactory. In this paper, we consider a model where both left- and right-handed f's are composites in a manner that maintains the quark-lepton symmetry of weak interactions. In this framework, the fundamental field F feels the weak interactions and the scalar φ possesses strong and electromagnetic interactions as, for example, suggested by Greenberg and Sucher[5)].

Since weak interaction quantum numbers are now carried by spinor fields, it is more difficult, if not impossible, to think of a model which is sound at the basic level (i.e., no Adler-Bell-Jackiw anomaly of the fundamental binding interactions) and which has, at the same time, an intrinsic left-right asymmetry of the weak interactions of f's. The model that we shall consider actually leads to completely left-right symmetric weak interactions to start with. Is it then possible to conjecture some dynamical mechanisms which make the model consistent with present phenomenology? We shall address this question, concentrating on two basic facts:

i) the (almost) masslessness of the composite fermions relative to the intrinsic scale of the fundamental binding interaction ($\Lambda_H \simeq 100 \div 500$ GeV);

ii) the unlikelihood of the dynamical generation of mass scales differing from Λ_H itself by orders of magnitude.

In the context of the model, these points lead to several interesting physical consequences which should be testable in the near future in low energy experiments. To list a few of them, we expect the ν_e mass to be in the electron volt range ($m_{\nu e} \simeq 5 \div 25$ eV) and the existence of a heavy, neutral right-handed lepton N with $m_N \simeq 10 \div 60$ GeV, which leads to neutrinoless double β transition lifetimes $\approx 10^{22\pm2}$ years. We also expect deviations from the predictions of the standard model in low energy neutral and charged current weak interactions, testable in the next round of experiments. Another consequence of the model is the existence of several pseudo-Goldstone bosons with masses in the range of 5 - - 50 GeV and a massless true Goldstone boson, associated with spontaneously broken lepton number[6]. Needless to say that in the energy range of 100 to 500 GeV, all sorts of striking effects due to the existence of a new strong interaction will have to show up.

2. The basic Lagrangian of the model is locally invariant under $\mathcal{G} \equiv SU(4)_H \times$ $\times\, SU(3)_c \times U(1)_{em}$, where $SU(4)_H$ is the hypercolour responsible for the binding of the fundamental fields to give quarks and leptons, and $SU(3)_c \times U(1)_{em}$ are the standard unbroken gauge interactions. The preons consist of two fermions*):

$$F_\alpha^u \equiv (4,1,1/2) \qquad \alpha = 1,\dots,4$$
$$F_\alpha^d \equiv (4,1,-1/2) \tag{1}$$

(both helicity states) and two scalars:

$$\varphi_{ci}^\alpha \equiv (\bar{4},3,1/6) \qquad \alpha = 1,\dots,4 \tag{2}$$
$$\varphi_e^\alpha \equiv (\bar{4},1,-1/2) \qquad i = 1,2,3$$

transforming under $\mathcal{G}$ as indicated.

*) For a model with F_α's and φ^α_{ci} only, see Ref. 7). The flavour group in that model, however, is a gauge group.

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