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Flipped version of the supersymmetric strongly coupled preon model

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In the supersymmetric SU(5) [SUSY SU(5)] composite model (which was described in an earlier paper) the fermion mass terms can be easily constructed. The SUSY SU(5)⊗U(1), i.e., flipped, composite model possesses a completely analogous composite-particle spectrum. However, in that model one cannot construct a renormalizable superpotential which would generate fermion mass terms. This contrasts with the standard noncomposite grand unified theories (GUT's) in which both the Georgi-Glashow electrical charge embedding and its flipped counterpart lead to the renormalizable theories.

I. INTRODUCTION

The strongly coupled supersymmetric (SUSY) SU(5) preon model,[1] which we have studied previously, was in its physical content somehow parallel to the standard SU(5) grand unified theory[2] (GUT). The electroweak sector of this model contains the Abbott and Farhi $SU(2)_L \otimes U(1)_Y$ theory.[3] Recently,[4] it has been argued that the Abbott and Farhi model can be interpreted as an alternative guise of the standard electroweak model. It has also been shown[5] that the contribution of compositeness, described by the model,[3] to $(g-2)$ of the muon is small and within experimental limits. At present, the experimental tests of compositeness[6,7] are still being discussed.

Here we aim to complete our investigation of the SUSY SU(5) preon model by consideration of the flipped strongly coupled SUSY SU(5)⊗U(1) preon model. This research was partly inspired by recent investigations of the superstring-derived GUT models,[8] which have led to the revival of the flipped SU(5)⊗U(1) GUT theory.[9] This theory was originally proposed as the alternative to Georgi-Glashow[2] unification. In the context of the ordinary GUT theories there was no reason to suppose that flipped unification could have any superiority over other unification schemes. Only recently certain features of the flipped unification have been found to be advantageous. (For further information see Ref. 10.)

In the preon framework the SUSY SU(5) and the flipped SUSY SU(5)⊗U(1) models show some remarkable qualitative differences. In the SU(5) version one can construct a relatively simple superpotential[1,11] which easily and naturally generates fermion masses. The flipped SU(5)⊗U(1) version runs into great difficulties with superpotentials. It appears that one cannot construct a superpotential giving a renormalizable theory. This contrasts with the usual GUT theories[2,8,9] in which one can construct superpotentials in both versions.

The phenomenology of the flipped preon model is discussed in the second section of this paper. One can account for the quark and the lepton spectrum and for the electroweak interactions as well as it was possible in the model studied by Ref. 1.

The building of the preon model superpotentials, which is the most interesting part of this paper, is described in the third section.

II. GENERAL FEATURES

In the flipped model the world at low energies is described by the direct-product gauge group

$$G_{PF} = SU(2)_{HC} \otimes SU(3)_C \otimes U(1)_x \otimes U(1)_z \ , \quad G_{PF} \subset SU(5)' \otimes U(1)_x \ . \tag{2.1}$$

Three diagonal operators suffice to describe the difference between preon[1] and quark[2,8,9] realizations of the G_{PF} symmetries. Their five-dimensional representations are

$$\begin{aligned} I_3(5) &= \mathrm{diag}(\tfrac{1}{2}, -\tfrac{1}{2}, 0, 0, 0) \ , \\ Z(5) &= \mathrm{diag}(\tfrac{1}{2}, \tfrac{1}{2}, -\tfrac{1}{3}, -\tfrac{1}{3}, -\tfrac{1}{3},) \ , \\ X(5) &= \mathrm{diag}(3,3,3,3,3) \ . \end{aligned} \tag{2.2}$$

The charge matrix in our preon model cannot (and does not) contain the operator $I_3(5)$. In the preon model the $SU(2)_{HC}$-doublet states β must have equal charges. In the SU(5) (i.e., G_P) version of the model[1] this means[12]

$$Q(5) = Z(5) \ , \quad \overline{5} = \beta(2,1,-\tfrac{1}{2}) + d_L^c(1,\overline{3},\tfrac{1}{3}) \ . \tag{2.3}$$

The G_{PF} version is defined by

$$Q(5) = -\tfrac{1}{5}Z(5) + \tfrac{1}{5}X(5) = \mathrm{diag}(\tfrac{1}{2}, \tfrac{1}{2}, \tfrac{2}{3}, \tfrac{2}{3}, \tfrac{3}{3}) \ , \quad \overline{5} = \beta(2,1,-\tfrac{1}{2}) + u_L^c(1,\overline{3},-\tfrac{2}{3}) \ . \tag{2.4}$$

One also finds

$$\begin{aligned}
&Z(10)=\mathrm{diag}(\tfrac{1}{6},\tfrac{1}{6},\tfrac{1}{6},\tfrac{1}{6},\tfrac{1}{6},\tfrac{1}{6},-\tfrac{2}{3},-\tfrac{2}{3},-\tfrac{2}{3},1)\,,\\
&Z(1)=0\,,\\
&X(10)=\mathrm{diag}(1,1,1,1,1,1,1,1,1,1,)\,,\\
&X(1)=5\,,\\
&\mathbf{10}=\alpha(2,3,\tfrac{1}{6})+d_L^c(1,\overline{3},\tfrac{1}{3})+\nu_L^c(1,1,0)\,,\\
&\mathbf{1}=e_L^c(1,1,1)\,.
\end{aligned}\tag{2.5}$$

There is no arbitrariness in the choice of the diagonal $X(r)$ ($r=10,5,1$) matrices. As shown in Ref. 9 there are no triangular anomalies for a group $SU(N)\otimes U(1)$ if the diagonal elements of the X operator are given by

$$X(r)_{\alpha\alpha}=N-2b(r)\,. \tag{2.6}$$

This corresponds to an antisymmetric fermion representation which can be depicted by b Young boxes. (In the tensor language this means b antisymmetric indices.)

The operators Z and X [(2.2) and (2.5)] which satisfy (2.6) belong to the generators of an SO(10) group.[9] Thus our preon representations belong to the 16-dimensional representation of SO(10) which can be decomposed as

$$\begin{aligned}
&SO(10)\subset SU(5)'\otimes U(1)\,,\\
&\mathbf{16}=(10,1)+(\overline{5},-3)+(1,5)\,.
\end{aligned}\tag{2.7}$$

When the electric charge is given by (2.5) the electromagnetic coupling constant is

$$\frac{1}{\alpha_E(q)}=\frac{1}{25\alpha'_Z(q)}+\frac{1}{25\alpha'_X(q)}\,. \tag{2.8}$$

Including all 16 states (2.7) one finds the normalization

$$\begin{aligned}
&C_X^2\mathrm{Tr}X^2=2,\quad C_X^2=\tfrac{1}{40}\,,\\
&C_Z^2\mathrm{Tr}Z^2=2,\quad C_Z^2=\tfrac{3}{5}\,.
\end{aligned}\tag{2.9}$$

This gives the renormalization-group equation for the electromagnetic coupling ($b_E=-\mathrm{Tr}Q^2$):

$$\frac{1}{\alpha_E(q)}=\frac{1}{15\alpha'_Z(M)}+\frac{8}{5\alpha'_X(M)}-\frac{b_E}{2\pi}\ln\left[\frac{M}{q}\right]\,. \tag{2.10}$$

At the unification scale M, valid for the SU(5) subgroup, one has

$$\alpha'_Z(M)=\alpha_5(M)\,. \tag{2.11}$$

However, the operator X belongs to the U(1) subgroup, which is not necessarily unified at the same scale. By supposing, or imposing, the same scale, i.e.,

$$\alpha'_X(M)=\alpha_5(M)\,, \tag{2.12}$$

Eq. (2.10) goes into Eq. (1.15) of Ref. 1. The factors b_E, b_H, and b_C, which appear in the one-loop evolution equations, have the same values as the ones given in Ref. 1. The unification scale M is determined by Eq. (1.11) of Ref. 1. In the flipped version of the model, there are no problems with the magnitude of the electromagnetic coupling constant. With $\alpha'_X(M)\neq\alpha_5(M)$ one obtains, for example, the values[19]

$$\begin{aligned}
&M=2.7\times10^9\ \mathrm{GeV},\quad 1/\alpha_5(M)=4.82\,,\\
&b_E=-\tfrac{143}{6},\quad 1/\alpha_E(M)=127\,,
\end{aligned}\tag{2.13}$$

or

$$\begin{aligned}
&M=4.4\times10^{14}\ \mathrm{GeV},\quad 1/\alpha_5(M)=21.06\,,\\
&b_E=-\tfrac{163}{6}\,,\\
&\alpha'_X(M)=0.45,\quad 1/\alpha_E(M)=128\,.
\end{aligned}\tag{2.14}$$

As the charge and $SU(3)_C$ classification of the α and β preons do not change in the G_{PF} version of the model, the conclusions about left-handed fermions, intermediate vector bosons, and Kobayashi-Maskawa angles are the same as published previously.[1] It does not seem worthwhile to repeat the discussion about composites, since there are only superficial differences with the old[1] results.

III. FERMION MASSES

In the SUSY SU(5) preon model[1] the masses are generated in an essentially different way from the one employed in the ordinary GUT's. Those contain Higgs pentaplets which break electroweak group and give masses to quarks and leptons. In the SU(5) composite model,[1] where $SU(2)_{HC}\otimes SU(3)_C\otimes U(1)_Q$ is not broken, the masses can be generated through the superpotential analogous to the one used by Ref. 11.

The essential part of that superpotential has the SU(5) structure

$$W=\lambda_U\mathbf{10}\otimes\mathbf{10}\otimes\mathbf{5}+\lambda_D\mathbf{10}\otimes\overline{\mathbf{5}}\otimes\overline{\mathbf{5}}\,. \tag{3.1}$$

Here **10**, **5**, and $\overline{\mathbf{5}}$ are the preon superfields (2.3) [see also formula (1.5) in Ref. 1]. Written explicitly, the expression (3.1) contains terms which directly generates fermion masses, such as

$$\begin{aligned}
W&\in\lambda_U(\alpha\overline{\beta})u^c+\lambda_D(\alpha\beta)d^c+\lambda_D(\beta\beta)e^c\\
&=\lambda_U\Lambda_{HC}\overline{u}_Ru_L+\cdots\,.
\end{aligned}\tag{3.2}$$

Here Λ_{HC} is the hypercolor scale. No neutrino mass is generated.[1]

The mass generating superpotential for the model based on $SU(5)\otimes U(1)$ symmetry cannot be constructed in an analogous fashion. The preon superfields for the flipped model can be obtained from the SUSY SU(5) superfields by the exchange $u^c\leftrightarrow d^c$ and $e^c\leftrightarrow\nu^c$. Such an exchange turns (3.2) into an expression which does not conserve the electric charge.

In order to create "mass" terms, such as $(\alpha\overline{\beta})u^c$, $(\alpha\beta)d^c$, etc., one has to consider the combinations

$$\begin{aligned}
&\lambda_U(10,1)\otimes(5,3)\otimes(\overline{5},-3)\propto(u,\nu)\,,\\
&\lambda_D(10,1)\otimes(10,1)\otimes(\overline{5},-3)\propto(d)\,,\\
&\lambda_E(\overline{5},-3)\otimes(\overline{5},-3)\otimes(1,5)\propto(e)\,.
\end{aligned}\tag{3.3}$$

The notation here shows the SU(5) representation and the X operator values (2.2) and (2.5). The quark and lepton content is also indicated. The combinations (3.3) are neither SU(5) nor U(1) singlets. Furthermore the coupling multiplied by λ_U is not even supersymmetric. It is not a holomorphic function of superfields.

Using the SO(10) representations one can see that this problem originates from the fact that the product of three **16** preon (i.e., matter) superfields [16⊗16⊗16] [which in the flipped model correspond to the superpotential (3.1)], does not contain a singlet. Thus, one has to go to the nonrenormalizable quartic couplings

$$[16\otimes 16\otimes 16]_{\text{matter}}\otimes[16]_H \ , \qquad [16]_H=(10,1)+(5,3)+(1,5) \ . \tag{3.4}$$

The vacuum expectation value (VEV) of the singlet in $\mathbf{10}_H$ can generate mass terms for d and e composites.[14] At the SU(5)⊗U(1) level one can say that by adding Higgs decuplets $(10,1)_H$ to the last two terms one can generate SU(5)⊗U(1) scalars:

$$\lambda_D(10,1)\otimes(\bar{5},-3)\otimes(10,1)\otimes(10,1)_H \ , \qquad \lambda_E(\bar{5},-3)\otimes(\bar{5},-3)\otimes(1,5)\otimes(10,1)_H \ . \tag{3.5}$$

As the theory including such superpotential is no longer renormalizable, one can assume that this is an effective theory which was obtained by integrating out some more fundamental physics. This would agree nicely with the appearance of elementary right-handed fields u_R, d_R, ν_R, etc., in our multiplets which could be understood as effective fields describing some more fundamental composites.

The potential mass terms now contain Higgs-singlet fields S from $(10,1)_H$:

$$m_d \propto \tilde{\lambda}_d(\alpha\beta)d^c\langle S\rangle, \quad m_e \propto \tilde{\lambda}_e(\beta\beta)e^c\langle S\rangle \ . \tag{3.6}$$

Note that in this scheme there are no mass terms for u quark and neutrino. While the second feature might be admirable, it would be preposterous to claim that the first feature explains the experimental relation $m_d > m_u$. The coupling $\tilde{\lambda}$ must have the dimension characterized by some mass M associated with the more fundamental level of the theory: i.e.,

$$\tilde{\lambda}_A=\lambda_A M^{-1}, \quad m_A=\lambda_A M^{-1}\Lambda_H\langle S\rangle \ . \tag{3.7}$$

These details ought to provide sufficient illustration of the fundamental differences between SU(5) and SU(5)⊗U(1) based models. The SU(5)-based model does not require any Higgs fields for the generation of masses. The assorted higher supermultiplets (**75**, $\overline{\mathbf{50}}$, **24**, $\mathbf{10}_K$, $\overline{\mathbf{10}}_K$, etc.)[11] were needed to provide mass splitting within the pentaplets and decuplets. In the flipped SUSY SU(5)⊗U(1) model the mass generating superpotential requires additional Higgs decuplets and leads to the nonrenormalizable theory.

It would be quite pointless to use further effort in describing fine-tuning indicated by (3.7) or by designing some mechanism which could produce u or ν masses.

IV. DISCUSSION

The preon SU(5) leads to the phenomenology which is quite close[1,3–5] to the standard GUT SU(5) theory. From the preonic point of view, the standard GUT emerges as an effective theory. The fundamental differences in the underlying dynamics are reflected in the generation of the fermion masses. Formally, they are connected with the charge matrices[12] and with the interchanges which transform normal multiplets into flipped ones. Because of these symmetry properties, one runs into trouble with the mass-generating superpotentials in the flipped version of the preon model.

It is worth remembering[1] that the unification procedure[13] is also a difficult point in the whole model. However the precise dynamics of the binding forces might be immaterial at the present stage while we are still groping in the dark. The symmetry properties of the constituents (i.e., preons) and of the resulting composites (i.e., quarks, leptons, etc.) seem to be more revealing now as they are connectable, at least partially, to the experimentally explored reality.

The study of the superpotential problem in the SUSY SU(5)⊗U(1) model leads inevitably to speculation about the right-handed states (i.e., u_R, d_R, e_R, etc.) being composite objects[1,11] at some subpreonic level corresponding to the physics which is averaged out at the preonic level. While it seems aesthetically pleasing that all fermion states (i.e., right-handed and left-handed) should be composite, it is still premature to speculate which model, SU(5) or SU(5)⊗U(1), has a better chance to be a useful theoretical tool.

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