Superstring phenomenology by preon models

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Abstract

We analyze supersymmetric preon models and compare their global symmetries with the heterotic $E_8 \times E_8$ superstring theory. We compare Pati's supergravity based preon model and our supersymmetric, topological preon model with symmetries of superstring theory. Based on symmetries and phenomenological results we conclude that the fundamental particles are preons rather than standard model particles, in concord with the heterotic superstring theory. Chern-Simons theory based preon models may provide useful tools for studying superstring theory and phenomenology.

Keywords: Topological field theory, Chern-Simons theory, Supersymmetry, Superstring theory

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Contents

1 Introduction

We analyze briefly in this note group structure of the heterotic $E_8 \times E_8$ superstring theory in D $= 10$, and compare its symmetry structure to the composite models of quarks and leptons introduced by Pati [1] and us [2, 3]. The former model proposes gauge interactions between preons, while we utilize topological concepts for preon interactions.

In spite of its immense experimental success the standard model (SM) has its problems: lack of gravity and supersymmetry (no sparticles found), it requires many arbitrary constants and parameters that are not derived from the theory itself, no single solution to matter-antimatter asymmetry, no dark sector, what is the origin of lower scales such as M_W, what is the origin of the number of generations, to mention some of them. Superstring theory has its well known problems and is diffficult to test experimentally in general. Superstring theory can solve in principle problems of the SM but a working phenomenology is missing.

Pati [1] and we [3] believe that the main cause of the difficulties listed above is the choice of the fundamental fields as quarks and leptons. The purpose of this note is to suggest that some of the problems of the standard model can be circumvented if we replace quarks and leptons by preonic fundamental particles. The quarks, the leptons and the Higgs particles (and perhaps some of the gauge particles) will have to be interpreted as preon composites. Curiously enough, as a bonus we obtain concordance between the preon models and superstring theory on global symmetry level.

The binding of preons by a non-abelian metacolor gauge force in the Pati model we replace by a topological Chern-Simons interaction for preons (here called chernons). This is because we want to have background independent model, and secondly, the preonic phase of matter occurs at very high energy scale where any regular spacetime has not yet formed [4]. In addition, baryon asymmetry and the "hiddenness" of supersymmetry can be explained [4].

This note is organized as follows. The section 2 is divided in three subsections. We first take a glimpse in heterotic $E_8 \times E_8$ superstring group theory. In subsection 2.2 we recap the Pati preon model. In the next subsection 2.3 we present a summary of the key features of our preon (called here chernon) model. The differences in the preon models considered here are pointed out but they do not influence the conclusions, which are given in section 3.

2 Superstrings and preon phenomenology

We begin with a concise recap of heterotic string theory $E_8 \times E_8$ in D = 10. This provides a yardstick for finding similar structures between superstrings and preons/chernons.

2.1 Superstring background

We start from the heterotic string theory $E_8 \times E_8$ in D = 10. It can be compactified to $M^4 \times K$ where M^4 is the four-dimensional Minkowski space and K a compact six-dimensional Calabi-Yau manifold with SU(3) holonomy [5]. This compactification leaves an unbroken N = 1 local supersymmetry at the Planck (or compactification) scale which may help resolve the gauge-hierarchy problem. Further, it breaks $E_8 \times E_8$ into $E_8 \times E_6$ if K is simply connected, and into a lower symmetry such as $E_8 \times SU(3) \times SU(2)_L \times [U(1)]^3$ or $E_8 \times SU(3) \times SU(2)_L \times [U(1)]^2$, if K is multiply connected. The topology of K determines the massless zero mode matter superfields in D = 4. These are in the form of several copies of 27's and $\overline{27}$'s of E_6 (even when it is broken). The number of generations is $N = n_{27} - n_{\overline{27}}$. This is given by half the Euler characteristic of K which is low enough if K is multiply connected. Models with 1, 2 and 4 generations are known [5]. Manifolds giving rise to three generations have been constructed in [6].

The anomaly-free $E_8 \times E_8$ superstring theory leads in D = 4 to chiral fermions (i.e. N > 0), which are in sets of 27 of E_6. These are just right to include the known quarks and leptons belonging to 16 of $SO(10) \in E_6$ plus some exotic fermions. The higher dimensional superstring theories can determine uniquely the number of families N, if one can solve the dynamics of compactification on the basis of the topology of K.

2.2 The Pati preon model

An economical preon-model which is based on N = 1 supergravity in D = 4 and which incorporates the two-scale idea is proposed in [7]. The model introduces just four left- plus four right-handed chiral superfields, each transforming as a fundamental or some fixed representation r of a non-abelian metacolor gauge symmetry G_M. The primordial preonic interactions are thus vectorial. The scale parameter Λ_M of G_M is determined to be rather high, $\sim 10^{12-16}$ GeV, from renormalization group equations. The familiar flavor ($W_{\mathrm{L,R}}$), color, and hypercolor gauge particles associated with an effective SU(4) gauge symmetry are interpreted as preonic composites of very small sizes $\sim 1/\Lambda_M$, bound by the primordial metacolor gauge force. Due to a two-fold replication, the model predicts four quark-lepton families (e, μ, τ and τ') - i.e. effectively eight flavors. Barring mixing the e and the μ families have very small sizes $\sim 1/\Lambda_M$, while the τ and the τ' families have large sizes $\sim 1/\Lambda_H \sim$1/TeV. The model possesses a novel mechanism for interfamily mass hierarchy.

Pati has shown that the precise field content of (four left + four right) - handed superfields of the model sketched above can be derived from the D = 10, $E_8 \times E_8$ superstring theory provided that the compactification to D = 4 leads to two copies of 27's of E_6 (i.e. $N = n_{27} - n_{\overline{27}}$) and that E_6 breaks at the compactification scale to a subgroup $G_0 = SU(4)_M \times \tilde{G}$ where $\tilde{G}$ is either $[U(1)]^3$ or $SU(2) \times [U(I)]^2$, or $[U(1)]^2$ or $SU(2) \times U(1)$. The symmetry $SU(4)_M$ is identified with the metacolour gauge symmetry which generates the preon binding force. The symmetry $\tilde{G}$, on the other hand, breaks completely at Λ_M, dynamically, due to preon condensates.

The further details of derivation of this preon model emerging from the $E_8 \times E_8$ superstring theory are given in [7].

2.3 The chernon model

The chernon model was developed originally from bottom up so that three chermons of certain charge (namely ±1/3) can produce the quark charges 2/3 and -1/3. Later we found that the model is resembles closely the supersymmetric Wess-Zumino model [8]. The next phase in developing the model was to make the model functioning with cosmology. To allow energy scale $\Lambda_{cr} \geq 10^{16}$ GeV for the model, T-duality was introduced [9]. Thirdly, Above Λ_{cr} the universe was in topological form with topological interactions and any metric is not necessarily defined. Therefore, 2+1 dimensional Chern-Simons (CS) interactions between the chernons (hence the new name for preons) inside a 3+1 dimensional spacetime were introduced [3]. Chernons with certain spontaneous symmetry breaking turned out to give a natural explanation for baryon asymmetry. Furthermore, the chernon model explains why supersymmetry has not been observed in nature. The preon interaction is the main difference between the Pati model(s) and ours.

Chern-Simons-Maxwell (CSM) models have been studied in condensed matter physics (for most original references see [3]). In this note we apply the CSM model in particle physics phenomenology in the early universe. The following CS-QED action has been defined

$$
\begin{aligned}
S^{\rm SSB}_{\rm CS-QED} = \int d^3x \Big\{ & -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} + \frac{1}{2}M_A^2 A^\mu A_\mu \\
& - \frac{1}{2\xi}(\partial^\mu A_\mu)^2 + \overline{\psi}_+(i\partial\!\!\!/ - m_{eff})\psi_+ \\
& + \overline{\psi}_-(i\partial\!\!\!/ + m_{eff})\psi_- + \frac{1}{2}\theta\epsilon^{\mu v\alpha}A_\mu\partial_v A_\alpha \\
& + \partial^\mu H \partial_\mu H - M_H^2 H^2 + \partial^\mu\theta\partial_\mu\theta - M_\theta^2\theta^2 \\
& - 2yv(\overline{\psi}_+\psi_+ - \overline{\psi}_-\psi_-)H - e_3\left(\overline{\psi}_+ A\!\!\!/ \psi_+ + \overline{\psi}_- A\!\!\!/ \psi_-\right) \Big\}
\end{aligned} \tag{2.1}
$$

where the mass parameters

$$
M_A^2 = 2v^2e_3^2, \quad m_{eff} = m_{ch} + yv^2, \quad M_H^2 = 2v^2(\zeta + 2\lambda v^2), \quad M_\theta^2 = \xi M_A^2 \tag{2.2}
$$

depend on the SSB mechanism: v^2, the vacuum expectation value, and y is the parameter that measures the coupling between fermions and Higgs scalar. Being a free parameter, v^2 indicates the energy scale of the spontaneous breakdown of the $U(1)$ local symmetry. The Proca mass M_A^2 represents the mass acquired by the photon through the Higgs mechanism. The Higgs mass, M_H^2, is associated with the real scalar field. The Higgs mechanism also contributes to the chernon mass m_{ch}, resulting in an effective mass m_{eff}. There are two photon mass-terms in (2.1), the Proca and the topological one. Now the idea of ()2.1) is that the parameters of the model can be chosen such that photon mass is high enough to create an attractive, very short range Yukawa force which is stronger than the repulsive Coulomb force between equal charge preons.

The chernon-chernon scattering amplitude in the non-relativistic approximation is obtained by calculating the t-channel exchange diagrams of the Higgs scalar and the massive gauge field. The propagators of the two exchanged particles and the vertex factors are calculated from the action (2.1).

The gauge invariant effective potential for the scattering considered is obtained in [10, 11]

$$
V_{\rm MCS}(r) = \frac{e^2}{2\pi}\left[1 - \frac{\theta}{m_{ch}}\right] K_0(\theta r) + \frac{1}{m_{ch}r^2}\left\{l - \frac{e^2}{2\pi\theta}[1 - \theta r K_1(\theta r)]\right\}^2 \tag{2.3}
$$

where $K_0(x)$ and $K_1(x)$ are the modified Bessel functions and l is the angular momentum ($l = 0$ in this note).

One sees from (2.3) the first term may be positive or negative while the second term is always positive. The function $K_0(x)$ diverges as $x \to 0$ and approaches zero for $x \to \infty$ and $K_1(x)$ has qualitatively similar behavior. For our scenario we need negative potential between equal charge chernons. We can give one relation between these parameter values for an attractive potential. We must require the condition

$$
\theta \gg m_{ch} \tag{2.4}
$$

The attractive equal charge potential plays the key role when chernons begin to form quarks and leptons [3].

For applications to condensed matter physics, one must require $\theta \ll m_e$, and the scattering potential given by (2.3) then comes out positive [12].

The arguments of subsection 2.1 apply in this subsection as well as in the Pati model case in subsection 2.2. The different preon and chernon binding interactions is not expected to make any difference.

3 Conclusions and outlook

In this note we have sought connection between superstrings and chernons. We compare first the two models of Pati and us discussed in subsections 2.2 and 2.3, respectively. In Pati's model, the existence of vacuum solutions $M^4 \times K$ at the tree level are known. Such a compactification leaves an unbroken N = 1 local supersymmetry at compactification scale, which may help resolve the gauge-hierarchy problem. It breaks $E_8 \times E_8$ into $E_8 \times E_6$ if K is simply connected and E_6 breaks at the compactification scale to a subgroup $G_0 = SU(4)_M \times \tilde{G}$. Pati identifies the symmetry group $SU(4)_M$ is with the metacolor gauge symmetry. The field theory with this gauge group is asymptotically free in UV and confining in IR [13]. In our model, a global attractive potential (2.3) at tree level is obtained after the introduction of the Higgs mechanism in the context of the MCS-QED [12]. This allows Yukawa bound states of chernons below the scale Λ_{cr} and free chernons above the scale Λ_{cr}. Qualitatively, at least, both preon models have similar behavior on preon interaction level.

We have found significant experimental support for the chernon model: (i) it reduces to the standard model at accelerator energies [2], (ii) it has proposal for the dark sector (not observed/understood yet) [3], (iii) it explains the baryon asymmetry in the universe in a natural way [3], (iv) it can be extended beyond $\Lambda_{cr} \sim 10^{16}$ GeV up to say $M_{\rm Pl}$, (v) it provides coherent T-dual topological evolution of the universe [9], and it explains why supersymmetry has not been found in experiments [4]. Our model is in addition endorsed by the the topological quantum gravity models of Witten [14] and Fang and Gu [15, 16].

These agreements are found using phenomenological methods rather than by mathematically rigorous proofs. It is our understanding in any case that superstring theory has enough support from experiment that it cannot be considered a mere mathematical construction, in spite of e.g. compactification is not well enough understood.

One crucial question for our model is can Chern-Simons theory be derived from the topology of K. Our results point towards deep mathematical structures and symmetries that underlie both CS and superstring theories. This may provide a way to study quantum aspects of superstring theory using Chern-Simons theory as a tool. This has been studied formally in [17, 18]. We wish to able to continue along these lines in more detail in the future.

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