A Model for Matter-Antimatter Asymmetry

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January 14, 2020

Abstract

A previous preon scenario based on unbroken global supersymmetry is developed further to provide a natural physical reason for the observed matter-antimatter asymmetry. A tentative mechanism for asymmetric genesis of matter in early cosmology is proposed. With global supersymmetry made local the scenario can be extended to supergravity.

PACS 12.60.Rc

Keywords: Standard Model and Beyond, Preons, Baryon an Lepton Asymmetry, General Relativity, Extra Dimensions, Supergravity

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1 Introduction

In fundamental physics, when one goes towards smaller and smaller length scales beyond, say 10^{-18} m, the symmetries describing physics may change. The hadron symmetries in the standard model need not be as relevant as before. Or rather, perhaps they are derived quantities of a smaller scale theory which is our target.

The original version [1] of this scenario was redefined in terms of fields with charge, spin, and light mass in [2]. As shown by Finkelstein [3, 4], this kind of preon model (his as well as ours) can be extended to possess topological symmetry property of the quantum group SLq(2) which provides consistent representations for quarks, leptons *and* preons. Both scenarios agree with the standard model group structure.[1] Recently, it was realized that the original scenario obeyed unbroken global supersymmetry [1, 2] without the superpartner problem. Present experimental evidence indicates that standard model superpartners may not exist.

The preon scenario is developed below further by adopting features from the direction of general relativity to solve the matter-antimatter asymmetry problem. The asymmetry is considered starting from the hydrogen atom which includes matter components only. But when the proton and the electron are described in terms of preons one notices that the world is preon-antipreon symmetric. A specific mechanism to obtain the asymmetry in the early universe is proposed. Furthermore, preons provide a unified picture of quarks and leptons, different from traditional grand unified theories.

Another challenging issue, gravity is no more mere speculation as in [1]. Namely the preon, or superon, scenario can be self-consistently completed by replacing global supersymmetry with local supersymmetry to obtain supergravity [7] as a framework for model development. From supergravity, it is hoped by many, one may ultimately go towards a UV finite, consistent theory of quantum gravity within superstring or M-theory [8].

The model is based on supersymmetry and Poincaré invariance on the fundamental level. Electromagnetism is supposed to be derivable from a fifth dimension. The gauge groups in the model are Abelian. Consequently, this approach has simpler vacuum and it is more constrained than the standard grand unified or superstring theory. The validity of the scheme can be analyzed and tested both by phenomenological comparisons with data and constructing explicit, realistic models for supergravity.

The article is organized as follows. In section 2 a very brief description is given of how preon cosmology differs from the cosmological standard model. In section 3 the main result of this note, the natural connection between preons and atomic matter asymmetry is presented. A tentative solution to baryon and lepton asymmetry genesis is discussed. In section 4 neutrino charge radius is

[1] Harari [5] and Shupe [6] have also proposed preon models of this type. All of four models are physically equivalent with each other and the standard model but their preon internal symmetries are different from ours.

considered briefly. Section 5 is a brief description of a framework for developing supergravity models on the basis of the superon scenario. Explicit models are beyond the scope of this note. Conclusions are given in section 6. This concise note should be considered an introductory entry for further studies with calculations.

2 Difference with Standard Cosmology

The universe started in a process called Big Bang, be it one time or cyclic without singularity [9]. The details of cosmology are beyond the scope of this note. The focus is in the role of preons forming the contents of the present universe.

The laws of physics are unknown before the Planck time $\sim 10^{-43}$ s. At that time the temperature of the universe was $\sim 10^{32}$ K or $\sim 10^{19}$ GeV and the length scale was $\sim 10^{-35}$ m. As time flowed on different phases occurred in the universe according to the cosmological standard model: (i) inflation between $10^{-35} - 10^{-32}$ s followed by reheating, (ii) grand unified theory (GUT) phase down to temperature 10^{16} GeV, called later Λ_{cr}, (iii) electro-weak symmetry breaking at 10^{-12} s with a temperature 240 GeV and (iv) the quark-gluon to hadron phase transition at T = 140 MeV.

In the present scenario the GUT transition at $\Lambda_{cr} \sim 10^{16}$ GeV is replaced by the preon phase transition in which quarks and leptons are formed as composite states of three preons [2], and the universe enters from the early preon phase to the standard model phase about at the end of inflation. The strong and weak non-Abelian gauge interactions operate only below Λ_{cr} between the three preon bound states as they do between the SM particles. But above Λ_{cr} they do not contribute at all - in any case the non-Abelian couplings would be small.

3 Matter Asymmetry

After protons have been formed at about 10^{-6} s one would expect on general grounds the universe to be matter-antimatter symmetric, which is not the case experimentally [10]. The magnitude of baryon (B) asymmetry is usually described by the ratio $r_B = (N_{\text{B}} - N_{\bar{\text{B}}})/N_{\text{photons}}$, which is measured to be $\sim 10^{-10}$.

It is rather curious that the hydrogen atom, noticeably baryon and lepton asymmetric, is on the preon level a *symmetric* collection of preons and antipreons as follows

$$\begin{aligned} H \equiv p + e &= u + u + d + e \\ &= \sum_{l=1}^{4} \left[m_l^+ + m_l^- + m_l^0 \right] \end{aligned} \tag{3.1}$$

where $u_k = \epsilon_{ijk} m_i^+ m_j^+ m^0$, $d_k = \epsilon_{ijk} \frac{1}{\sqrt{2}} m^- (m_i^0 m_j^0 + m_i^- m_j^+)$ (k = 1, 2, 3) and $e = \epsilon_{ijk} m_i^- m_j^- m_k^-$ (the neutrino is $\nu = \epsilon_{ijk} \frac{1}{\sqrt{2}} m_i^0 (m_j^0 m_k^0 + m_j^- m_k^+)$) [2]. This preon structure is the basic reason for matter-antimatter asymmetry.

There is a problem though. Preons in one region of the universe can form quarks and leptons combinatorially (mod 3) [11] fulfilling all states with charges $-\frac{1}{3}$, $\frac{2}{3}$ and -1, like in 3.1 first line. Later atoms of hydrogen and helium (hydrogen H for brevity) form below T $\sim$ 3000 K. But in other regions of the universe, nearby or far away, atoms of antihydrogen $\bar{H}$ may appear from preon combination if the m^+ preons combine into positrons and the m^- predominantly into quarks. One is getting back towards baryon and lepton symmetry.

In the present scenario, however, the H and $\bar{H}$ abundances, N_H and $N_{\bar{H}}$, need not be the same since the preon combination finally into H or $\bar{H}$ is stochastic. Statistically $r_H = N_{\bar{H}}/N_H$ can vary between zero and ∞, the expectation value being $\langle r_H \rangle = 0$ leading to a radiation dominated universe. But the measure of $r_H = 1$ is zero while the measure of values $r_H \neq 1$ is one. It is reasonable to assume $r_H \neq 1$ within some one σ. Then any excess of H or $\bar{H}$ is annihilated away and radiation together with an asymmetric remains of either matter or antimatter universe is obtained, causing at most a redefinition of the sign of charge. In this situation there is no way to control the amount of radiation, which increases H and $\bar{H}$ symmetry, and must have thermodynamic role. Therefore matter must have been formed originally in an asymmetric way. Such a model construction is attempted next.

Let us try breaking first preon C invariance phenomenologically by giving different masses to charged preons: $M_{m^+} < M_{m^-}$. Call m^- a fermion and m^+ an antifermion in the Dirac tradition. Assume that preons are produced in the very early phases of the universe abundantly pairwise when the curvature of spacetime and the preon matter density are very high. This can be the situation during or towards the end of inflation. Now the heavier m^- attract each other gravitationally in 5D more than their antiparticles do. Therefore the electrons with three m^- form first. Quarks with one and two m^-, i.e. d and $\bar{u}$, form later because all three species (colors) have to be formed. $\bar{d}$- and u-quarks follow and finally positrons form last of these standard model particles. This mechanism suggests that distinctly more hydrogen is produced than antihydrogen. Later when the matter density decreases in the expanding universe the preon mass difference vanishes, and C invariance is restored.

Can this mechanism be supported by any theory? The answer is affirmative. In general relativity with spin $\frac{1}{2}$ particles included, the Einstein-Cartan-Kibble-Sciama theory [12, 13], the torsion tensor due to spin is regarded as a dynamical variable like the metric tensor. Corrections from the cubic Hehl-Datta term [14, 15] in the Dirac equation to the energy levels of a spinor in a constant background torsion are C asymmetric. Fermions have higher energy levels than antifermions due to the Hehl-Datta term and are thus effectively more massive. Non-propagating torsion generates a repulsive force between fermions, which would be of interest for singularity avoidance in cyclic cosmology and composite state m^+m^- stability. Torsion operates within matter only at much higher density than nuclear matter.

The dark sector is more like guesswork at the moment, and the experimental situation is unclear. Dark matter candidates are gravitinos, which have a mass due to spontaneous breaking of symmetry [7]. Gravitinos may slowly decay into preons above Λ_{cr} or any other particles below Λ_{cr} because gravity is universal. Therefore they would form dark matter only if they are stable. Dark energy may have something to do with spacetime structure, like cell surfaces around preon composites which may have tiny positive surface energy leading to the cosmological constant. But one must remember that for the dark sector there are various considerations [16], and, at this writing, there are discussions going on about issues in the supernova Ia measurements leading to dark energy.

4 Neutrino Charge Radius

The neutrino has a charge radius in the standard model due to radiative corrections. The calculations have a long, eventful history [17]. The result obtained in one-loop approximation, including terms from the γ-Z mixing and box diagrams with W and Z bosons, is [18]

$$\langle r_{\nu_l^2} \rangle = \frac{G_F}{4\sqrt{2}\pi^2}\left[3 - 2\log\left(\frac{M_l^2}{M_W^2}\right)\right] \tag{4.1}$$

where G_F is the Fermi coupling, $l = e, \mu, \tau$ and the M's are the masses of the leptons and the W. Numerically $\langle r_\nu^2 \rangle \sim 10^{-33}\text{cm}^2$ for all three neutrino species. Experimental vales are larger, in the range $0.5 \times 10^{-32} < \langle r_\nu^2 \rangle < 10 \times 10^{-32}\text{cm}^2$ [17] leaving a possibility to physics beyond the standard model.

In the preon scenario the situation is different from the standard model because the neutrino has charged constituents with $m^+m^- \longleftrightarrow m^0 + m^0$ mixing. A model calculation for the three preon wave function would require a simplifying assumption of the spacetime cell structure and reduction to a two body problem. In electron scattering QED holds down to distances 10^{-18} m. The Cartan radius of the electron is 10^{-27} m. The composite structure is expected to appear at distances between these two values.

5 Supergravity

In this section a brief glance for future developments for superons is taken. Compactification of extra dimensions has been studies actively beyond 4D, up to 10D superstring theory, 11D supergravity and even 12D. Eleven has been shown to be (i) the maximum number of dimensions with a single graviton and (ii) the minimum number required of theory to contain the standard model gauge group $SU(3) \times SU(2) \times U(1)$. Within the present model, however, the condition (ii) can be dropped when the current situation in the search of SM superpartners is taken at face value.

In the N=1 supersymmetric model there are the graviton G and its spin $\frac{3}{2}$ superpartner the gravitino $\tilde{G}$ The massless Rarita-Schwinger field $\tilde{G}$ obeys the curved space equation [7] (full details in [8])

$$\epsilon^{\lambda\rho\mu\nu}\gamma_5\gamma_\mu D_\nu \tilde{G}_\rho = 0 \tag{5.1}$$

where $\epsilon^{\lambda\rho\mu\nu}$ is the Levi-Civita symbol and the γs are the Dirac matrices. This the graviton supermultiplet.

Secondly, as introduced in [19, 1, 2], there are the massless fields the photon γ and its neutral spin $\frac{1}{2}$ superpartner, the photino $\tilde{\gamma}$, denoted in [2] as $\tilde{m}^0$. They form the vector supermultiplet. The $\tilde{m}^0$ is a Majorana fermion with spin up or down.

The third supermultiplet is the spin $\frac{1}{2}$ fermion m^+ obeying the Dirac equation and two scalar superpartners $\tilde{s}^+_{1,2}$ [1, 2]. The free massless Lagrangian for the chiral multiplet is of the form [19, 8]

$$\mathcal{L} = -\frac{1}{2}\bar{m}^+ \not{\partial} m^+ - \frac{1}{2}(\partial \tilde{s}^+_i)^2 - \frac{1}{2}(\partial p)^2, \ i = 1, 2 \tag{5.2}$$

where p is a pseudoscalar which is not considered here.

The R-parity for the above fields is simply $P_R = (-1)^{2\times spin}$. The m^+ and $\tilde{m}^0$ are assumed to have zero, or light mass of the order of the first generation quark and lepton mass scale.

Now, with supergravity being formally defined for superons, this scenario may be coming towards the main stream theory. Namely according to Weinberg rationale, *"Supergravity is itself only an effective nonrenormalizable theory which breaks down at the Planck energies. So if there is any truth to supersymmetry then any realistic theory must eventually be enlarged to superstrings which are ultraviolet finite. Supersymmetry without superstrings is not an option."* [8].

6 Conclusions and Outlook

The present supersymmetric superon model is based on spacetime symmetries alone and on the proposal that the physical domain of supersymmetry is the preon level instead of the traditional quark and lepton level of the standard model. The key feature of the present scenario is that all the fundamental fields and their superpartners are in the basic supermultiplets to begin with. Therefore no superpartners, light or heavy, need to be searched for experimentally. Baryons and leptons are treated in a unified way in terms of superons.

The main result of this note is the natural physical origin of the observed matter asymmetry in the universe. A tentative model for a genesis process in terms of superons and torsion in general relativity is proposed. It may be mentioned also that there is no black hole information paradox because the superon quantum numbers are not destroyed by black holes [1].

The gravitino may have a role for dark matter. Superon composite states are candidates for scalar particles predicted by other models, like the axion or more Higgs particles [2]. Non-singular bouncing and, if you wish, inflationary cosmologies (the latter with e.g. a hilltop potential of the form $V = A(\phi^2(v-\phi)^2$ [19]) are part of this framework.

A major goal is to go from global supersymmetry to study supergravity [7, 8, 20]. It has been defined in dimensions $4 \leq D \leq 11$. It is hoped that the framework of this note would increase interest in extra dimensions starting in 5D, which may lead to a unified, consistent quantum theory of gravity and electromagnetism. With unbroken supersymmetry and Poincaré invariance, i.e. Abelian interactions of the elementary fermions, there is less freedom, fewer parameters and a simpler vacuum for new model building.

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