A Scenario for Asymmetric Baryon/Lepton Genesis

Risto Raitio*
02230 Espoo, Finland

Feruary 5, 2020

Abstract

A previous preon scenario for the standard model particles, based on unbroken global supersymmetry, is developed further to provide a natural physical reason for the observed matter-antimatter asymmetry. Based on plausible assumptions, a two mass scale 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 and Lepton Genesis, General Relativity, Torsion, Supergravity

*E-mail: risto.raitio@gmail.com

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 for substructure of the standard model particles supposed the subconstituents to have charge $\frac{1}{3}$, spin $\frac{1}{2}$ and a heavy mass. The model was redefined in terms of fields with charge, spin, and light mass in [2]. Here we propose a model where both versions play a role in a specific Big Bang process producing matter-antimatter asymmetry.

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] Only very recently, we realized that the original scenario [1, 2] obeyed unbroken global supersymmetry [5] without the superpartner problem. This is satisfying because present experimental evidence indicates that standard model superpartners may not exist.

The preon scenario is developed below further by adopting features from general relativity to solve the matter-antimatter asymmetry problem. The asymmetry is considered starting from the hydrogen atom which includes asymmetrically matter components only. But when the proton and the electron are described in terms of preons one notices that the atom is preon-antipreon *symmetric* - in fact, all atoms are. Furthermore, preons provide a novel unified picture of quarks and leptons, different from traditional grand unified theories.

The way from preons to atomic matter is, however, somewhat complex. To obtain the matter-antimatter asymmetry in the universe, a specific semiclassical mechanism is proposed, including a mass scale $\Lambda_{cr} \sim 10^{16}$ GeV and torsion of spacetime causing temporary C violation between $\Lambda_{cr} < T \lessapprox M_{\rm Pl} = 2.4 \times 10^{18}$ GeV.

The major challenging issue in the scenario, (quantum) gravity, for preon "confinement" inside quarks and leptons, is still a question without solution, but it is no more mere speculation as in [1]. Namely the preon, or superon (synonyms here), scenario can be self-consistently reinforced by replacing global supersymmetry with local supersymmetry to obtain supergravity [8] 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 [9].

The model is based on supersymmetry and Poincaré invariance on the fundamental level. Electromagnetism is supposed to be derivable from a fifth dimen-

[1] Harari [6] and Shupe [7] 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.

sion, which is not discussed here in any detail. 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 by constructing realistic models for supergravity. Explicit models are beyond the scope of this note.

The article is organized as follows. In section 2 a very brief description is given of how superon cosmology differs from the cosmological standard model. In section 3 the main result of this note, the natural connection between superons and ordinary atomic matter asymmetry is presented. A tentative solution to baryon and lepton asymmetric genesis is proposed. In section 4 neutrino charge radius is considered briefly. Section 5 is a brief description of a framework for developing supergravity models on the basis of the superon scenario. Conclusions are given in section 6.

This concise note should be considered a concept analysis necessary for going beyond the esteemed standard model with calculations.

2 Difference with Standard Cosmology

The universe started in a process called Big Bang, be it one time or cyclic without singularity [10]. The details of cosmology are beyond the scope of this note. The focus is in the role of superons 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 (re)heating, (ii) grand unified theory phase transition at temperature $\Lambda_{cr} \sim 10^{16}$ GeV, (iii) electro-weak symmetry breaking at 10^{-12} s with a temperature 240 GeV and (iv) the quark-gluon to hadron phase transition at $\mathrm{T} = 140$ MeV.

In the present model (i) inflation takes place as usually within the gravitational concepts of the model. The grand unified theory phase transition point (ii) is physically different here. Before time $\sim 10^{-32}$ s the curvature was very high, energy density much above the nuclear density, and the typical mass scale was M_{Pl}. It has been shown in [11] that in a 4D theory with gravity and a U(1) gauge field with coupling g, the effective theory breaks down near the scale M_{Pl} where gravity becomes strongly coupled. For small g (= α in this case), the effective theory breaks down below the Planck mass at scale $\Lambda \lesssim \alpha M_{\mathrm{Pl}}$. There must be a charged particle with a mass $M \sim \alpha M_{\mathrm{Pl}}$. These particles are modeled as superons in the Planck scale mode $\mathcal{M}$ [1].

In the present scenario, at the temperature $\Lambda_{cr} \sim 10^{16}$ GeV a transition takes place in which Planck scale superons $\mathcal{M}$ transform into standard model scale superons m [2]. The universe enters the standard model phase. The strong and weak non-Abelian gauge interactions operate only (i) when $M \ll \Lambda_{cr}$, and

(ii) between the three light superon composite states as they do between the SM particles. But above Λ_{cr} they do not contribute at all - in any case their non-Abelian standard model couplings are 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 [12]. The magnitude of baryon (B) asymmetry is usually indicated by the ratio $r_B = (N_{\mathrm{B}} - N_{\bar{\mathrm{B}}})/N_{\mathrm{photons}}$, which is measured to be $\sim 10^{-10}$.

It is rather curious that the hydrogen atom, noticeably asymmetric baryon and lepton bound state, 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 physical reason for matter-antimatter asymmetry in the present scenario.

There is a problem though. Preons in one region of the universe can form quarks and leptons combinatorially (mod 3) [13] 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 matter-antimatter symmetry.

The H and $\bar{H}$ abundances, N_H and $N_{\bar{H}}$, need not be, however, the same since the preon combination process 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. Therefore matter must have been formed originally in an asymmetric way. Such a model construction is attempted next.

Let us go to the inflationary period and analyze the 4D theory of gravity with the electromagnetic gauge field. Consider breaking the C invariance of Planck scale preon $\mathcal{M}$ phenomenologically by giving different masses to charged preons: $M_{\mathcal{M}^+} < M_{\mathcal{M}^-}$. Call $\mathcal{M}^-$ a fermion and $\mathcal{M}^+$ an antifermion in the Dirac tradition. Assume that superons are produced in the very early phases of the universe abundantly pairwise when the curvature of spacetime and the superon matter density are very high. Postponing electromagnetic interactions between the $\mathcal{M}$s to the next paragraph, the heavier $\mathcal{M}^-$ attract each other gravitationally more than their antiparticles $\mathcal{M}^+$ do. Therefore the electrons with three $\mathcal{M}^-$ form first. Quarks with one and two $\mathcal{M}^-$, i.e. $\mathcal{D}$ and $\bar{\mathcal{U}}$, form later because all three species (colors) have to be formed. $\bar{\mathcal{D}}$- and $\mathcal{U}$-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.

In the previous paragraph there are two issues needing explanation. First, the Coulomb repulsion of like charge superons $\mathcal{M}$ needs attention because it is stronger than the gravitational attraction. For particles with $M \lesssim \alpha M_{\rm Pl}$ gravity is the weaker force. But in the case where charged particles have a mass $M > \alpha M_{\rm Pl}$, the Coulomb repulsive force between the like charge particles is overcome by the gravitational attraction [11].

Secondly, can the C symmetry breaking 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 [14, 15], the torsion tensor due to spin is regarded as a dynamical variable like the metric tensor. Torsion operates within matter only at much higher density than nuclear matter. Corrections from the cubic Hehl-Datta term [16, 17] 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.

Now the universe consists of heavy $\mathcal{U}$ and $\mathcal{D}$ quarks and the corresponding leptons $\mathcal{E}$ and $\mathcal{N}$. In the present scenario the strong or weak interactions are low energy ($\mathrm{E} \ll 10^{16}$ GeV) phenomena. Therefore there are no such decays of these particles. But the original gravity plus U(1) theory has charged light fermions to which the gauge field couples. In lack of solid theory, we may think that in the cooling universe the very early strongly fluctuating quantum spacetime freezes into cells, or polyhedra of loop quantum gravity [18, 19] or structures in string theory (i) releasing the energies of the $\mathcal{M}$, $\mathcal{U}$, $\mathcal{D}$, $\mathcal{E}$ and $\mathcal{N}$ particles and (ii) producing the preons m and ordinary standard model first generation particles u, d, e, and ν. These phenomena cannot be measured experimentally in any foreseeable future. Therefore, in trying to explain the asymmetry of matter one is perhaps allowed to accept some hypotheses, which are based on models under consistent development.

The energy released in the transition is observed as scalar fields, or vacuum energy, of various forms like the inflaton, (re)heating, Higgs vev, dark matter, and dark energy [20], which form a complicated dynamical system. The second and third generation of quarks and leptons are supposed to be excitations in spacetime structure, i.e. by gravity. These problems are left for another project.

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 [21]. The result obtained in one-loop approximation, including terms from the γ-Z mixing and box diagrams with W and Z bosons, is [22]

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

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 $0.5 \times 10^{-32} < \langle r_\nu^2 \rangle < 10 \times 10^{-32}\text{cm}^2$ [21] 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 standard model 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 spacetime equation [8] (full details in [9])

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

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 [5, 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 [5, 9]

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

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.

6 Conclusions and Outlook

The present 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. There is no black hole information paradox because the superon quantum numbers are not destroyed by black holes [1].

Based on plausible, though somewhat complex assumptions, we have disclosed in this note a natural physical origin of the observed matter-antimatter asymmetry in the universe starting from C symmetric superons. A tentative model for a genesis process in terms of superons and torsion in general relativity is proposed. Two high mass scales are included in the scenario, one where superons are liberated at $\Lambda_{cr} \sim 10^{16}$ GeV and the other the traditional Planck scale. The scenario extensible for further studies in cosmology and supergravity.

References

[1] Risto Raitio, A Model of Lepton and Quark Structure. Physica Scripta, 22, 197 (1980). PS22,197, viXra:1903.0224 [2]

[2] Risto Raitio, Supersymmetric preons and the standard model, Nuclear Physics B931 (2018) 283–290. doi:10.1016/j.nuclphysb.2018.04.021 arXiv:1805.03013

[3] Robert Finkelstein, On the SLq(2) Extension of the Standard Model and the Measure of Charge, Int. Journal of Modern Physics A, Vol. 32 (2017). arXiv:1511.07919

[2] The model was conceived in November 1974 at SLAC. I proposed that the c-quark would be a gravitational excitation of the u-quark, both composites of three 'subquarks'. The idea was opposed by the community and was therefore not written down until five years later.

[4] Robert Finkelstein, The SLq(2) extension of the standard model, Int. Journal of Modern Physics A, Vol. 30, No. 16, 1530037 (2015). doi:10.1142/S0217751X15300379

[5] J. Wess and B. Zumino, Supergauge transformations in four dimensions, Nucl. Phys. B 70 (1974) 39. 10.1016/0550-3213(74)90355-1

[6] H. Harari, A schematic model of quarks and leptons, Phys. Lett. B86, 83 (1979). doi:10.1016/0370-2693(79)90626-9

[7] M. Shupe, A composite model of leptons and quarks, Phys. Lett. B86, 87 (1979). doi:10.1016/0370-2693(79)90627-0

[8] Daniel Z. Freedman, P. van Nieuwenhuizen, and S. Ferrara, Progress toward a theory of supergravity, Phys. Rev. D 13, 3214 (1976).

[9] Steven Weinberg, The Quantum Theory of Fields: Volume 3, Supersymmetry, Cambridge University Press (2005).

[10] Jordan L. Cubero and Nikodem J. Poplawski, Analysis of big bounce in Einstein-Cartan cosmology, Class. Quantum Grav. 37, 025011 (2020). arXiv:1906.11824

[11] Nima Arkani-Hamed, Luboš Motl, Alberto Nicolis and Cumrun Vafa, The String Landscape, Black Holes and Gravity as the Weakest Force, JHEP 0706 (2007) 060. arXiv:hep-th/0601001

[12] Laurent Canetti, Marco Drewes, Mikhail Shaposhnikov, Matter and Antimatter in the Universe, New J. Phys. 14 (2012) 095012, DOI:10.1088/1367-2630/14/9/095012. arXiv:1204.4186

[13] Risto Raitio, Combinatorial Preon Model for Matter and Unification, Open Access Library Journal, 3: e3032 (2016). OALibJ 3:e3032

[14] T. W. B. Kibble, J. Math. Phys. (N.Y.) 2, 212 (1961).

[15] D. W. Sciama, in Recent Developments in General Relativity (Pergamon, New York, 1962), p. 415; D. W. Sciama, Rev. Mod. Phys. 36, 463 (1964); D. W. Sciama, Rev. Mod. Phys. 36, 1103 (1964).

[16] F. W. Hehl and B. K. Datta, J. Math. Phys. (N.Y.) 12, 1334 (1971).

[17] Nikodem J. Poplawski, Matter-antimatter asymmetry and dark matter from torsion, Phys. Rev. D 83 (2011) 084033, DOI: 10.1103/PhysRevD.83.08. arXiv:1101.4012

[18] Carlo Rovelli, Francesca Vidotto, Covariant Loop Quantum Gravity: An Elementary Introduction to Quantum Gravity and Spin Foam Theory, Cambridge University Press, 2015.

[19] J. Manuel García-Islas, Quantum Geometry I: Basics of Loop Quantum Gravity. The Quantum Polyhedra, Revista Mexicana de Física E 65, 2019, 7-11. arXiv:1902.05709

[20] Pedro G. Ferreira, Annual Review of Astronomy and Astrophysics, Vol. 57 (2019) pp 335-374. arXiv:1902.10503

[21] Carlo Giunti and Alexander Studenikin, Neutrino electromagnetic interactions: a window to new physics, Rev. Mod. Phys. 87 (2015) 531. arXiv:1403.6344

[22] J. Bernabéu, J. Papavassiliou, and J. Vidal, The neutrino charge radius is a physical observable, Nucl. Phys. B680 (2004) 450-478, DOI: 10.1016/j.nuclphysb.2003.12.025. arXiv:hep-ph/0210055