Framework for Baryon Asymmetry
and Supergravity Models

Risto Raitio*
02230 Espoo, Finland

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Abstract
A previous composite particle scenario based on unbroken global supersymmetry is extended to five dimensions as a proposal for a unified model of matter and interactions. It is proposed that the strong and weak interactions decouple at the fundamental UV level of particle theory. A preon scenario for baryon and lepton asymmetry is presented. With local supersymmetry one arrives at supergravity as a framework for phenomenological model development towards UV finite theory.

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

When one goes towards smaller and smaller length scales all the hadron scale symmetries, like the eightfold way, quark SU(3) or weak SU(2), need not be relevant any more. Quantum gravity does not respect baryon and lepton number conservation. The scenario of this article was originally proposed as preons having quantum numbers taken from black holes: charge, spin and a heavy mass [1]. Later the model was redefined in terms of chiral fields [2] instead of heavy objects. Secondly, it turned out to be extensible to possess topological symmetry property of the quantum group SLq(2) which provides consistent representations for quarks, leptons and preons [3, 4]. Thirdly, the early scenario obeyed unbroken global supersymmetry [1, 2].

Baryon asymmetry of the universe is considered starting from the hydrogen atom, which is baryon and lepton asymmetric. But when the proton and electron are described in terms of supersymmetric preons (superons) one notices that the result is preon-antipreon symmetric. But the same preons can also combine to form an antihydrogen atom. Therefore a mechanism is proposed to guarantee that there will be baryon and lepton asymmetry in the early universe.

Gravity is no more mere speculation as in [1]. Namely the scenario can be self-consistently completed by replacing global supersymmetry with local supersymmetry to obtain supergravity [5]. From supergravity, it is hoped by many, one may go towards a UV finite, consistent theory of quantum gravity within superstring or M-theory [6]. The gauge groups within the present model are Abelian. Therefore this approach has simpler vacuum and is more constrained than the standard superstring theory. The validity of the scheme can be analyzed and tested, proven or disproven, by constructing explicit, realistic models for supergravity, which is beyond the scope of this brief note.

The article is organized as follows. In section 2 a solution to baryon and lepton asymmetry is considered. Section 3 is devoted to a framework of developing supergravity models. Conclusions are given in section 4. This note is hoped to be an introductory section for further consideration in the community.

2 Baryon Asymmetry

Our universe started in a process called Big Bang, be it one time or cyclic. 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 standard model: (i) inflation between \( 10^{-35} - 10^{-32} \) s, (ii) grand unified theory (GUT) phase transition at temperature \( 10^{16} \) GeV (called later \( \Lambda_{\text{GUT}} \)), (iii) electro-weak transition at \( 10^{-12} \) s with a temperature 240 GeV and (iv) the quark-gluon phase transition at \( T = 140 \) MeV. In the present scenario the GUT transition 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 the standard model phase.

In other words, the non-Abelian gauge interactions operate between the three preon bound states as between the SM particles only below $\Lambda_{cr}$. But above $\Lambda_{cr}$ they do not contribute at all because preons undergo a phase transition to Kaluza-Klein phase (see section 3). This condition stems in fact from the asymptotic freedom property of the non-Abelian interactions. This requirement is be made stronger by relegating the color and weak interactions occurring only between quark and lepton composite states below $\Lambda_{cr}$.

After protons have been formed at about $10^{-6}$ s one would expect the universe to be baryon-antibaryon symmetric as within field theory, which is not the case experimentally [7]. The magnitude of baryon (B) asymmetry is usually described by the ratio $(N_B - N_{\bar{B}})/N_{\text{photons}}$ which is measured to be $\sim 10^{-10}$.

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

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

(2.1)

where $u_k = \epsilon_{ijk}m_i^+m_j^+m_k^0$, $d_k = \epsilon_{ijk}m_i^-m_j^0m_k^0$ and $e = \epsilon_{ijk}m_i^-m_j^-m_k^-$. [2].

However, preons in other regions of the universe can form the composite state of antihydrogen, and we are back in baryon and lepton symmetry. Therefore it is necessary to find a plausible physical mechanism for positively charged preons to gather mostly in quarks and negatively charged in leptons.

The period for preon charge separation is expected near the end of inflation and early reheating, where the temperature is $T \sim \Lambda_{cr} \sim 10^{16}$ GeV and conductivity is increasing. In that period preons and anti-preons are abundantly produced pairwise. Near the end of inflation preons form a gas where electromagnetic fields occur. Primordial fields of large coherence scales are naturally generated during inflation. If the phase transition is of first order magnetic fields may arise favorably [8]. The cause of the phase transition is proposed to be due transition of quantum gravitational discretized spacetime structure into gas of gravitons, photons and preons (with a possible liquid phase of gravitons in between). So one arrives at the gauge theory of gravitation with the vierbein being the gauge potential of the new symmetry of translations.

It has been estimated that primordial magnetic fields of strength $10^{-9}$ G (as redshifted to the present epoch) may have existed in the early universe [8]. Another source of electromagnetic field may be charged primordial black holes due to density fluctuations of the inflating stuff. The hypothesis now is that in the early universe near the end of inflation a magnetic field, even weak and time varying, guided positive and negative charge preons of zero or very small mass in opposite directions. Thus separate clouds of positive charge preons were formed.

1They provide the luxury of nuclear physics, chemistry and biology
in various locations all over spacetime together with clouds of negative charge in
opposite direction of each positive charge cloud. Consequently positive charge
preons combined gravitationally with each other together with neutral preons,
which appear everywhere, to form quarks. Negative charge preons combined
correspondingly to form charged leptons and neutral preons formed neutrinos.
The net result is prominent, if not full, baryon asymmetry with some possible odd anti-baryons and -leptons annihilating all with baryons and leptons,
respectively.\footnote{Otherwise one would have to appeal to multiverse hypothesis or the anthropic principle to have baryon asymmetry.} A detailed quantitative analysis is must be done for the process outlined above. Other charge separating mechanisms may be working and the formation of the three generations may be due to gravitational dynamics or a new symmetry principle.

3 Supergravity

The idea of unifying gravity with electromagnetism is about as old as general
relativity. Nordström\textsuperscript{[9]} in 1914 and Kaluza\textsuperscript{[10]} in 1921 were the first physicists
to make this unification (for a review, see\textsuperscript{[11]}). They proposed a theory in
five dimensions with variables $(x^0, x^1, ..., x^4)$. Both physicists assumed that
all derivatives with respect to the fifth dimension variable $x^4$ vanish. They
obtained successfully the field equations of both gravity and electromagnetism.
This success is due to $U(1)$ gauge invariance added onto Einstein’s equations
in the guise of invariance with respect of coordinate transformations in the $x^4$
direction. Klein\textsuperscript{[12]} showed that the fifth dimension should be handled by the
method of compactification: $x^4$ has circular topology and its scale is very small,
like of the order of Planck scale.

Compactification of extra dimensions has been studies actively beyond 5D,
up to 10D superstring theory and 11D supergravity. Eleven has been shown to be
(i) the maximum number of dimensions with a single graviton and (ii) the
minimum number required of a Kaluza-Klein 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 in fact be dropped because the current situation in the
search of SM superpartners is taken at face value.

Supersymmetry transforms bosons to fermions, and vice versa\textsuperscript{[13, 6]}. An
operator $Q$ which generates such transformations is an anti-commuting spinor
carrying spin $\frac{1}{2}$: $Q|\text{boson}\rangle = |\text{fermion}\rangle, Q|\text{fermion}\rangle = |\text{boson}\rangle$, and its hermitian
conjugate $Q^\dagger$. Therefore supersymmetry must be a spacetime symmetry.

In the $N=1$ supersymmetric model there is the graviton $G$ and its spin $\frac{3}{2}$
superpartner gravitino $\tilde{G}$

$$
G = \left( \begin{array}{c} \rightarrow \\ \leftarrow \end{array} \right) \quad \text{and} \quad \tilde{G} = \left( \begin{array}{c} \rightarrow \\ \leftarrow \end{array} \right)
$$

\text{(3.1)}
where the horizontal arrows refer to helicity states and the massless Rarita-Schwinger field $\tilde{G}$ obeys the curved space equation [5] (more details in [6])

$$\epsilon^{\lambda\rho\mu\nu} \gamma_5 \gamma_\mu D_\nu \tilde{G}_\rho = 0 \quad (3.2)$$

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

Secondly, as introduced in [1, 2], there are the massless fields the photon $\gamma$ and its neutral spin $\frac{1}{2}$ superpartner, the photino $\tilde{\gamma}$, denoted in [2] $\tilde{m}^0$. They form the vector supermultiplet

$$\gamma = \left( \begin{array}{c} \rightarrow \\ \leftarrow \end{array} \right) \text{ and } \tilde{m}^0 = \left( \begin{array}{c} \uparrow \\ \downarrow \end{array} \right), \quad (3.3)$$

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 $\tilde{s}^+_{1,2} [1, 2]$

$$m^+ = \left( \begin{array}{c} \uparrow \\ \downarrow \end{array} \right) \text{ and } \tilde{s}^+_{1,2} \quad (3.4)$$

The free massless Lagrangian for the chiral multiplet is of the form [13, 6] (where full supersymmetric details are given)

$$\mathcal{L} = -\frac{1}{2} \tilde{m}^+ \partial \tilde{m}^+ - \frac{1}{2} (\partial \tilde{s}^+)^2 - \frac{1}{2} (\partial p)^2, \ i = 1, 2 \quad (3.5)$$

where $p$ is a pseudoscalar which is not considered here.

It turns out that the charge needed in (3.4) is $\frac{1}{3}$ of electron charge. The R-parity for fields is simply $P_R = (-1)^{2(\text{spin})}$. 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 supersymmetric preons (superons) this scenario is coming towards the main stream theory. Namely according to Weinberg rationale, "Supergravity is itself only an effective non-renormalizable 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." [6]. Are superstrings and superons mathematically connected remains the problem to be studied.

4 Conclusions

The present supersymmetric preon model is based on the proposal that the physical domain of supersymmetry is the preon level instead of 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
(3.1), (3.3) and (3.4) to begin with. Therefore no heavy superpartners need to be searched for experimentally. The other distinctive feature of the model is that the strong and weak interactions are phenomena only between superon composite states below energies $\Lambda_{cr}$.

From global supersymmetry the next intermediate step is to study supergravity [5, 6, 14]. It can be defined in dimensions $4 \leq D \leq 11$. It is hoped that this model would increase interest in e.g. superstring theory in 5D, which may be the unified, consistent quantum theory of gravity and electromagnetism. This article is intended to help to set up a novel scene for a research project, which is hoped to receive community response.

What would this framework change? With unbroken supersymmetry and Abelian interactions of the elementary fermions there is less freedom, fewer parameters and a simpler vacuum for new model building. Gravitino and some superon composite states as dark matter, baryon asymmetry and inflation (with a hilltop form potential of the form $V = A(\phi^2(v - \phi)^2$ [13]) may find natural explanations within this scenario. Other experimental tests are hard to find because the scenario works like the SM below $\Lambda_{cr}$.

The graviton and the gravitino are with the present facilities difficult to observe experimentally. The latter has due to spontaneous breaking of local supersymmetry non-zero mass and long lifetime [5]. The spin $\frac{1}{2}$ fermions are supposed to be observable only above $\Lambda_{cr}$ but an unbound light scalar charge $\frac{1}{3}$ particle seems possible. The intended test of the framework is constructing consistent models for supergravity and beyond as well as finding a quantitative model for superon phase transition behind baryon and lepton asymmetry.

References


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3The 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.


