A Chern-Simons model for baryon asymmetry

Risto Raitio*
02230 Espoo, Finland

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Abstract

In search of a phenomenological model that would describe physics from Big Bang to the Standard Model (SM), we propose a model with the following properties (i) above an energy about $\Lambda_{cr} > 10^{16}$ GeV there are Wess-Zumino supersymmetric preons and Chern-Simons (CS) fields, (ii) at $\Lambda_{cr} \sim 10^{16}$ GeV spontaneous gauge symmetry breaking takes place in the CS model and the generated topological mass providing attractive interaction to equal charge preons, (iii) well below 10^{16} GeV the model reduces to the standard model with essentially pointlike quarks and leptons, having a radius $\sim 10^{-31}$ m. The baryon asymmetry turns out to have a fortuitous ratio $n_B/n_\gamma \ll 1$.

Keywords: Isospin violation, Baryon asymmetry, Supersymmetry, Chern-Simons model

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

1 Introduction

The observation of expanding baryon asymmetric universe is about 100 years old. The concordance (standard) model [2] has been developed explaining observations though not with the same precision and extension as in particle physics. Even unexplained observations exist like dark matter and baryon asymmetry.

In this note we take a first step to draft a model for both particles and cosmology with simplicity as the main principle of unification. It is commonly understood that the quark electric charges and running interaction coupling constants in the standard model (SM) imply a large unified gauge group with rich spectra of particles. We take an alternative position of keeping number of elementary particles small, determined by global supersymmetry, and fermions obeying Dirac equation with SM gauge interactions. In addition, we reinforce our previous model by topological concepts of Chern-Simons model.

We split quarks in three pointlike constituents, called in this note chermons (synonym for preon[1] or superon). Of the preon models in the literature there are two of them which are like ours. One of them was proposed by Harari, and independently by Shupe [4, 5]. The model of Finkelstein [6] was developed from a different basis, including the quantum symmetry group SLq(2) and knot theory. It turned out, however, to agree with [4, 5]. The major difference between the above models and our model [7, 8] is that ours has its basis in unbroken global supersymmetry where superpartners are in the model initially, not as new sparticles to be found in the future.

The scale where three chermon bound states form, making the standard model particles in 1+3 dimensions, is assumed to be near the usual grand unified theory (GUT) scale, about 10^{16} GeV, denoted here by Λ_{cr}. Below Λ_{cr} all the four preon scenarios of the previous paragraph revert to the standard model at accelerator energies. Above Λ_{cr} in the early universe chermons are located nearly fixed in the comoving frame of the rapidly expanding universe making the 1+2 dimensional potential energy description a reasonable approximation.

Chern-Simons-Maxwell (CSM) models (3.1) have been studied in condensed matter physics papers, e.g. [9, 10, 11]. In this note, instead, we apply the CSM model in particle physics phenomenology at high energy in the early universe.

We construct the visible matter of two fermionic chermons: (i) one charged m^-, (ii) one neutral m^0_V, V = R, G, B, carrying quantum chromodynamics (QCD) color, and the photon A. The action is C symmetric. The chermons have zero (or small) mass. Weak interactions operate below Λ_{cr} between quarks and leptons, just as in SM. The chermon baryon (B) and lepton (L) numbers are zero. Given these quantum numbers, leptons and quarks consist of three chermons, as indicated in table 1. There could be more composite states like those containing m^+m^- pair. This annihilates immediately into other particles, which form later leptons and quarks.

[1] The term was coined by Pati and Salam in 1974 [3]. This note did include also baryon asymmetry discussion.

SM quark	chermon state
u_R	$m^+m^+m^0_R$
u_G	$m^+m^+m^0_G$
u_B	$m^+m^+m^0_B$
d_R	$m^-m^0_Gm^0_B$
d_G	$m^-m^0_Bm^0_R$
d_B	$m^-m^0_Rm^0_G$

Table 1: Quark-chermon correspondence. The upper index of m is charge zero or $\pm\frac{1}{3}$. The lower index is color R, G or B.

The article is organized as follows. In section 2 we present the Wess-Zumino model kinetic terms of the supersymmetric chermons and some scalars. The full Chern-Simons-QED$_3$ action is given in section 3. The chermon-chermon interaction potential is disclosed in 4. A mechanism for baryon asymmetry based on the results of the previous sections is proposed in section 5. Conclusions are given in section 7. In the appendix A a table of visible and dark matter is shown.

2 Wess-Zumino action kinetic terms

We briefly recap our chermon (superon) scenario of [7, 8], which turned out to have close resemblance to the simplest $N = 1$ globally supersymmetric 4D model, namely the free, massless Wess-Zumino model [12, 13] with the kinetic Lagrangian including three neutral fields m, s, and p with $J^P = \frac{1}{2}^+, 0^+$, and 0^-, respectively

$$\mathcal{L}_{\mathrm{WZ}} = -\frac{1}{2}\bar{m}\partial\!\!\!/ m - \frac{1}{2}(\partial s)^2 - \frac{1}{2}(\partial p)^2 \tag{2.1}$$

where m is a Majorana spinor, s and p are real fields (metric is mostly plus).

We assume that the pseudoscalar p is the axion [14], and denote it below as a. It has a fermionic superparther, the axino n, and a bosonic superpartner, the saxion s^0.

In order to have visible matter we assume the following charged chiral field Lagrangian

$$\mathcal{L}_{-} = -\frac{1}{2}m^-\partial\!\!\!/ m^- - \frac{1}{2}(\partial s_i^-)^2, \quad i = 1, 2 \tag{2.2}$$

3 Chern-Simons-QED$_3$ action

A number of 1+2 dimensional models have properties close to 1+3 dimensional world as can be found in [9, 15, 16], see also [17]. Our choice here is 1+2 dimensional Chern-Simonss (CS) action is [18, 19]

$$S = \frac{k}{4\pi} \int_M \mathrm{tr}(\mathrm{A} \wedge \mathrm{dA} + \frac{2}{3} \mathrm{A} \wedge \mathrm{A} \wedge \mathrm{A}) \tag{3.1}$$

where k is the level of the theory and A the connection.

The action for a Chern-Simons-QED$_3$ model [11, 20] including two polarization $\pm$ fermionic fields (ψ_+, ψ_-), a gauge field A_μ and a complex scalar field φ with spontaneous breaking of local U(1) symmetry is

$$\begin{aligned} S_{\mathrm{CS-QED_3}} = \int d^3x \{ &-\frac{1}{4} F^{\mu\nu} F_{\mu\nu} + i\overline{\psi}_+ \gamma^\mu D_\mu \psi_+ + i\overline{\psi}_- \gamma^\mu D_\mu \psi_- \\ &+ \frac{1}{2} \theta \epsilon^{\mu v \alpha} A_\mu \partial_v A_\alpha - m_e(\overline{\psi}_+ \psi_+ - \overline{\psi}_- \psi_-) \\ &- y(\overline{\psi}_+ \psi_+ - \overline{\psi}_- \psi_-) \varphi^* \varphi + D^\mu \varphi^* D_\mu \varphi - V(\varphi^* \varphi) \}, \end{aligned} \tag{3.2}$$

where the covariant derivatives are $D_\mu \psi_\pm = (\partial_\mu + ie_3 A_\mu)\psi_\pm$ and $D_\mu \varphi = (\partial_\mu + ie_3 A_\mu)\varphi$. θ is the important topological parameter and e_3 is the coupling constant of the $U(1)$ local gauge symmetry, here with dimension of (mass)$^{1/2}$. $V(\varphi^*\varphi)$ represents the self-interaction potential,

$$V(\varphi^*\varphi) = \mu^2 \varphi^*\varphi + \frac{\zeta}{2}(\varphi^*\varphi)^2 + \frac{\lambda}{3}(\varphi^*\varphi)^3 \tag{3.3}$$

which is the most general sixth power renormalizable potential in 1+2 dimensions [21]. The parameters μ, ζ, λ and y have mass dimensions 1, 1, 0 and 0, respectively. For potential parameters $\lambda > 0, \zeta < 0$ and $\mu^2 \leq 3\zeta^2/(16\lambda)$ the vacua are stable.

In 1+2 dimensions, a fermionic field has its spin polarization fixed up by the sign of mass [22]. The model includes two positive-energy spinors (two spinor families). Both of them obey Dirac equation, each one with one polarization state according to the sign of the mass parameter.

The vacuum expectation value v of the scalar field φ is given by:

$$\langle \varphi^* \varphi \rangle = v^2 = -\zeta/\left(2\lambda\right) + \left[\left(\zeta/\left(2\lambda\right)\right)^2 - \mu^2/\lambda \right]^{1/2} \tag{3.4}$$

The condition for its minimum is $\mu^2 + \frac{\zeta}{2} v^2 + \lambda v^4 = 0$. After the spontaneous symmetry breaking, the scalar complex field can be parametrized by $\varphi = v + H + i\theta$, where H represents the Higgs scalar field and θ the would-be Goldstone boson. For manifest renormalizability one adopts the 't Hooft gauge by adding the gauge fixing term $S^{gt}_{R_\xi} = \int d^3x[-\frac{1}{2\xi}(\partial^\mu A_\mu - \sqrt{2}\xi M_A \theta)^2]$ to the broken action. Keeping only the bilinear and the Yukawa interaction terms one has the following action

$$
\begin{aligned}
S^{\mathrm{SSB}}_{\mathrm{CS-QED}} = \int d^3x \Big\{ & -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} + \frac{1}{2}M_A^2 A^\mu A_\mu \\
& - \frac{1}{2\xi}(\partial^\mu A_\mu)^2 + \overline{\psi}_+(i\partial\!\!\!/ - m_{eff})\psi_+ \\
& + \overline{\psi}_-(i\partial\!\!\!/ + m_{eff})\psi_- + \frac{1}{2}\theta\epsilon^{\mu v\alpha}A_\mu\partial_v A_\alpha \\
& + \partial^\mu H \partial_\mu H - M_H^2 H^2 + \partial^\mu\theta\partial_\mu\theta - M_\theta^2\theta^2 \\
& - 2yv(\overline{\psi}_+\psi_+ - \overline{\psi}_-\psi_-)H - e_3\left(\overline{\psi}_+ A\!\!\!/\psi_+ + \overline{\psi}_- A\!\!\!/\psi_-\right)\Big\}
\end{aligned} \tag{3.5}
$$

where the mass parameters

$$
M_A^2 = 2v^2e_3^2, \quad m_{eff} = m_e + yv^2, \quad M_H^2 = 2v^2(\zeta + 2\lambda v^2), \quad M_\theta^2 = \xi M_A^2 \tag{3.6}
$$

depend on the SSB mechanism. The Proca mass, M_A^2originates from the Higgs mechanism. The Higgs mass, M_H^2, is associated with the real scalar field. The Higgs mechanism also contributes to the chermon mass, resulting in an effective mass m_{eff}. There are two photon mass-terms in (3.5), the Proca and the topological one.

4 Chermon-chermon interaction

The chermon-chermon 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 (3.5) [11].

The gauge invariant effective potential for the scattering considered is obtained in [23, 24]

$$
V_{\mathrm{CS}}(r) = \frac{e^2}{2\pi}\left[1 - \frac{\theta}{m_e}\right]K_0(\theta r) + \frac{1}{m_e r^2}\left\{l - \frac{e^2}{2\pi\theta}[1 - \theta r K_1(\theta r)]\right\}^2 \tag{4.1}
$$

where $K_0(x)$ and $K_1(x)$ are the modified Bessel functions and l is the angular momentum ($l = 0$ in this note). In (4.1) the first term [ ] corresponds to the electromagnetic potential, the second one $\{\ \}^2$ contains the centrifugal barrier $\left(l/mr^2\right)$, the Aharonov-Bohm term and the two photon exchange term.

One sees from (4.1) 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 chermons. Being embarrassed of having no data points for several parameters in (4.1) we can give one relation between these parameter values for a negative potential. We must have the condition[2]

$$\theta \gg m_e \tag{4.2}$$

The potential (4.1) also depends on v^2, the vacuum expectation value, and on y, 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.

5 Baryon asymmetry

We now examine the potential (4.1) in the early universe. Consider large number of groups of twelve chermons each group consisting of four m^+, four m^- and four m^0 particles. Any bunch may form only hydrogen (H) atoms, only anti-hydrogen ($\bar{\mathrm{H}}$) or some combination of both H and $\bar{\mathrm{H}}$ atoms [7, 8]. This is achieved by arranging the chermons appropriately (mod 3) using table 2. This way the transition from matter-antimatter symmetric universe to matter-antimatter asymmetric one happens straightforwardly.

When the Yukawa force (4.1) is the strongest force each chermon in an electron and positron is tightly bound to the two other chermons. Therefore the e^-, e^+ and the neutrinos are expected to form first at the onset of inflation. To obey condition $B - L = 0$ of baryon-lepton balance and to sustain charge conservation, for one electron made of three chermons, a proton containing nine chermons has to be created. Likewise, one neutrino requires a neutron to be created. The m^0 carries in addition color enhancing neutrino formation. This makes neutrinos different from other leptons and the quarks.

Because chermons choose at random whether they are constituents of H or $\bar{\mathrm{H}}$ there are regions of space of various sizes dominated by H or $\bar{\mathrm{H}}$ atoms. Since the universe is the largest statistical system it is expected that there is only a very slight excesses of H atoms (or $\bar{\mathrm{H}}$ atoms which only means a charge sign redefinition) which remain after the equal amounts of H and $\bar{\mathrm{H}}$ atoms have annihilated. The ratio n_B/n_γ is thus predicted to be $\ll 1$. The ratio n_B/n_γ is a multiverse-like concept.

Fermionic dark matter has in this scenario no mechanism to become "baryon" asymmetric like visible matter. Therefore we expect that part of fermionic dark matter has annihilated into bosonic dark matter. Secondly, we predict there should exist both dark matter and anti-dark matter clumps attracting visible matter in the universe. Collisions of anti-dark matter and dark matter celestial bodies would give us a new source for wide spectrum gravitational wave production (the lunar mass alone is $\sim 10^{49}$ GeV).

[2]For applications to condensed matter physics, one must require $\theta \ll m_e$, and the scattering potential given by (4.1) then comes out positive [11].

6 Nucleon isospin violation

Care must be taken not to do double counting for d/u-quark mass difference with respect to CS-QED$_3$ calculations and QCD/QED lattice results.[3]

The topological mass works in favor of heavier d-quark and neutron, in qualitative agreement with lattice calculations. It is plausible that the topological terms in action (3.2) are very small on scales $\ll \Lambda_{cr}$ in 1+3 dimensions and therefore QCD/QED only contribute to the mass difference.

7 Conclusions and Outlook

Above Λ_{cr} the fermionic chermons are C symmetric with equal masses and charges symmetrically around zero: {-1/3, 0, 1/3}. Below the transition energy Λ_{cr} fractional charge chermon composites form quarks while charge zero and one states are leptons as shown in table 2. These composite states behave to a good approximation like pointlike particles: the composite radius being of the order of 10^{-31} m corresponding to a photon energy of $\Lambda_{cr} \sim 10^{16}$ GeV. Below this energy the standard model is obtained [4, 5, 6, 8] and photons lose their resolving power to differentiate the Yukawa trapped chermons inside SM particles.

The main results of this note are the Chern-Simons-QED$_3$ extension of the Wess-Zumino Lagrangian (2.1), (2.2) and the viable mechanism for baryon asymmetry with the ratio $n_B/n_\gamma \ll 1$. Large scale cosmological simulations are needed to obtain detailed information of the properties of the model proposed above. The central experimental test of our scenario is finding no broken supersymmetry (MSSM) superpartners [26] in the universe.

On the theoretical side the situation is interesting. When the Chern-Simons, or Kodama, state

$$\psi(A) = \mathcal{N} \exp\Big(- \frac{3}{2l_{\mathrm{Pl}}^2 \Lambda} Y_{CS} \Big) \tag{7.1}$$

where l_{Pl} is the Planck length and Λ the cosmological constant and

$$Y_{\mathrm{CS}} = \int A^I dA^I + \frac{1}{3} \epsilon_{IJK} A^I A^J A^K \tag{7.2}$$

is reduced to mini-superspace it becomes, with some reservations, the Fourier dual of the Hartle-Hawking wave function of the universe [27, 28, 29].

Another interesting matter, though likewise troubled, is the possible connection of the Kodama state to quantum gravity [30].

[3] In this section we revise our treatment of the masses in question which was without reason ignored SM [25]. Baryon asymmetry, however, was included, though dropped by chance from the title.

A Chermon-particle correspondence

The table 2 gives the chermon content of SM matter and a proposal for dark matter.

SM Matter	chermon state
ν_e	$m_R^0 m_G^0 m_B^0$
u_R	$m^+ m^+ m_R^0$
u_G	$m^+ m^+ m_G^0$
u_B	$m^+ m^+ m_B^0$
e^-	$m_R^- m_G^- m_B^-$
d_R	$m^- m_G^0 m_B^0$
d_G	$m^- m_B^0 m_R^0$
d_B	$m^- m_R^0 m_G^0$
Dark Matter	**chermon state**
boson (or BC)	axion(s), s^0
e'	axino n
meson, baryon o	$n\bar{n}, 3n$
nuclei (atoms with γ')	multi n
celestial bodies	any dark stuff
black holes	any chermon

Table 2: Visible and Dark Matter with corresponding particles. m^0 is color triplet, $m^\pm$ are color singlets. e' and γ' refer to dark electron and dark photon, respectively. BC stands for Bose condensate. Identical chermon state antisymmetrization not shown.

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in November 1974 at SLAC. I proposed that the c-quark would be an 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.

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