BARYOGENESIS MOTIVATED ON STRING CPT VIOLATION

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We discuss a mechanism for generating the baryon asymmetry of the Universe that involves a putative violation of CPT symmetry arising from string interactions.

1 Introduction

In this contribution we describe a baryogenesis mechanism based on a possible violation of the CPT symmetry that arises in string field theory. Our mechanism is based on the observation that certain string theories may spontaneously break CPT symmetry and Lorentz invariance. If CPT and baryon number are violated then a baryon asymmetry can be generated in thermal equilibrium. We assume that the source of baryon-number violation is due to processes mediated by heavy leptoquark bosons of mass $M_X$ in a generic GUT whose details are not important in our discussion.

The CPT-violating interactions are shown to arise from the trilinear vertex of non-trivial solutions of the field theory of open strings and in the corresponding low-energy four-dimensional effective Lagrangian via couplings between Lorentz tensors $N$ and fermions. The CPT and Lorentz invariance violation appears when components of $N$ acquire non-vanishing vacuum expectation values $\langle N \rangle$. For simplicity, we consider here only the subset of the CPT-violating terms leading directly to momentum- and spin-independent energy shift of particles relative to antiparticles that are diagonal in the fermion fields, $\psi$, and involve expectation values of only the time components of $N$:

$$\mathcal{L}_I = \frac{\lambda \langle N \rangle}{M_S^k} \psi (\gamma^0)^{k+1} (i\partial_0)^k \psi + h.c. + ... , \quad (1)$$

where $\lambda$ is a dimensionless coupling constant and $M_S$ a string mass scale which is presumably close to the Planck scale. Since no large CPT violation has been observed, the expectation value $\langle N \rangle$ must be suppressed in the low-energy effective theory. The suppression factor is some non-negative power $l$ of the ratio of the low-energy scale $m_l$ to $M_S$, that is $\langle N \rangle = \langle m_l / M_S \rangle^l M_S$. Since each factor of $i\partial_0$ also provide a low-energy suppression, the condition $k + l = 2$ corresponds to the dominant terms. Assuming that each fermion represents a standard-model quark of mass $m_q$ and baryon number $1/3$, then the energy splitting between a quark and its antiquark arising from Eq. (1) can be viewed as an effective chemical potential,

$$\mu \sim \left( \frac{m_l}{M_S} \right)^l \frac{E^k}{M_S^{k-1}} , \quad (2)$$

driving the production of baryon number in thermal equilibrium.
The equilibrium phase-space distributions of quarks $q$ and antiquarks $\bar{q}$ at temperature $T$ are $f_q(\vec{p}) = (1 + e^{(E - \mu)/T})^{-1}$ and $f_{\bar{q}}(\vec{p}) = (1 + e^{(E + \mu)/T})^{-1}$, respectively, where $\vec{p}$ is the momentum and $E = \sqrt{m_q^2 + \vec{p}^2}$. If $g$ is the number of internal quark degrees of freedom, then the difference between the number densities of quarks and antiquarks is

$$n_q - n_{\bar{q}} = \frac{g}{(2\pi)^3} \int d^3p \ [f_q(\vec{p}) - f_{\bar{q}}(\vec{p})] . \quad (3)$$

The contribution to the baryon-number asymmetry per comoving volume is given by

$$n_B / s \equiv (n_q - n_{\bar{q}}) / s,$$ 

and on its turn the entropy density $s(T)$ of relativistic particles is given by

$$s(T) = \frac{2\pi^2}{45} g_s(T) T^3 , \quad (4)$$

where $g_s(T)$ is the sum of the number of degrees of freedom of relativistic bosons and fermions at temperature $T$.

As shown in Ref. [1] it follows from eqs. (3) and (4) that each quark generates a contribution to the baryon number per comoving volume of

$$n_q - n_{\bar{q}} \sim \frac{45g}{2\pi^3 g_s(T)} I_k(m_q/T) , \quad (5)$$

where

$$I_k(r) = \int_r^{\infty} dx \frac{x\sqrt{x^2 - r^2}}{\cosh x + \cosh(\lambda_k x^k)} \sinh(\lambda_k x^k) \cosh x$$

and

$$\lambda_k = \left( \frac{m_l}{M_S} \right)^l \left( \frac{T}{M_S} \right)^{k-1} . \quad (6)$$

The relevant case for baryogenesis is $k = 2$ and $\lambda_2 = T/M_S$. A good estimate of the integral $I_2(m_q/T)$ can be obtained by setting $m_q/T$ to zero, since fermion masses either vanish or are much smaller than the decoupling temperature $T_D$ and hence $I_2(m_q/T) \approx I_2(0) \approx 7\pi^4 T / 15 M_S$. This yields for six quark flavours a baryon asymmetry per comoving volume given by

$$\frac{n_B}{s} \approx \frac{3}{5} \frac{T}{M_S} . \quad (7)$$

Therefore for an appropriate value of the decoupling temperature $T_D$, the observed baryon asymmetry of the Universe $n_B/s \approx 10^{-10}$, can be obtained provided the interactions violating baryon number are still in thermal equilibrium at this temperature. In estimating the value of $T_D$, dilution effects must be taken into account.

A particularly relevant source of baryon asymmetry dilution are the baryon violating sphaleron transitions. These processes are unsuppressed at temperatures above the electroweak phase transition. Assuming the GUT conserves the quantity $B - L$, $B$ and $L$ denoting the total baryon- and lepton-number densities, sphaleron-induced baryon-asymmetry dilution occurs when $B - L$ vanishes, and hence

$$\frac{n_B}{s} \approx \left( \frac{m_L}{T_W} \right)^2 \frac{T_D}{M_S} . \quad (8)$$
Taking the heaviest lepton to be the tau and the freeze-out temperature $T_W$ to be the electroweak phase transition scale, then the baryon asymmetry generated via GUT and CPT violating processes is diluted by a factor of about $10^{-6}$. Thus, the observed value of the baryon asymmetry can be reproduced if, in a GUT model where $B - L = 0$ initially, baryogenesis takes place at a decoupling temperature $T_D \simeq 10^{-4}M_S$, followed by sphaleron dilution. This value of $T_D$ is shown to be close to the GUT scale and leptoquark mass $M_X$, as required for consistency.

In the less interesting case of GUT models where initially $B - L \neq 0$, as already mentioned, spharelon dilution effects are not important, however other mechanisms such as for instance dilaton decay, can set the baryon asymmetry (8) to the observed value.

We point out that the decoupling temperature $T_D \simeq 10^{-4}M_S$ is sufficient low for our baryogenesis mechanism to be compatible with string-inspired primordial supergravity inflationary models.

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