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The Role of Particle Creation Processes in the Scalar Condensate Baryogenesis Model

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Abstract. We discuss a scalar field baryogenesis model with a complex scalar field φ, carrying a baryon charge $B \neq 0$, generated at inflation.We follow the evolution of φ, accounting for particle creation processes in different ways (qualitatively and quantitatively). It was shown that B evolution and the final value of B after φ decay, numerically calculated with a precise account for particle creation processes, gives considerably different results from those calculated semi-analytically. Hence, a numerical approach is necessary for more reliable calculation of B and the baryon asymmetry of the Universe. We have calculated numerically the produced baryon asymmetry for natural ranges of model parameters.

1 Introduction

The existence of a local baryon asymmetry $\beta = (n_B - n_{\bar{B}})/n_\gamma$ is still an unresolved cosmological mistery. The observational data from cosmic rays and gama rays experiments show a strong predominance of matter over antimatter in our vicinity up to 1 Mpc. The value of β is usually defined as $\beta = (n_B - n_{\bar{B}})/n_\gamma \sim n_B/n_\gamma = \eta$, where η is the baryon to photon density and η is determined in different ways, the most precise being: from D measurements towards low metalicity quasars and Big Bang nucleosynthesis (BBN) [1], and using BBN based on observational data of D, ^{3}He, ^{4}He, ^{7}Li [2, 3]. The most precision observational determination is given from CMB anisotropy measurements by WMAP $\eta = 6, 1.10^{-10}$ [4].

Due to considerations based on the existence of an inflationary period, it is known that $\beta \neq 0$ may not be postulated as an initial condition [5]. The baryon asymmetry should be generated in the early Universe before BBN epoch. There exist different types of baryogenesis models [6, 7].

Here we discuss a scalar field condensate baryogenesis model (SCB), similar to the pioneer models discussed in refs. [8, 9], based on the Affleck and Dine baryogenesis scenario [10]. We examine the most natural case when after inflation there exist two scalar fields - the inflaton ψ and the scalar field φ and the inflaton density dominates: $\rho_\psi > \rho_\varphi$. Hence, $\psi = m_{PL}(3\pi)^{-1/2}\sin(m_\psi t)$ and $H = 2/(3t)$. We follow numerically the evolution of $\varphi(t)$ after inflation until the B-conservation (BC) epoch. In the expanding Universe, φ satisfies the equation of motion:

$$\ddot{\varphi} - a^{-2}\partial_i^2\varphi + 3H\dot{\varphi} + \frac{1}{4}\Gamma\dot{\varphi} + U'_\varphi = 0,$$

where

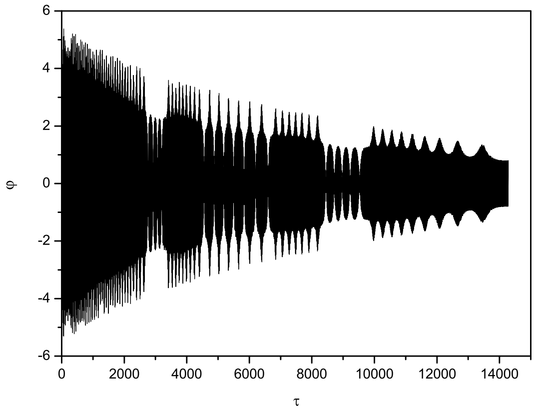
$$U(\varphi) = m^2\varphi^2 + \frac{\lambda_1}{2}|\varphi|^4 + \frac{\lambda_2}{4}(\varphi^4 + \varphi^{*4}) + \frac{\lambda_3}{4}|\varphi|^2(\varphi^2 + \varphi^{*2})$$

is the field potential. The term containing Γ accounts for the particle creation processes. The initial conditions are taken to be $\varphi_o^{max} = 2^{-1/4}H\lambda^{-1/4}$ and $\dot{\varphi}_o = H^2$ based on the natural assumption that the energy density of φ at inflation is $\sim H^4$. At early epoch, when $\varphi >> m$, the field φ oscillates with a decreasing amplitude because of the Universe expansion and the particle production processes. In case it oscillates, φ is damped due to the coupling to fermions $g\varphi\bar{f}_1 f_2$ and B is damped as well [9, 11]. If the damping is slow, B, contained in φ could survive until the BC epoch $\varphi \sim m$. At late times, when $\varphi \sim m$, the field φ decays into quarks and leptons $\varphi \to q\bar{q}\gamma$ with mean baryon charge $B \neq 0$. The generated β is determined by this B transferred to quarks.

2 Numerical Analysis

We studied numerically the evolution of $\varphi(t)$ in the period after inflation until the BC epoch. The tipical range of energies discussed is $10^{12} - 100$ GeV. We analyzed φ evolution for natural ranges of values of the model's parameters: $\lambda = 10^{-2} - 5\times 10^{-2}, \alpha = 10^{-3} - 5\times 10^{-2}, H = 10^7 - 10^{12}GeV, m = 100 - 800GeV$. Particle creation processes play essential role for the determination of β [8,11], hence it is important to account for them as precisely as possible. We accounted for particle production processes in two different ways, namely qualitatively - using the analytical form for $\Gamma = \alpha\Omega$, where the frequency Ω is estimated as $\Omega \sim \lambda^{1/2}\varphi$, $g^2/4\pi = \alpha$, and quantitatively - calculating numerically Ω at each step. We solved the system of ordinary differential equations, corresponing to the equation of motion for the real and imaginary part of φ, by Runge-Kutta 4th order method for both cases. We have found that the results for φ and B evolution and the final value of B at BC epoch considerably differ when different accounts for particle creation processes are made.

In Figures 1 and 2, we illustrate the evolution $B(\tau)$ for fixed model's parameters $\lambda_1 = 5\times10^{-2}, \lambda_2 = \lambda_3 = 5\times10^{-4}, \alpha = 10^{-3}, H = 10^{11}GeV, m = 350GeV$, $\varphi_o = 2^{-1/4}H\lambda^{-1/4}$, and $\dot{\varphi}_o = H^2$, and in two different cases, namely when the particle creation is accounted either numerically or analytically. The amplitude of B_{num} decreases more sharply than the amplitude of B_{anal} and hence at BC



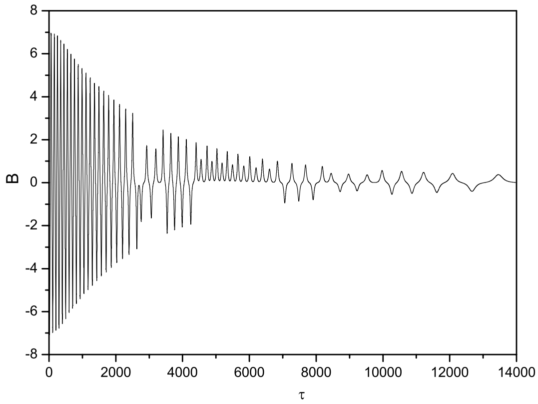


Figure 1. The evolution of the scalar field $\varphi(\tau)$ and the baryon charge $B(\tau)$ for $\lambda_1 = 5 \times 10^{-2}$, $\lambda_2 = \lambda_3 = 5 \times 10^{-4}$, $\alpha = 10^{-3}$, $H = 10^{11} GeV$, $m = 350 GeV$, $\varphi_o = 2^{-1/4} H \lambda^{-1/4}$, and $\dot{\varphi}_o = H^2$. The particle creation processes are accounted analitically.

epoch $B_{num} = -2.2 \times 10^{-3}$ and $B_{anal} = -1.7 \times 10^{-2}$. *Therefore, a precise numerical approach for the account of particle creation processes is necessary for constructing a realistic baryogenesis model.*

We have calculated β produced for different range of model's parameters.

Using the numerical account for Γ we have calculated $B(\tau)$ for $\alpha = 10^{-3}, 10^{-2}, 5 \times 10^{-3}$ and fixed other parameters. The dependence of B on α is very strong, as can be expected, knowing that particle creation processes play essential role for the evolution of the field and the baryon charge, contained in

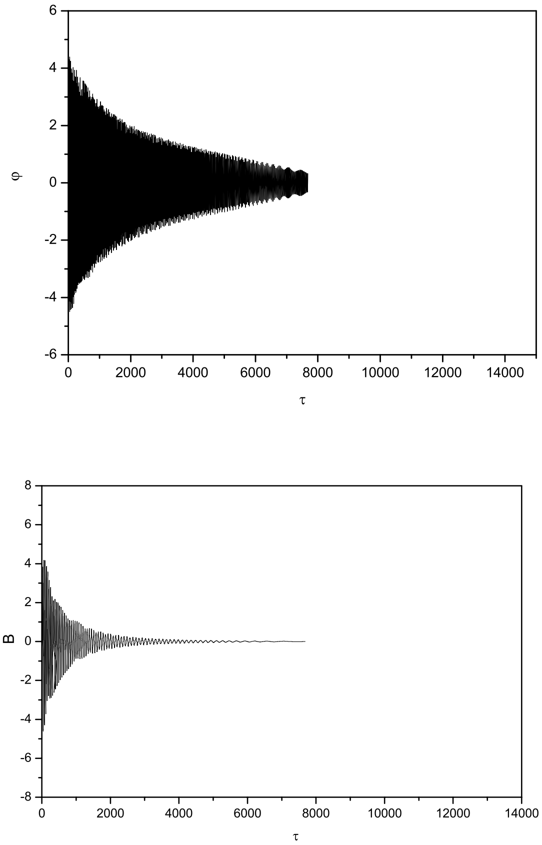


Figure 2. The evolution of the scalar field $\varphi(\tau)$ and baryon charge $B(\tau)$ for $\lambda_1 = 5 \times 10^{-2}$, $\lambda_2 = \lambda_3 = 5 \times 10^{-4}$, $\alpha = 10^{-3}$, $H = 10^{11} GeV$, $m = 350 GeV$, $\varphi_o = 2^{-1/4} H \lambda^{-1/4}$, and $\dot{\varphi}_o = H^2$. The particle creation processes are accounted numerically.

it, and keeping in mind that $\Gamma = \alpha\Omega$. *With increasing α, B evolution becomes shorter and the final B decreases.* An illustration of this dependence $B(\alpha)$ is given in Figure 3.

We have followed the evolution $B(\tau)$ varying H for fixed values of the other parameters. Our analysis shows that *B evolution becomes longer and the final B value decreases with H increase.* We have calculated $B(\tau)$ varying m at fixed λ_1, λ_2, λ_3, α and H. *For lower values of m, B evolution is shorter and the final B value is smaller.* This behavior corresponds to the expected one, as far as m defines the onset of BC epoch. The results may be useful for constructing SCB baryogenesis models.

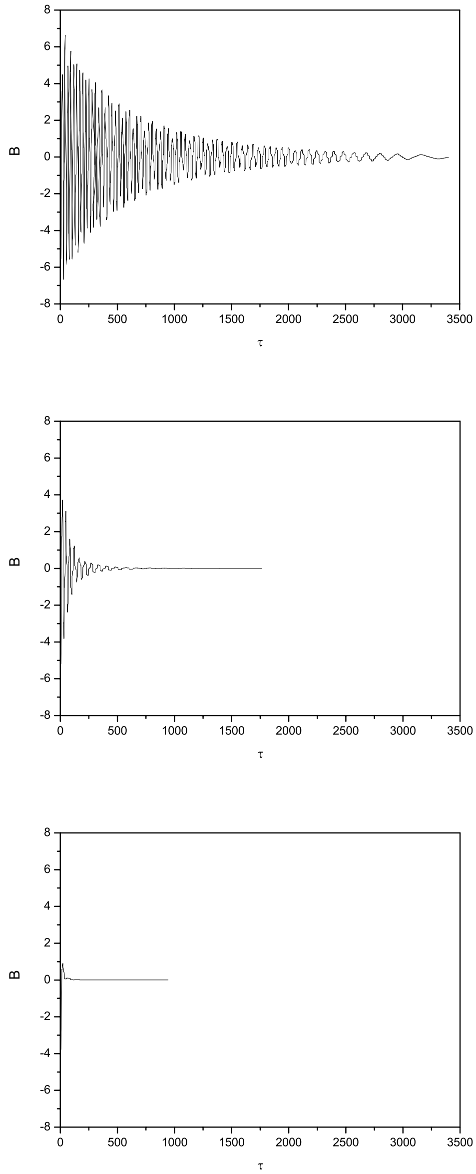


Figure 3. The evolution of the baryon charge $B(\tau)$ for $\lambda_1 = 5 \times 10^{-2}$, $\lambda_2 = \lambda_3 = 5 \times 10^{-4}$, $H = 10^{10} GeV$, $m = 350 GeV$, $\alpha = 10^{-3}, 10^{-2}, 5 \times 10^{-2}$.

3 Results and Conclusions

We have provided more precise numerical analysis of the Scalar Field Condensate baryogenesis model numerically accounting for the particle creation processes. We have showed that it is important to use a numerical approach to calculate Γ instead of analytical estimation because of the considerable difference in the obtained results. We have investigated the dependence of the baryon charge evolution and its final value on the model's parameters.

The results can be used to determine the range of the values of the model's parameters, necessary to produce the baryon asymmetry β, consistent with the observed one. Our preliminary analysis shows that for a natural range of SCB model's parameters, a value of β higher by an order of magnitude or two (depending on the parameters) than the observed one is obtained. This result points to the necessity of processes, diluting the produced β to its observed today value.

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