Possible CPT violation and the Baryon Asymmetry of the Universe

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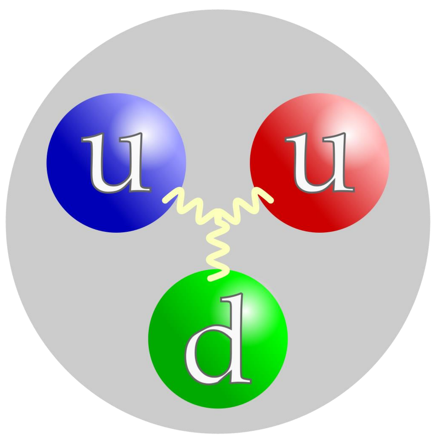
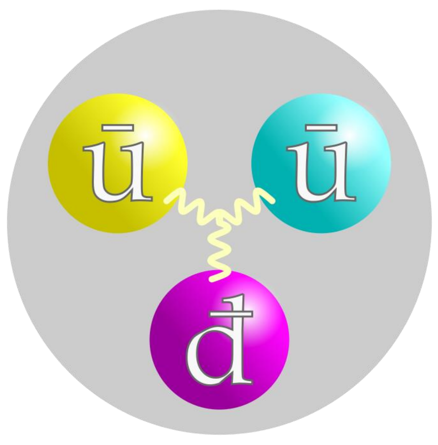
Introduction



After C.D. Anderson's discovery of the positron, the problem was obvious: for some unknown reasons the observable universe is matter dominated.
In the expanding universe without some disturbances in baryon-antibaryon ratio soon after the Big Bang, both matter and antimatter would have been annihilated and you would not have been reading this.



One of several competing models is baryogenesis, which requires the fulfillment of Sakharov's conditions, but we do not have relevant results in the Standard Model. Another way to explain the observed value of the Baryon Asymmetry of the Universe(BAU) is the matter-antimatter mass difference in the early universe, which is accompanied to possible CPT violation and it can happen in Friedmann-Robertson-Walker spaces. Therefore, the key may lie in the strong gravitational fields at the early stages of the Universe expansion.

Sakharov conditions

The ratio of protons and antiprotons evaluated using direct probes(PAMELA,FERMI) from other parts of our galaxy in the form of cosmic rays:

$$\frac{\bar{p}}{p} \sim 10^{-4}$$

The Baryon Asymmetry of the Universe(BAU) can be estimated by the baryon to photon ratio:

$$\eta = \left.\frac{n_b - n_{\bar{b}}}{n_\gamma}\right|_{T=3K} \approx \left.\frac{n_b}{n_\gamma}\right|_{T=3K}$$

From the experimental values:

$$\eta \sim 10^{-10}.$$

This asymmetry may have been created dynamically by baryognesis(production of matter excess).
Three necessary conditions for successful baryogenesis were first formulated by Sakharov(1967)

1. Baryon-number violation
2. C & CP violation(laws of nature must be biased so that a matter excess results and not an antimatter excess).
3. Departure from thermal nonequilibrium(an "arrow of time")

$$\Gamma(Y + B \to X) = \Gamma(X \to Y + B)$$

The Standard Model in principle fulfills all three Sakharov conditions, but effects are too small than the observed values:

1. B number is violated by sphaleron processes
   't Hooft(1976) showed that It is associated with the vacuum structure of SU(N) gauge theories with spontaneously broken symmetry. Using Chern-Simons number and baryon current:

   $$N_{CS} = \int d^3x K^0, \qquad K^\mu = \frac{g^2}{32\pi^2}\epsilon^{\mu\nu\alpha\beta}\left(F^a_{\nu\alpha}A^a_\beta - \frac{g}{3}\epsilon_{abc}A^a_\nu A^b_\alpha A^c_\beta\right)$$

   't Hooft discovered that tunneling occurs between n-vacua through field configurations called instatons. And he showed that the tunneling amplitude is:

   $$A \sim e^{-\frac{8\pi^2}{g^2}} \sim 10^{-173}$$

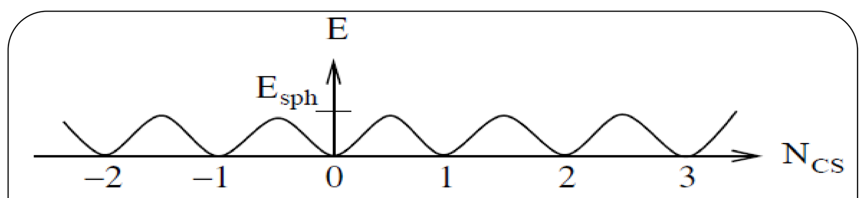
   

   Fig. 8. Energy of gauge field configurations as a function of Chern-Simons number.

   which is so small as to never have happened during the lifetime of the universe.
   In 1985 Shaposhnikov et al. – sphaleron processes
2. P, CP are violated by weak interactions
   Parity is violated in Kaon decays, beta-decays(Wu, 1957)
   CP violating decay: $K^0_L \to \pi^+\pi^-$ (1964)
3. Nonequilibrium condition is fulfilled due to the expansion of the universe

Conclusion

- Baryogenesis is very unlike to be achieved within SM
- Observed BAU can be explained by the possible violation of the CPT-theorem in the strong gravitational fields at early stages of the Universe expansion
- On GUT scale we have estimated the leptoquark-antileptoquark mass difference and we have got the observed BAU

$$\frac{\Delta m_X}{m_X} \sim 10^{-10}$$

Outlook

- Considering reheating epoch, where we would have T violation and thus possible CPT violation
- Estimate inflaton-antiinflaton mass difference during reheating epoch

Calculations

One of the applications of CPT theorem:
Mass and lifetime equality between particles and antiparticles

Find leptoquark-antileptoquark mass difference on GUT scale

$$\frac{\Delta m_X}{m_X} = (\dot{a}|_{\tau=0})\frac{\tau}{a_0}$$

Leptoquark acquires its mass in t time interval:

$$t \sim a_0\tau \sim \frac{(1 \div 10^{-1})}{m_X}, \tau = \int\frac{dt}{a(t)}, \tau \ll 1$$

considering dark-energy dominated era, i.e. during the period when $\rho = const,$ the evolution of the Universe is described by the de Sitter expansion law

$$a = a_0 \cdot e^{Ht} = \frac{a_0}{1 - a_0 H\tau}$$

where considering those constants

$$H = K\sqrt{\rho}, \qquad K = \sqrt{\frac{8\pi G}{3}}$$

Taking a derivative of scale factor

$$\dot{a} = a_0(1 - a_0 H\tau)^{-2}a_0 H = \frac{{a_0}^2 H}{(1 - a_0 H\tau)^2}|_{\tau=0} = {a_0}^2 H$$

And plugging into our main formula we get:

$$\frac{\Delta m_X}{m_X} \sim H a_0 \tau \sim Ht = K\sqrt{\rho} = \sqrt{\frac{8\pi G\rho}{3}} \sim (10^{-2} \div 1)\cdot\frac{m_X}{M_{pl}} \sim (10^{-2} \div 1)\cdot 10^{-4}$$

So we have estimated the observed value of BAU:

$$\boldsymbol{\frac{\Delta m_X}{m_X} \sim 10^{-10}}$$

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