

SPECIAL ISSUE

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Violation of CP invariance, C asymmetry, and baryon asymmetry of the universe

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Из записки С. Окубо
при довольно неуклюжем
для Вселенной сшива шубы
но ее кривой фигуре

Literal translation: *Out of S. Okubo's effect
At high temperature
A fur coat is sewed for the Universe
Shaped for its crooked figure.*

The theory of the expanding universe, which presupposes a superdense initial state of matter, apparently excludes the possibility of macroscopic separation of matter from antimatter; it must therefore be assumed that there are no antimatter bodies in nature, i.e., the universe is asymmetrical with respect to the number of particles and antiparticles (C asymmetry). In particular, the absence of antibaryons and the proposed absence of baryonic neutrinos implies a nonzero baryon charge (baryonic asymmetry). We wish to point out a possible explanation of C asymmetry in the hot model of the expanding universe (see Ref. 1) by making use of effects of CP invariance violation (see Ref. 2). To explain baryon asymmetry, we propose in addition an approximate character for the baryon conservation law.

We assume that the baryon and muon conservation laws are not absolute and should be unified into a "combined" baryon-muon charge $n_c = 3n_B - n_\mu$. We put

for antimuons μ_+ and $\nu_\mu = \mu_0$: $n_\mu = -1$, $n_K = +1$.

for muons μ_- and $\nu_\mu = \mu_0$: $n_\mu = +1$, $n_K = -1$.

for baryons P and N : $n_B = +1$, $n_K = +3$.

for antibaryons P and N : $n_B = -1$, $n_K = -3$.

This form of notation is connected with the quark concept; we ascribe to the p , n , and λ quarks $n_c = +1$, and to antiquarks, $n_c = -1$. The theory proposes that under laboratory conditions processes involving violation of n_B and n_μ play a negligible role, but they were very important during the earlier stage of the expansion of the universe.

We assume that the universe is neutral with respect to the conserved charges (lepton, electric, and combined), but C asymmetrical during the given instant of its development (the positive lepton charge is concentrated in the electrons and the negative lepton charge in the excess of antineutrinos over the neutrinos; the positive electric charge is concentrated in the protons and the negative in the electrons; the positive combined charge is concentrated in the baryons, and the

negative in the excess of μ neutrinos over μ antineutrinos).

According to our hypothesis, the occurrence of C asymmetry is the consequence of violation of CP invariance in the nonstationary expansion of the hot universe during the superdense stage, as manifest in the difference between the partial probabilities of the charge-conjugate reactions. This effect has not yet been observed experimentally, but its existence is theoretically undisputed (the first concrete example, Σ_+ and Σ_- decay, was pointed out by S. Okubo as early as 1958) and should, in our opinion, have much cosmological significance.

We assume that the asymmetry has occurred in an earlier stage of the expansion, in which the particle, energy, and entropy densities, the Hubble constant, and the temperatures were of the order of unity in gravitational units (in conventional units the particle and energy densities were $n \sim 10^{98} \text{ cm}^{-3}$ and $\epsilon \sim 10^{14} \text{ erg/cm}^3$).

M. A. Markov (see Ref. 3) proposed that during the early stages there existed particles with maximum mass of the order of one gravitational unit ($M_0 = 2 \times 10^{-5} \text{ g}$ in ordinary units), and called them maximons. The presence of such particles leads unavoidably to strong violation of thermodynamic equilibrium. We can visualize that neutral spinless maximons (or photons) are produced at $t < 0$ from contracting matter having an excess of antiquarks, that they pass "one through the other" at the instant $t = 0$ when the density is infinite, and decay with an excess of quarks when $t > 0$, realizing total CPT symmetry of the universe. All the phenomena at $t < 0$ are assumed in this hypothesis to be CPT reflections of the phenomena at $t > 0$. We note that in the cold model CPT reflection is impossible and only T and TP reflections are kinematically possible. TP reflection was considered by Milne, and T reflection by the author; according to modern notions, such a reflection is dynamically impossible because of violation of TP and T invariance.

We regard maximons as particles whose energy per particle ϵ/n depends implicitly on the average particle density n . If we assume that $\epsilon/n \sim n^{-1/3}$, then ϵ/n is proportional to the interaction energy of two "neighboring" maximons $(\epsilon/n)^2 n^{1/3}$ (cf. the arguments in Ref. 4). Then $\epsilon \sim n^{2/3}$ and

