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CP-NONINVARIANCE AND BARYON ASYMMETRY OF THE UNIVERSE

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We shall assume that at the present time the universe as a whole has a non-zero baryon number, i.e., baryon asymmetry exists, but the universe is neutral with respect to all other numbers and charges during the entire time of its existence. As to the baryon number, in the proposed model the universe is initially symmetrical with respect to it, and becomes asymmetrical only later. This is attained by introducing an interaction that does not conserve the baryon number and contains a CP-noninvariant admixture (cf. [1]). As will be shown here, the model explains in a natural manner the very occurrence of the baryon asymmetry and its magnitude.

Let us construct an interaction that does not conserve the baryon number. We write the interaction Hamiltonian in the form:

$$\begin{aligned}
 H &= (G/\sqrt{2}) J^\mu J_\mu^+, \\
 J^\mu &= J_W^\mu - i\alpha T^\mu - i\alpha J_W^{\mu'} + \beta B^\mu, \\
 J_W^\mu &= L^\mu + J^\mu + S^\mu, \quad J_W^{\mu'} = L^{\mu'} + J^{\mu'} + S^{\mu'}.
 \end{aligned}
 \tag{1}$$

Here  $G$  is the weak-interaction constant;  $J_W^\mu$  is the standard charged weak current;  $L^\mu$ ,  $J^\mu$ , and  $S^\mu$  are the lepton and strangeness-conserving and nonconserving currents, respectively; the current  $S^\mu$  satisfies the rule  $\Delta S = \Delta Q$ . The current  $T^\mu$  is the strangeness-nonconserving hadron current and satisfies the rule  $\Delta S = -\Delta Q$  [2]. The current  $T^\mu$  is defined in such a way that the corresponding terms in the Hamiltonian are CP-odd, and the value of the coefficient  $\alpha \sim 10^{-3}$  ensures the experimentally observed magnitude of the effects of CP-nonconservation in  $K^0$ -meson decay. The additional current  $\alpha J_W^{\mu'}$  introduced by us is a small CP-noninvariant admixture to the standard weak current. Finally, the current  $B^\mu$  does not conserve the Baryon number. Let  $E^\mu$  have the following structure:

$$B^\mu = (\bar{\kappa} C^\mu \rho) + (\bar{\kappa} C^\mu \Sigma \tau) + \dots \tag{2}$$

We have introduced here a new neutral fermion  $\kappa$  of the Majorana type, i.e.,  $\kappa \equiv \bar{\kappa}$ , so that it is possible to construct states satisfying the CP equation  $|\kappa\rangle = \pm |\bar{\kappa}\rangle$ . Thus, the current  $B^\mu$  satisfies the rule  $|\Delta B| = 1$ , where  $B$  is the baryon number.

Thus, the Hamiltonian contains the following terms:

$$\begin{aligned}
H &= H_w + H'_{w1} + H'_{w2} + H_\kappa + H'_{\kappa1} + H'_{\kappa2}, \\
H'_{w2} &= (i\alpha C/\sqrt{2})[J_w J_w'^+ - J_w' J_w^+], \\
H_\kappa &= (\beta C/\sqrt{2})[J_w B^+ + B J_w^+], \\
H'_{\kappa1} &= (i\alpha f G/\sqrt{2})[B T^+ - T B^+], \\
H'_{\kappa2} &= (i\alpha f C/\sqrt{2})[B J_w'^+ - J_w' B^+],
\end{aligned} \tag{3}$$

where  $H_w$  is the standard CP-even weak-interaction Hamiltonian,  $H'_{w1}$  is the Wolfenstein CP-odd Hamiltonian [2],  $H'_{w2}$  is a CP-odd term analogous to that introduced by Wolfenstein and resulting from multiplication of the currents  $J_w^\mu$  and  $J_w^{\mu'}$ , and  $H_\kappa$  and  $H'_\kappa$  are the CP-even and CP-odd parts of the Hamiltonian of interaction that does not conserve the baryon number.

The model described by equations (1) - (3) leads to the following results: 1) The introduced interaction causes decay of  $\kappa$  via the channels  $\kappa \rightarrow p l^- \bar{\nu}$ ,  $p \pi^-$ ,  $n \pi^0$ ,  $\Sigma^- \pi^+$ , etc. and also via the charge-conjugate channels  $\kappa \rightarrow \bar{p} l^+ \nu$ ,  $\bar{p} \pi^+$ ,  $\bar{n} \pi^0$ , etc. 2) CP-noninvariance and T-invariance may become violated in  $\kappa$  decay (as a result of interference between  $H_\kappa$  and  $H'_{\kappa2}$ ). The relative magnitude of the effects is  $10^{-9}$ . The most important fact is that charge asymmetry can occur in the  $\kappa$  decays.

The magnitude of the charge asymmetry is  $10^{-9}$  and does not depend on the absolute strength of the interaction  $\beta G$ , which does not conserve the baryon number.

It is possible to determine the current  $J^\mu$  without introducing the term  $J_w^{\mu'}$ , and to confine oneself to one CP-odd term in  $T^\mu$ . It can be shown that in this case charge symmetry occurs in the  $\kappa$  decays only if the current  $B^\mu$  contains a term satisfying the rule  $\Delta S = -\Delta Q$ .

It is known [3] that in the hot-universe model the baryon asymmetry amounts to  $10^{-9}$  over the entire early expansion stage.

Thus, the magnitude of the charge asymmetry in  $\kappa$  decay coincides with magnitude of the baryon asymmetry of the universe at the early stage.

Let us turn to cosmology and examine the conditions that  $\beta$  and  $m_\kappa$  must satisfy in order that the magnitude of the charge asymmetry in  $\kappa$  decay lead to the observed value of the baryon asymmetry of the universe. The required baryon asymmetry of matter occurs when the  $\kappa$  particles decay during the expansion stage, when the process in which  $\kappa$  takes part becomes non-equilibrium if the  $\kappa$  concentration at that instant is of the order of the nucleon concentration. This leads to the condition  $T(t) \sim n_\kappa$  at  $\tau \sim t$ , where  $\tau$  is the time of establishment of equilibrium [4] relative to the interaction described by  $H_\kappa$ . Taking into account the dependence of the temperature on the cosmological time [4]

$$T(t) \approx 10^{-3} t^{-1/2} m_p,$$

we obtain, estimating  $\tau$  in accord with [4]:

$$\beta^2 (n_\kappa / m_p) \sim 10^{-5}. \tag{4}$$

On the other hand, definite limitations on the possible values of  $\beta$  and  $m_\kappa$  follow from contemporary experimental data. The model in question

admits of the processes  $p + p \rightarrow \pi^+\pi^+$ ,  $p + p \rightarrow \ell^+ + \nu + \ell^+ + \nu$ ,  $n + n \rightarrow \pi^0 + \pi^0$ , etc., and also of the oscillating process  $n \rightleftharpoons \tilde{n}$  in second order in  $\beta G$ . Using the experimental data on the stability of the nucleons in the nucleus [5] and estimating the permissible value of the period of the oscillations of the free neutron at  $10^4$  sec, we obtain approximately equal limitations in both cases:  $\beta < 10^{-9}(m_\kappa/m_p)^{1/2}$ . Taking (4) into account we get  $\beta < 10^{-7}$  and  $(m_\kappa/m_p) > 10^3$ .

It should be noted that the diagram of the process  $n \rightleftharpoons \tilde{n}$  diverges, so that the estimate of the corresponding transition probability depends on the employed cutoff momentum (we chose  $\Lambda \sim m_p$ ). The obtained limitations on  $\beta$  and  $m_\kappa$  are still far from the values that should be ascribed to the maximons [6] if the  $\kappa$  particles are identified with them, namely  $m_\kappa \sim 10^{19} m_p$  and  $\beta \sim 10^{-33}$ .

It must be emphasized that, in light of the foregoing, searches for the process of baryon-number nonconservation are of great interest, especially searches for the oscillation process  $n \rightleftharpoons \tilde{n}$ .

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#### INSTABILITY OF INHOMOGENEOUS DEFORMATION AND OF CARRIER DENSITY IN A SEMICONDUCTOR, INDUCED BY A DEFORMATION POTENTIAL

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In an isotropically-elastic medium, in electron-phonon interaction via a deformation potential, the law of dispersion of the charge-acoustical longitudinal waves is given by [1]

$$(s^2 k^2 - \omega^2) \left( Dk^2 + \frac{1}{r} + i(kv - \omega) \right) - ADs^2 k^4 = 0, \quad A = \frac{b^2 n_0 \mu}{e \gamma s^2 D}. \quad (1)$$

The deformation, the carrier density, and the electrostatic potential are assumed to be proportional to  $\exp i[\vec{k} \cdot \vec{r} - \omega t]$ ,  $s$  is the velocity of longitudinal sound in the absence of carriers,  $D$ ,  $n_0$ ,  $\mu$ ,  $\tau$ , and  $\vec{v}$  are the diffusion coefficient, the equilibrium concentration, the mobility, the Maxwellian relaxation time, and the drift velocity of the carriers,  $\gamma$  is the density of the medium, and  $b$  is the constant of the deformation potential.

It is known [2] that when  $v > s$  Eq. (1) has roots  $k(\omega)$  corresponding to the growth of a sound wave in space or in time (amplification). However, it turns out that when  $A > 1$  the growth exists also when  $v < s$  and even in the