VIOLATION OF CP INVARIANCE IN K^0-MESON DECAYS AND THE NON-INVARIANT VACUUM

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As is well known, the decay $K_2^0 \to \pi^+\pi^-$ was observed in several recent experiments [1,2], thus casting doubt on the CP invariance of elementary-particle interactions.

In the present letter we develop the point of view that CP invariance can indeed be violated, but only in processes with K_1^0 and K_2^0 mesons. The reason for the violation is the very method by which K_1^0 and K_2^0 mesons are constructed from K^0 and $\overline{K}^0$, a method connected with a transition to a different, nonequivalent representation of the von Neumann ring creation and annihilation operators, namely to a different vacuum. The existence of two vacuums (invariant and non-invariant with respect to CP transformation) leads to the appearance, besides the K_1^0 and K_2^0 of the usual vacuum, also of particles constructed in the same manner as K_1^0 and K_2^0 but defined for a different vacuum. The possibility of such a degeneracy of K_1^0 and K_2^0 was pointed out in [3,4], but in our case $K_1^{0'}$ and $K_2^{0'}$ do not have any definite CP parity. The appearance of a different vacuum and the definition of $K_1^{0'}$ and $K_2^{0'}$ for it are in our model the consequences of strong interactions between the K^0 and $\overline{K}^0$ mesons.

Assume that we have a system of K^0 and $\overline{K}^0$ mesons which interact strongly with one another, so that the Lagrangian takes the form

$$L = g^{\mu\nu} \frac{\partial \overline{K}^0}{\partial x_\mu} \frac{\partial K^0}{\partial x_\nu} - \overline{K}^0 m^2 K^0 - g(\overline{K}^0 K^0)^2 \tag{1}$$

We write the Euler equation for K^0 and $\overline{K}^0$ in the approximation corresponding to the generalized Hartree-Fock method in the nonrelativistic theory of superconductivity, i.e., in analogy with [5,6], we replace the operator products K^0K^0 and $\overline{K}^0\overline{K}^0$ by averages over the vacuum $\langle\Phi|K^0K^0|\Phi\rangle$ and $\langle\Phi|\overline{K}^0\overline{K}^0|\Phi\rangle$. We then obtain for K^0 and $\overline{K}^0$

$$\left.\begin{aligned} (\Box - m'^2)K^0 &= 2g\langle\Phi|K^0K^0|\Phi\rangle\overline{K}^0 \\ (\Box - m'^2)\overline{K}^0 &= 2g\langle\Phi|\overline{K}^0\overline{K}^0|\Phi\rangle K^0 \end{aligned}\right\} \tag{2}$$

Here m'^2 is the result of the usual renormalization. From (2) we easily obtain an equation for the K_1^0 and K_2^0 mesons (more accurately, for $K_1^{0'}$ and $K_2^{0'}$).

Introducing the notation [5]:

$$\left.\begin{aligned} G^{00}(x - x') &= \langle\Phi|K^0(x)K^0(x')|\Phi\rangle \\ \tilde{G}^{00}(x - x') &= \langle\Phi|\overline{K}^0(x)\overline{K}^0(x')|\Phi\rangle \end{aligned}\right\} \tag{3}$$

We easily obtain in analogy with [5] the condition for $G^{00}(0)$ and $\tilde{G}^{00}(0)$, necessary for the existence of a nontrivial solution $G^0, \tilde{G}^0 \not\equiv 0$:

$$1 = -2ig\int\frac{\alpha^4 p}{(p^2 - m'^2)^2 - 4g^2G^{00}(0)\tilde{G}^{00}(0) - i\delta} \tag{4}$$

The theory developed by us is not invariant against gauge transformations which lead to strangeness conservation (the very method of "linearizing" the interaction, connected with the transition to a different vacuum, has led to the breaking of this symmetry). We have succeeded in this manner to go over to particles which are very similar to K_1^0 and K_2^0, yet without knowing anything concerning the weak interactions. Let us see what operators describe $K_1^{0'}$ and $K_2^{0'}$. We define:

$$\left.\begin{aligned} a^{(-)}(\bar{p}) &= (\eta_p K^{0(+)}(-\bar{p}) + \xi_p \bar{K}^{0(-)}(\bar{p})) \\ \bar{a}^{(+)}(\bar{p}) &= (\xi_p K^{0(+)}(\bar{p}) - \eta_p \bar{K}^{0(-)}(-\bar{p})) \\ \bar{a}^{(-)}(\bar{p}) &= (\eta_p \bar{K}^{0(+)}(-\bar{p}) + \xi_p K^{0(-)}(\bar{p})) \\ a^{(+)}(\bar{p}) &= (\xi_p K^{0(+)}(\bar{p}) - \eta_p K^{0(-)}(-\bar{p})) \end{aligned}\right\} \tag{5}$$

where

$$\xi_p^2 + \eta_p^2 = 1 \tag{6}$$

η_p is imaginary.

Then

$$\left.\begin{aligned} [a^{(-)}(\bar{p}), \bar{a}^{(+)}(\bar{p}')] &= \delta(\bar{p} - \bar{p}') \\ [\bar{a}^{(-)}(\bar{p}), a^{(+)}(\bar{p}')] &= \delta(\bar{p} - \bar{p}') \end{aligned}\right\} \tag{7}$$

The initial vacuum Φ_0 was defined by:

$$\left.\begin{aligned} \bar{K}^{0(-)}(\bar{p})\,|\Phi_0\rangle &= 0 \\ K^{0(-)}(\bar{p})\,|\Phi_0\rangle &= 0 \end{aligned}\right\} \tag{8}$$

We define a new vacuum Φ:

$$\left.\begin{aligned} a^{(-)}(\bar{p})\,|\Phi\rangle &= 0 \\ \langle\Phi|\bar{a}^{(+)}(\bar{p}) &= 0 \end{aligned}\right\} \tag{9}$$

where

$$\begin{aligned} |\Phi\rangle &= \prod_{\bar{p}}(\xi_p - \eta_p K^{0(+)}(\bar{p})K^{0(+)}(-\bar{p})\,|\Phi_0\rangle \\ \langle\Phi| &= \langle\Phi_0|\prod_{\bar{p}}(\xi_p + \eta_p \bar{K}^{0(-)}(\bar{p})\bar{K}^{0(-)}(-\bar{p}) \end{aligned} \tag{10}$$

The vacuum $|\Phi\rangle$ has strangeness and is CP invariant (consequently, the states defined for it are also CP-invariant); in addition it has the property

$$\langle\Phi|K^{0(+)}(\bar{P})K^{0(+)}(-\bar{P})\,|\Phi\rangle = -\langle\Phi|\bar{K}^{0(-)}(\bar{P})\bar{K}^{0(-)}(-\bar{P})\,|\Phi\rangle \neq 0 \tag{11}$$

which corresponds to the point of view of [7], but without $\Delta Q = -\Delta S$ transitions, and to an imaginary interaction constant [8]. In connection with (11), the question arises of the Goldstone theorem [9], which at any rate has not yet been finally solved in the literature.

Assuming the possibility of decay of $K_1^{0'}$ and $K_2^{0'}$ into pions, we can explain the K^0-meson decay experiments. However, from the point of view of the proposed theory, violations of CP parity are possible also in three-pion decays, as well as in lepton decays of K^0 mesons. No numerical estimates are made for the decay probabilities, since they are analogous to those given in [7].

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INTERACTION OF THE ALTERNATING JOSEPHSON CURRENT WITH RESONANT MODES IN A SUPERCONDUCTING TUNNEL STRUCTURE 1)

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It was noted earlier [1,2] that the voltage-current characteristics of superconducting-film tunnel structures, which clearly display the Josephson effect, also exhibit small steps characterized by the fact that the change of the current through the tunnel junction, a change usually determined by the measuring circuit, occurs at almost constant voltage on the junction, $V \neq 0$. We have shown [3] that this is accompanied by emission of photons of frequency $\omega = 2eV/\hbar$, corresponding to the frequency of the alternating Josephson supercurrent [4]. In the present note we propose a simple model, in which the steps result from excitation of resonant electromagnetic oscillations in a tunnel structure when alternating Josephson current flows between the films. We present experimental data confirming these notions.

Let us consider the conditions for the propagation of electromagnetic waves in a layer of oxide between superconducting tin films. In such a system there can propagate slowed-down transverse electromagnetic waves [5] with phase velocity $\bar{c} = c\sqrt{[\ell/\epsilon d]}$, where c is the velocity of light, ℓ the thickness of the oxide, ϵ the dielectric constant of the oxide, and $d = 2\lambda_L + \ell$ (λ_L is the London depth of penetration). Since the wave resistance of this strip line is very small [4,5], strong reflection of the wave will occur on the boundary, and resonant modes with sufficiently high Q will be able to exist in the bounded system. The condition for the resonance of the electromagnetic waves in the region forming the tunnel junction between the films is written in the form

$$n\frac{\lambda_p^{(n)}}{2} = W \qquad (n = 1, 2, 3, \ldots) \qquad (1)$$

where $\lambda_p^{(n)}$ is the n-th resonant wavelength in the strip resonator and W is the dimension of the rectangular resonator along which resonance occurs. Using the Josephson frequency ratio, the