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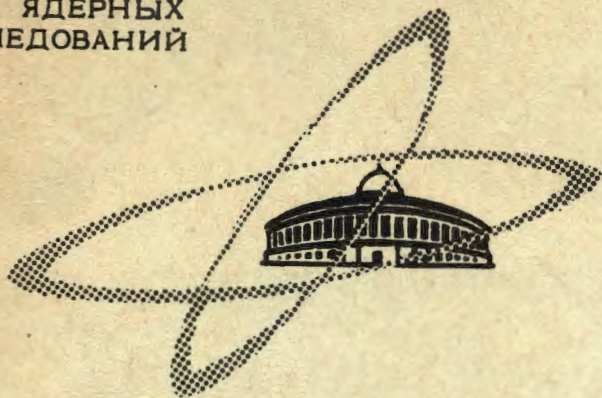
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CP-VIOLATION IN P-CONSERVING
ELECTROMAGNETICALLY-WEAK
AND MINI-WEAK INTERACTIONS

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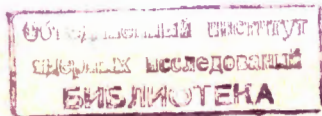
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**CP-VIOLATION IN P-CONSERVING
ELECTROMAGNETICALLY-WEAK
AND MINI-WEAK INTERACTIONS**

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Experimental studies of K^0 -decays and the search for the CP-violation in other processes do not yet lead to the understanding of the CP-violating mechanism. Furthermore, some recent experimental data ^{3,4} force us to a new discussion of the mechanism which disagreed with earlier measurements of the parameters $|\eta_{00}|$ and ϕ_{+-} ^x. We consider here the class of such models in which the "direct" CP-odd transitions are small as compared to the transitions $K_2 \rightarrow K_1 \rightarrow 2\pi$ induced by the CP-violation in the mass matrix. These models called in what follows "minimal" ones are characterized by the condition $|\epsilon_2| \ll |\epsilon_0|$. By use of the well known phenomenological analysis based on CPT one may then infer that in the minimal models the CP-violating parameters should satisfy the equations

$$\phi_{+-} \approx \phi_{00} = \phi_0 \approx \arctg\left(\frac{2\Delta m}{\Gamma_2}\right) = (42.7 \pm 1.3)^\circ; \quad \text{Re } \epsilon_0 \approx |\eta_{+-}| \cos \phi_\epsilon = (1.44 \pm 0.10) \cdot 10^{-3}; \quad 3,4.$$

The experimental result $\text{Re } \epsilon_0 = (1.16 \pm 0.18) \cdot 10^{-3}$ obtained from asymmetry in the decays $K_L \rightarrow \pi \ell \nu$ and from $\Delta Q = \Delta S$ rule (see for this ⁴), is in reasonable agreement with these predictions. The recent measurement of ϕ_{+-} also does not contradict them; $\phi_{+-} = (46 \pm 15)^\circ$ ³, $\phi_{+-} = (51 \pm 11)^\circ$ ⁴. By use of the Wu Yang triangle we then may obtain ³ $|\eta_{00}| = (0.7 \pm \frac{1.0}{0.7}) \cdot 10^{-3}$. This rather poor accuracy prevents one from any serious conclusions and the direct measurements of this important quantity gave rather controversial results in the range $(0 \pm 4) \cdot 10^{-3}$. Bearing in mind this rather obscure situation we want to stress strongly that the large value $|\eta_{00}| = (3.6 \pm 0.6) \cdot 10^{-3}$ contradicting the minimal models and strongly suggested in ⁵, clearly disagrees with $|\eta_{00}|$ calculated from the Wu-Yang triangle.

The most popular minimal model is the superweak model of Wolfenstein in which the minimality condition $|\epsilon_2| \ll |\epsilon_0|$ is produced by the $|\Delta S| = 2$ selection rule. Different models were suggested with $|\epsilon_2| \ll |\epsilon_0|$ condition following the $|\Delta T| = 1/2$ rule. We discuss here the new class of minimal models in which this condition is provided by the parity selection rule. Consider CP-odd parity conserving "mini-weak" (MWP) ^{xx} or electromagnetically weak (EWP) interactions (CP-conservation or nonconservation denoted by P or \bar{P}). P-violating direct transitions $K_2 \rightarrow 2\pi$ may then go only through the combined action of EWP (MWP) and $W^{\bar{P}}$ so that $|\epsilon_2|/|\epsilon_0| \lesssim G_w m^2 \sim 10^{-6} + 10^{-7}$,

x) See e.g. ^{1,2} where the extended list of references and the review of the experimental data may be found. The notations of the review ¹ are adopted here.

xx) Hypothetical mini-weak interactions are supposed to be $10^2 - 10^3$ times weaker than the usual weak interactions.

where $G_w \approx \frac{10^{-5}}{m_p^2}$, m is some characteristic mass of the $K_L \rightarrow 2\pi$ decay.

The opinion is widely accepted (see e.g. ⁴) that in minimal models all effects of CP-nonconservation must be small and give only small (10^{-2} to 10^{-3}) corrections to CP-conserving amplitudes. This opinion is absolutely groundless. For example, a mini-weak interaction with a strong energy dependence may give quite large CP-violating terms in amplitudes of some process, Q-value being large enough. A model of this kind was considered by us previously ⁶. Furthermore, an essentially arbitrary EWP-interaction may create significant CP-odd effects in weak radiative decays.

Let us consider now the most important predictions of such interactions ^x).

1) There must exist the decay forbidden by CP-invariance: $K_S \xrightarrow{EWP} \pi^0 \gamma \xrightarrow{E} \pi^0 e^+ e^-$ with partial width $\sim 10^{-6}$.

2) In the decays $K_{L,S} \rightarrow 2\gamma$ must exist the interference, which is forbidden by CP-conservation, photons being unpolarized. The observation of this interference is not a difficult task if $\Gamma(K_S \rightarrow 2\gamma) \gg \Gamma(K_L \rightarrow 2\gamma)$ but we do not know any serious arguments suggesting such inequality. It is quite possible that $\Gamma(K_S \rightarrow 2\gamma) \sim \Gamma(K_L \rightarrow 2\gamma)$ and in this case the interference effect is observable only near the K^0 -meson generation point, the minimal distance growing with the energy of K^0 . One may eventually observe that the P-conservation in the CP-violating transition $K^0 \rightarrow 2\gamma$ may be tested by the measurement of the correlation between the (e^+e^-) planes in the decay $K_L \rightarrow 2\gamma \rightarrow (e^+e^-)$.

3) E and EWP mechanisms predict the quite large CP-forbidden interference in $K_{L,S} \rightarrow \pi^+ \pi^- \gamma$ decays ². For the EWP this effect should be small. In fact the bremsstrahlung amplitude $K_L \xrightarrow{EWP} \pi^+ \pi^- \xrightarrow{E} \pi^+ \pi^- \gamma$ is P-odd and the CP-odd direct emission process $K_{L2} \xrightarrow{EWP} \pi^+ \pi^- \gamma$ conserves P. Thus, only the direct emission amplitudes may interfere. For the same reason the charge asymmetry parameters in $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ appear to be small. (In E and WEP mechanism they might be of the order 10-30%. See e.g. ⁶).

4) In $K \rightarrow 3\pi \gamma$ decays quite large effects of CP-violation must be observable. As a matter of fact $K \rightarrow 3\pi$ decay is P-conserving and so the bremsstrahlung amplitude $K \xrightarrow{WP} 3\pi \xrightarrow{E} 3\pi \gamma$ may interfere with the CP-odd direct emission amplitudes. Thus, for example, the partial widths $\Gamma(K^0 \rightarrow 2\pi^0 \gamma), \Gamma(K^0 \rightarrow 2\pi^+ \pi^- \gamma)$ must be quite different, the photon energies being such that the bremsstrahlung and the direct emission amplitudes are

^x) We consider here only the large effects of the CP-violation and so may put $K_S \approx K_L, K_L$

comparable. In the decay $K_L \rightarrow 3\pi^0 \gamma$ only \mathcal{P}, CP and P, CP interactions may contribute and so the observation of the term $\vec{p}(\vec{q} \times \vec{k})$ in the momentum dependence of its probability would be the direct proof of the CP-violation. This effect for EWP interaction may be of the order 10-30% but its observation is an extremely difficult task, for $\Gamma(K_L \rightarrow 3\pi^0 \gamma) \lesssim 10^{-7} \Gamma_L$

5) The important prediction of EWP mechanisms is the smallness of the electric dipole moments. For the neutron e.g. $d_n \lesssim G_w^2 m_p^2 e \sim 2 \cdot 10^{-4} e \cdot cm$

6) In conclusion, we should like to point out that the EWP-coupling constant ($\sim G_w e$) may be estimated if we know $|\eta_{+-}|$. If in the mass matrix we take into account only the transition $K_2 \xrightarrow{CP} \pi^0 \gamma \xrightarrow{CP} K_1$ then, making a cut-off in the corresponding Feynman integral on the virtual momenta $\sim m_p$, we find the vertex $K_2 \rightarrow \pi^0 \gamma$ thus estimating $K_L \rightarrow \pi^0 e^+ e^-$. An EWP-model with the photon coupled to the strange conserved vector current may also be constructed. In such a model all the CP-violation parameters may be calculated without any ambiguities.

We should also like to stress that the previously discussed EWP model with coupling constant $\sim G_w e$ predicts too large widths of the K-meson and baryon radiative decays and so it is in poor agreement with experimental facts. In contrast with this the EWP-model discussed here is in good agreement with all the firmly established experimental data and predicts quite large CP-violation effects in the decays $K_L \rightarrow \pi^0 e^+ e^-$, $K_{L,S} \rightarrow 2\gamma$, $K \rightarrow 3\pi \gamma$ and in some other weak radiative processes which we did not consider here.

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