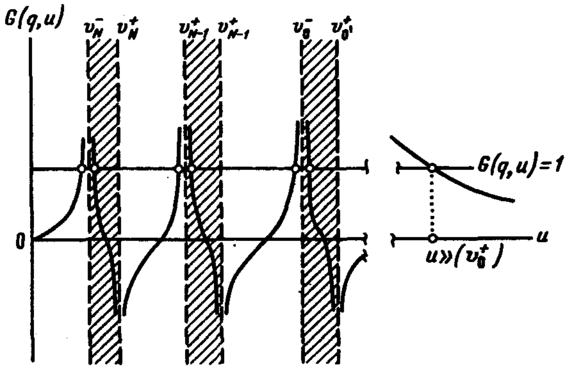

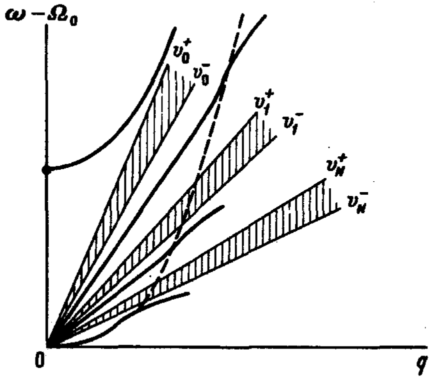

when $\lim_{q=0} u = \text{const}$, there exist (2N + 1) solutions of the type

$$\omega_l = \Omega_0 + c_l q, \tag{8}$$

and the values of c_i are obtained from the equation

$$\sum_{n=0}^{N} \ln \frac{v_n^+ - c_l}{v_n^+ + c_l} \cdot \frac{v_n^- + c_l}{v_n^- - c_l} = 0.$$

The solutions (6) - (8) can be obtained by plotting G(q, u) at fixed values of q and finding the points of intersection of G(q, u) and the line G = 1. Such a plot is shown in Fig. 1. The damping in the shaded regions is large, so that N + 2 out of the 2N + 3 branches of the spectrum are undamped. Undamped quantum electromagnetic waves were obtained in [4]. The thick lines in Fig. 2 show the approximate dispersion curves $\omega(q)$, and the shaded sections of the (ω, q) plane show the regions of strong damping. The spectrum (6) (upper curve of Fig. 2) corresponds to the classical limit [1], whereas the QSW (7) and (8) are possible only in the quantum state when $\Omega_0 < \Omega$.

On the other hand, if $\Omega_0 > \Omega$, then the QSW are impossible, owing to the large Landau damping. An analysis of (5) shows, however, that even if $\Omega_0 > \Omega$, but if $\psi < 0$, undamped QSW are possible if q exceeds q* and depends on ψ and $(\Omega_0 - \Omega)$.

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VIOLATION OF CP-INVARIANCE IN WEAK ELECTROMAGNETIC AND MINIWEAK PARITY CONSERVING INTERACTIONS

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Submitted 2 September 1968
ZhETF Pis. Red. 8, No. 9, 493 - 496 (5 November 1968)

Experimental studies of K^0-meson decays and searches for CP-violation in other processes have not explained so far the mechanism of this violation. Moreover, recent experimental data [3, 4] make it necessary to return to a discussion of the mechanisms that contradict the earlier measurements $|\eta_{00}|$ and θ_{+-}.[1] We consider here the class of such models of CP violation, in which the "direct" CP-odd transitions $K_2 \to 2\pi$ are small compared with the transitions $K_2 \to K_1 \to 2\pi$ induced by CP nonconservation in the mass matrix. These models, henceforth called "minimal," are characterized by the condition $|\varepsilon_2| << |\varepsilon_0|$. Using the customary phenomenological analysis based on CPT conservation, we find hence that the parameters of the $K^0 \to 2\pi$ decays should satisfy in the minimal models the relations

$$\eta_{+-} \simeq \eta_{00} \simeq \epsilon_0$$

i.e.

$$\phi_{+-} \simeq \phi_{00} - \phi_{\epsilon_0} \simeq \text{arc tg}\,\frac{2\Delta m}{\Gamma_S} = (42{,}7 \pm 1{,}3)^\circ;$$

$$\text{Re}\,\epsilon_0 \simeq |\eta_{+-}| \cos\phi_{\epsilon_0} = (1{,}44 \pm 0{,}10)10^{-3}$$

(cf. [3, 4]. These predictions agree with the value Re $\varepsilon_0 = (1.16 \pm 0.18) \times 10^{-3}$, obtained from the asymmetry in the $K_L \to \pi e \nu$ decays and the rule $\Delta Q = \Delta S$, which has been verified with good accuracy in [4]. The latest measurement of ϕ_{+-} yielded $\phi_{+-} = (46 \pm 15)^\circ$ [4] and $\phi_{+-} = (51 \pm 11)^\circ$ [4], which likewise do not contradict the prediction of the minimal models. Knowing η_{+-} and Re ε_0, we can determine by the triangle rule [3] $|\eta_{00}| = (0.7^{+1.9}_{-0.7}) \times 10^{-3}$. This accuracy, however, does not suffice for any final conclusions, and direct measurements of this important quantity yield contradictory results scattered in the range $(0 - 4) \times 10^{-3}$. We emphasize in this connection that the large value $|\eta_{00}| = (3.6 \pm 0.6) \times 10^{-3}$, which contradicts the prediction of the minimal models and retained in [5], does not agree with the value of $|\eta_{00}|$ presented above and obtained from the triangle rule.

The most popular minimal model is the weak-interaction model, in which the condition $|\varepsilon_2| << |\varepsilon_0|$ is ensured by the selection rule $|\Delta S| = 2$. Various other models were also proposed, in which an analogous rule is played by the rule $|\Delta T| = 1/2$. We discuss here a different class of minimal models, in which the condition $|\varepsilon_2| << |\varepsilon_0|$ follows from the parity selection rules. Let us consider CP-odd "miniweak" (MW^P)[2] or electromagnetic-weak (EW^P) parity-conserving interactions (parity conservation or nonconservation will be denoted by P and $\not{P}$, respectively). Then the parity-nonconserving direct transition $K_2 \to 2\pi$ is possible only under the joint action of EW^P (MW^P) and $W^{\not{P}}$, i.e., $\varepsilon_2/\varepsilon_0 \lesssim G_W m^2 \sim 10^{-6} - 10^{-7}$, where $G_W \approx 10^{-5}/m_p^2$ and m is a certain mass characteristic of the $K_L \to 2\pi$ decay.

It is widely believed (cf., e.g. [4]) that CP-nonconservation effects in minimal models should be small and can yield only small corrections to the main CP-even matrix elements. This is in error. For example, a miniweak interaction that depends strongly on the energy can lead to large CP-violation effects in processes in which the energy release is large. An example of this kind was considered by us earlier [6]. Conversely, any EW^P

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[1] See [1, 2], where reference to original papers and a summary of the experimental data can be found. We use the notation of [1].

[2] Miniweak interactions are weaker by a factor $10^2 - 10^3$ than weak interactions, and are sometimes called "milliweak" [2].

interaction produces large CP-odd effects in weak radiative decays. We shall discuss the most important properties of such interactions: (i) There should exist a CP-forbidden decay $K_2 \xrightarrow{EW^P} \pi^0\gamma \xrightarrow{E} \pi^0e^+e^-$ with partial width $\sim 10^{-6}\Gamma_L$. (ii) In the $K_{L,S} \rightarrow 2\gamma$ decays there should exist an interference that is CP-forbidden if the photon polarization does not change. Observation of such an interference is easiest under the condition $\Gamma(K_S \rightarrow 2\gamma) >> \Gamma(K_L \rightarrow 2\gamma)$, but we know of no convincing arguments in favor of such an inequality, and it is quite probable that $\Gamma(K_S \rightarrow 2\gamma)$ and $\Gamma(K_L \rightarrow 2\gamma)$ are of the same order of magnitude. In this case the interference can be observed only at a short distance from the point where the K^0 mesons are generated, and it is convenient to use K^0 mesons of maximum energy. We note that, owing to parity conservation, CP violation in the $K_2 \rightarrow 2\gamma$ is impossible, and that this can be verified in principle by measuring the correlation of the planes of the (e^+e^-) pairs in the decay $K_L \rightarrow 2\gamma \rightarrow (e^+e^-)(e^+e^-)$. (iii) The mechanisms E and $EW^{\not P}$ predict a large interference in the $K_{L,S} \rightarrow \pi^+\pi^- \gamma$ decays [2]. In the EW^P case this effect should be small. Indeed, the amplitude of the bremsstrahlung $K_1 \xrightarrow{W^{\not P}} \pi^+\pi^- \xrightarrow{E} \pi^+\pi^-\gamma$ is P-odd, and the CP-odd amplitudes of the processes $K_{1,2} \xrightarrow{EW^P} \pi^+\pi^-\gamma$ conserve P. Therefore only the amplitudes of the structure radiation can interfere, and this determines the smallness of the effect. Analogously, the coefficients of the charge asymmetry, which can reach 10 - 30% in the E and $EW^{\not P}$ mechanisms (cf., e.g., [6]), are small in the decays $K^\pm \rightarrow \pi^\pm\pi^0\gamma$. (iv) To the contrary, in the $K \rightarrow 3\pi\gamma$ decays, there should be observed large CP-nonconservation effects. Indeed, in the $K \rightarrow 3\pi\gamma$ decays the parity is conserved, and therefore the amplitudes of the bremmstrahlung $K \xrightarrow{W^P} 3\pi \xrightarrow{E} 3\pi\gamma$ can interfere with the amplitudes of the CP-odd direct transitions. In particular, the widths $d\Gamma(K^+ \rightarrow 2\pi^+\pi^-\gamma)$ and $d\Gamma(K^- \rightarrow 2\pi^-\pi^+\gamma)$ should be different in the photon-energy region where the bremsstrahlung and structure amplitudes are comparable in magnitude. Only the P, CP or P, CP interactions can contribute to the $K_L \rightarrow 3\pi^0\gamma$ decay, and therefore observation of a correlation of the type $\vec{p}(\vec{p}\times\vec{k})$ in its probability would point unambiguously to CP nonconservation. For the EW^P mechanism, such an effect can reach several times ten per cent, but its observation is exceedingly difficult, since $(K_L \rightarrow 3\pi^0\gamma) \lesssim 10^{-7}\Gamma_L$. (v) One more important prediction of the EW^P mechanism is the smallness of the electric dipole moments of the particles. For example, for the neutron we obtain $d_n < G_W^2 m_p^3 e \sim 2 \times 10^{-24}$ e-cm. (vi) In conclusion we note that the EW^P-interaction constant $(G_W e)$ can be obtained if the parameter $|\eta_{+-}|$ is known. Thus, if only the transitions $K_2 \xrightarrow{\not{CP}} \pi^0\gamma \xrightarrow{CP} K_1$ are taken into account in the calculation of the mass matrix and the corresponding Feynam integral is cut off at a virtual momentum m_p, we obtain then the $K_2 \rightarrow \pi^0\gamma$ vertex, which determines the estimate given above for $K_L \rightarrow \pi^0e^+e^-$. It is also possible to construct an EW^P model in which the photon is connected with a strange conserved vector current. In such a model, practically all the parameters of the CP violation are predicted uniquely. We wish to mention, finally that the non-minimal EW^P model discussed in detail in [7], with a coupling constant $\sim G_W e$, predicts too large values for the probabilities of the radiative decays of baryons and K mesons, and therefore cannot be reconciled with experiment. The EW^P model does not contradict even one established experimental fact, and predicts large CP-violation effects in the decays $K_L \rightarrow \pi^0e^+e^-$, $K_{L,S} \rightarrow 2\gamma$, $K \rightarrow 3\pi\gamma$, and in several other radiative processes not considered here.

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ERRATA

Article by V. V. Kurylev et al., Vol. 8, No. 6, p. 196

First line: "in a superconducting structure...." should read " in a semiconductor structure..."