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CP and CPT

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Some aspects of CP violation in CPT invariant and CPT non-invariant world are discussed. In particular, an attention is attracted to the fact, that CPT invariance is tested for $\{K^0, \bar{K}^0\}$ system with 2% accuracy only. The perspectives to improve in the near future our knowledge about the origin of CP violation and to increase an accuracy in measurement of the parameters characterizing CPT violation are considered.

Fig. - 6,ref - 52

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1 What we know about CPT invariance from the experiments with kaons.

The discrete symmetries play an important role in particle physics. In particular, the usual field theory of the microscopic processes is built in such a way, that it is invariant under the product of charge conjugation (C), space reflection (P) and time reversal (T).

Beginning from 1956 we know that P-invariance is violated in weak interactions [1] and beginning from 1964 we know that in weak interactions CP invariance is violated too [2], but with a strength much smaller than the strength of P violation.

What about CPT invariance?

Because of CP violation was observed in the system $\{K^0\ ,\ \bar{K}^0\}$ it is natural to look for CPT violation in the same system. As it is well known [3], one of the consequences of CPT invariance is the equality of masses of a particle and its antiparticle. And the most impressive limit on mass difference between particle and its antiparticlle was obtained exactly for $\{K^0\ ,\ \bar{K}^0\}$ system. In the literature, the estimate exists

$$\left|\frac{m_{K^0}-m_{\bar{K}^0}}{m_{K^0}}\right| \leq 4\cdot 10^{-18} \qquad [4] \tag{1}$$

More strict analysis leads to the estimate

$$\left|\frac{m_{K^0}-m_{\bar{K}^0}}{m_{K^0}}\right| < 3.5\cdot 10^{-16} \qquad [5] \tag{2}$$

which also looks as the impressive result. But is means really that CPT invariance is tested for $\{K^0\ ,\bar{K}^0\}$ system with 2% accuracy only! To clear up this paradoxial conclusion let's consider the $\{K^0\ ,\ \bar{K}^0\}$ system supposing that CPT violation is initiated by CP violation at conserved T invariance. Then, a possible CPT violation is described by the parameter Δ which enters in the wave functions of K_L and K_S mesons in the following way:

$$\begin{aligned} K_S &= (K_1+\varepsilon K_2+\Delta K_2^2)/\sqrt{1+\mid\varepsilon+\Delta\mid^2} \\ K_L &= (K_2+\varepsilon K_1-\Delta K_1)/\sqrt{1+\mid\varepsilon-\Delta\mid^2} \end{aligned} \tag{3}$$

where ε is the parameter describing CP violation in CPT invariant world. The parameter Δ is connected to mass difference of K^0 and $\bar{K}^0$ in the

following way (see the formula (74) of ref. [6]):

$$\Delta = 1/2(< \bar{K}^0 \mid H \mid \bar{K}^0 > - < K^0 \mid H \mid K^0 >)/(m_L - m_S + i(\Gamma_S - \Gamma_L)/2) \tag{4}$$

where m_L , m_S , Γ_S are the masses and widths of the K_L and K_S mesons. The above equation gives:

$$m_{\bar{K}^0} - m_{K^0} = 2(m_L - m_S)(Re\Delta - \cot\Phi_{sw} Im\Delta) \tag{5}$$

$$\frac{1}{2}(\Gamma_{K^0} - \Gamma_{\bar{K}^0}) = 2(m_L - m_S)(Im\Delta + \cot\Phi_{sw} Re\Delta) \tag{6}$$

where

$$\Phi_{sw} = \arctan[2(m_L - m_S)/(\Gamma_S - \Gamma_L)] = 43.7^0 \pm 0.2^0.$$

The eq.(5) shows that even at $\Delta \sim 1$ the ratio $(m_{\bar{K}^0} - m_{K^0})/m_{K^0}$ would be very small due to factor

$$2(m_L - m_S)/m_{K^0} \cong 1.4 \cdot 10^{-14} \tag{7}$$

which has nothing with CPT violation. Therefore, the extraordinary smallness of the limits (1) or (2) is not yet an evidence of extreme smallness of the parameter Δ describing CPT violation.

Besides, the limit (1) can not be used for the rigorous statement that the parameter Δ is less than $3 \cdot 10^{-4}$. In fact, the estimate (1) itself rests on some assumptions including such a crucial one as the absence of the direct CPT violation originating the transition $K_2^0 \to 2\pi$. The estimate (2) is free of such a doubtful assumption, and as I shall show, it leads to conclusion that CPT invariance is tested for the $\{K^0, \bar{K}^0\}$ system at 2% level only.

As it is seen from eqs. (5) and (6), to obtain $\Delta m_{K^0\bar{K}^0}$ one needs to know $Re\Delta$ and $Im\Delta$.

But these quantities can not be extracted from existing data directly. Indeed, all measured to date CP-violating (and possibly, CPT violating at the same time) effects depend either on combination of CPT violating and CPT conserving parameters, or on combination of $Re\Delta$ with CPT violating parameter y_l and with the parameters $x_l(\bar{x}_l)$ characterizing a strength of violation of the $\Delta Q = \Delta S$ rule.

So,

$$\eta_{\pm} = \varepsilon - \Delta + (a + \varepsilon')(1 + \omega)^{-1} \tag{8}$$

$$\eta_{00} = \varepsilon - \Delta + (a - 2\varepsilon')(1 - 2\omega)^{-1} \tag{9}$$

$$\delta_L = \frac{\Gamma(K_L \to e^+\nu\pi) - \Gamma(K_L \to e^-\nu\pi)}{\Gamma(K_L \to e^+\nu\pi) + \Gamma(K_L \to e^-\nu\pi)} = \\ = 2Re(\varepsilon - \Delta) - 2Rey_l - Re(x_l - \bar{x}_l) \tag{10}$$

where

$$a = \frac{A(K_2^0 \to 2\pi\ , I = 0)}{A(K_1^0 \to 2\pi\ , I = 0)} \tag{11}$$

$$\omega = \frac{1}{\sqrt{2}} A(K_S^0 \to 2\pi\ , I = 2)/A(K_S^0 \to 2\pi\ ,\ I = 0) \tag{12}$$

$$\varepsilon' = \frac{1}{\sqrt{2}} A(K_2^0 \to 2\pi\ , I = 2)/A(K_S^0 \to 2\pi\ , I = 0) \tag{13}$$

The parameters x_l and $\bar{x}_l$ are defined by the relations

$$x_l = < l^+\nu_l\pi^- \mid \bar{K}^0 > / < l^+\nu_l\pi^- \mid K^0 > , \\ \bar{x}_l = < l^-\bar{\nu}_l\pi^+ \mid K^0 >^* / < l^-\bar{\nu}_l\pi^+ \mid \bar{K}^0 >^* \tag{14}$$

The parameter y_l describing the direct CPT violation in K_{l3}-decay amplitude is defined as follows:

$$< l^+\nu_l\pi^- \mid K^0 > / < l^-\bar{\nu}_l\pi^+ \mid \bar{K}^0 >^* = (1 - y_l)/(1 + y_l) \tag{15}$$

The combination

$$\frac{2}{3}\eta_{+-} + \frac{1}{3}\eta_{00} + \frac{2}{3}(\eta_{+-} - \eta_{00})\omega = \varepsilon - \bar{\Delta} \tag{16}$$

where

$$\bar{\Delta} = \Delta - a \tag{17}$$

does not contain $x_l(\bar{x}_l)$ or y_l. But it defines a difference between CPT conserving parameter ε and CPT violating parameter $\bar{\Delta}$. For this reason, basing on smallness of η_{+-} and η_{00}, one can not declare that ε and $\bar{\Delta}$ separately are small too.

To determine $\bar{\Delta}$ we need a measurement of some other CP (and CPT)-violating correlations, depending on other combinations of the above parameters. In principle, these parameters may be determined from data on proper-time dependence of probability of the decays into $\pi l\nu$ for particles which were produced initially as K^0 and $\bar{K}^0$. The programm of necessary

measurements was considered by Tanner and Dalitz [7] and it may be fulfilled in experiments where $K^0(\bar{K}^0)$ are produced by $K^+(K^-)$ or in pair with $K^-(K^+)$ respectively, in particular, in the process

$$p + \bar{p} \to \pi^{\pm} K^{\mp} 2\pi \ .$$

belonging to the items of this conference.

An advancement in determination of Δ will be achieved also after a measurement of the charge asymmetry parameter δ_s for $K_s \to \pi l \nu$ decays at the Φ-factories

$$\begin{aligned} \delta_S &= \frac{\Gamma(K_S \to l^+\nu\pi) - \Gamma(K_S \to l^-\bar{\nu}\pi)}{\Gamma(K_S \to l^+\nu\pi) + \Gamma(K_S \to l^-\bar{\nu}\pi)} = \\ &= 2Re(\epsilon + \Delta) - 2Rey_l + Re(x_l - \bar{x}_l) \end{aligned} \tag{18}$$

Combining (11) with (19) we obtain

$$Re\Delta = \frac{1}{4}(\delta_S - \delta_L) - \frac{1}{2}Re(x_l - \bar{x}_l) \tag{19}$$

Therefore, to determine $Re\Delta$ it is necessary besides a measurement of δ_S to know the parameters x_l and $\bar{x}_l$ characterizing a deviation from the $\Delta Q = \Delta S$ rule.

In the standard theory the parameter $x_l(\bar{x}_l)$ must be very small because a violation of the $\Delta Q = \Delta S$ rule occurs in the second order of weak interaction and consequently $x_l \leq G_F m_K^2 \leq 2 \cdot 10^{-6}$. But the standard theory is CPT invariant one and $\Delta = 0$ in it.

So, testing CPT invariance it would not be right to affirm in advance that x_l and $\bar{x}_l$ are negligibly small.

The Particle Data Group [4] gives for x the value

$$"x" = 0.006 \pm 0.018 + i(0.003 \pm 0.026) \tag{20}$$

but this result was obtained supposing CPT invariance! If CPT does not hold the proper-time rates of decay into $\pi^+ l^- \bar{\nu}$ and $\pi^- l^+ \nu$ of the particle produced at $t = 0$ as K^0 are as follows:

$$N^-(l^-;t) \sim e^{\frac{-(\Gamma_S+\Gamma_L)}{2}t}[\cosh(\alpha t) - \cos(\beta t) - 2(Re\bar{x}\sinh(\alpha t) + Im\bar{x}\sin(\beta t))] \tag{21}$$

$$N^+(l^+;t) \sim e^{\frac{-(\Gamma_S+\Gamma_L)}{2}t}[\cosh(\alpha t) + \cos(\beta t) - \\ -2(Re(x+2\Delta)\sinh(\alpha t) + Im(x+2\Delta)\sin(\beta t))] \tag{22}$$

where $\alpha = \frac{1}{2}(\Gamma_S - \Gamma_L)$, $\beta = m_L - m_S$.

As it follows from the equations (21) and (23), studying $N^-(t)$ distribution one gets in fact the information on $\bar{x}$. The $N^+(t)$ distribution gives the information on $(x+2\Delta)$. Unfortunately, in all experimental works (see refs. in [4]), both distributions were fitted simultaneously assuming that $\Delta = 0$ and $x = \bar{x}$.

But the fact that both distributions were described with one and the same parameter »x" means that $\bar{x}$ and $(2\Delta + x)$ do not differ one from another and from »x" within the error bars in determination of »x".

Then the error bars for $\bar{x}$ and $(2\Delta + x)$ do not exceed $\sqrt{2}$ of error bars for the quantity »x" defined by the formula (20), and we conclude that

$$Re(2\Delta + x) = 0.006 \pm 0.025 \ , Re\bar{x} = 0.006 \pm 0.025 \tag{23}$$

Independently, from the experimental data on K^+_{e4} decay [4] we conclude that [1]

$$|\ x\ |^2 \leq 3 \cdot 10^{-4} \quad \text{at} 90\% CL \tag{24}$$

Consequently, $|\ Rex\ | \leq 0.017$ and combining this number with (23) we obtain

$$|\ Re\Delta\ | \leq 0.015 \tag{25}$$

The same analysis for $Im\Delta$ leads to the result

$$|\ Im\Delta\ | \leq 0.02 \tag{26}$$

Therefore, CPT invariance is tested for kaon mass matrix with 2% accuracy. The same limit takes place for Rcy_l. It can be obtained attracting the data [8] on integrated proper-time distributions of $\pi^+\pi^-$ from K^0 and $\bar{K}^0$ in the process

$$p\bar{p} \to K^0 \ \ (\text{or}\bar{K}^0)K^\pm + pions \tag{27}$$

These distributions are described by expression

$$N(\pi^+\pi^-;t) \ \sim \ e^{\frac{1}{2}\Gamma_s t}[1 \pm 2Re(\varepsilon - \Delta)] \pm$$

[1] Though the parameter x was introduced for K_{l3} decay, the same parameter must describe a violation of the $\Delta Q = \Delta S$ rule in K_{l4} decay, because an emission of additional pion in K_{l4} decay has nothing with change of strangeness.

$$\pm\ 2e^{-\frac{\Gamma_S+\Gamma_L}{2}t}\{[(1\mp 2Re\varepsilon)Re\eta_{+-}\pm 2Im\Delta Im\eta_{+-}]\cos(t\delta M)+ \tag{28}$$
$$+\ [(1\mp 2Re\varepsilon)Im\eta_{+-}\mp 2Im\Delta Re\eta_{+-}]\sin(t\delta M)\}+$$
$$+\ e^{-\frac{1}{2}\Gamma_L t}[1\mp 2Re(\varepsilon+\Delta)]\mid\eta_{+-}\mid^2$$

where $\delta M = m_L - m_S$ and the upper sign to be taken for the case of initial K^0 at $t=0$ and the lower sign – for $\bar{K}^0$ at $t=0$. At $t \gg 1/\Gamma_S$ ($t\to\infty$), only the last term of (29) is essential and

$$\frac{N_{\pi\pi}(\text{from } K^0)}{N_{\pi\pi}(\text{from } \bar{K}^0)} \simeq 1 - 4Re(\varepsilon+\Delta). \tag{29}$$

But the statistics of 2π decays will be very small in this region because of factor $\mid\eta_{+-}\mid^2$.

Really, to have a comparatively good statistics, one is forced to use the integrated ratio from t_{min} = few $(1/\Gamma_S)$ to $t_{max} \gg 1/\Gamma_L$. Such a ratio depends mainly on $Re(\varepsilon-\Delta)$ and it follows from the data that

$$Re(\varepsilon-\Delta) = (2.3\pm 6)10^{-3} \quad , \quad [7] \tag{30}$$

Then, using eq. (11) and our limits (23) on $Re\tilde{x}$ we conclude that Rey_l is consistent with zero within 2% accuracy.

Returning to the question on the most reliable limit on $m_{K^0} - m_{\bar{K}^0}$ we conclude using eqs. (5), (25) and (26) that the estimate of this quantity which is free of the additional assumptions on character of CPT violation is determined by eq. (2).

The limits on $Im\Delta$ and $Re\Delta$ may be improved making use of the Bell-Steinberger unitarity relation [9]. Then we obtain [5]

$$Im\Delta = (-0.78\pm 0.70)10^{-4}\ ,\ \ Re\Delta = (-0.8\pm 6)10^{-3} \tag{31}$$

but these results already depend on assumption that CPT violation does not spoil the unitarity necessary for a foundation of the Bell-Steinberger relation [10].

What's the news on CP violation, if CPT invariance is assumed to be exact symmetry?

2 CP violation in CPT invariant world.

There are three sources of the observable effects of CP violation

1. Indirect CP violation due to interaction changing the flavour number by two units.

2. Direct CP violation in transitions changing the flavour number by one unit.

3. CP violation caused by non-trivial structure of vacuum in QCD.

The first mechanism is realized in the superweak model of CP violation [11] dealing with the lagrangian

$$L(\Delta S = 2) = i g_{sw} (K^0)^2 + h.c. \tag{32}$$

The like mechanism may originate CP violation in the systems $\{D^0, \bar{D}^0\}$ and $\{B^0, \bar{B}^0\}$. But a value of the coupling constants $g_{sw}^{(D)}$ and $g_{sw}^{(B)}$ may be different of g_{sw}^{K} because of absence of a symmetry limiting the form of such transitions.

The first mechanism takes place in the Standard model (SM) too due to transitions of second order in G_F described by the diagrams in Fig. 1. The transitions of such kind lead to CP violation in $\{D^0, \bar{D}^0\}$ and $\{B^0, \bar{B}^0\}$ systems and a value of the effect can be expressed through the parameters of the Kobayashi-Maskawa matrix and masses of quarks.

The direct CP violation appears in SM as a consequence of a possibility for the coupling constants in the interaction of the left-handed currents to be the complex numbers. It is to the point to remind that such a mechanism becomes the possible one if the number of the quark families is not less than three. The reason is that $N \times N$ unitary matrix describing the rotations in the flavour space is characterized by N^2 parameters, $(2N-1)$ of which can be removed by redefinition of the phases of the quark fields. Out of the rest parameters, $(1/2)N(N-1)$ are real and $(1/2)(N-1)(N-2)$ are complex. Thus, a possibility to have the imaginary parts in the coupling constants necessary for CP violation appears beginning with $N = 3$.

The direct CP violation can occur also due to spontaneous breakdown of CP invariance in the Higgs sector [12]. In the models possessing GIM mechanism [13] of elimination of the non-diagonal neutral currents, the three families of the Higgs doublets are necessary [14].

Among the observable consequences of the direct CP violation, there are the electric dipole moments of elementary particles, the direct CP violation in the transitions $K \to 2\pi$, $K^{\pm} \to 3\pi$ and in the transitions of D and B mesons changing the flavour number.

The third source of CP violation is connected to the non-trivial topological structure of the QCD vacuum described by the so-called Θ-term [[15]

of the QCD lagrangian

$$\Delta L_{QCD}^{CP=-1} = -\Theta \frac{g^2}{32\pi^2} G_\mu^a \tilde{G}_\mu^a \tag{33}$$

This mechanism can induce CP-odd correlations in the NN and $N\bar{N}$ scattering and, of course, it induces the EDM of the nucleons.

Let's look now what the existing experimental data on CP-odd quantities say us about the possible sources of CP violation.

2.1 Electric Dipole Moments (EDM) of elementary particles.

An interaction of the EDM of a fermion with the electromagnetic field is of the form

$$\frac{1}{2} D\bar{u}(\gamma_\mu\gamma_\nu - \gamma_\nu\gamma_\mu)\gamma_5 k_\mu u A_\nu(k) \tag{34}$$

or

$$D\vec{\sigma}\vec{E}$$

in the fermion rest system. It violates P and T invariance and conserves C invariance. So, it violates CP invariance if CPT invariance is supposed.

There are the following data on this quantity [4]:

$$D_n \leq 1.2 \cdot 10^{-25} e\ cm\ ; \tag{35}$$

$$D_p = (-4 \pm 6) \cdot 10^{-23} e\ cm \tag{36}$$

$$D_e = (-3 \pm 8) \cdot 10^{-27} e\ cm\ . \tag{37}$$

The EDM of the nucleons can appear as a sum of the EDM's of constituent quarks. Then

$$D_n = \frac{4}{3} D_d - \frac{1}{3} D_u\ ,\ D_p = \frac{4}{3} D_u - \frac{1}{3} D_d \tag{38}$$

In the Standard Model, the EDM of quark appears only at the 3-loop level. The reason for absence D_q at the 2-loop lelvel is very simple. D_n is determined by the difference between contributions of the diagrams (a) and (b) shown in fig. 2, where the regularized vertex $\Gamma_{qq'\gamma}$ itself has the form [16]

$$\begin{aligned} \Gamma_{\bar{q}q\gamma} &= A \cdot (\hat{p} - m_q)\gamma_\mu(1-\gamma_5)(\hat{p}' - m_{q'}) + \\ &+ iB\varepsilon_{\mu\sigma\tau\nu} k_\sigma p_\tau \gamma_\nu (1+\gamma_5) + 0(k^2) \end{aligned} \tag{39}$$

Then, inserting the first term of eq. (40) into diagrams of fig. 2 we see, that the dependence of the diagrams (a) and (b) on the direction of propagation of the q and q' quarks disappears. As for the second term of eq. (40), it is already proportional to k and because the EDM is the static quantity, we can neglect the dependence on k in the q and q' propagators. Then, due to presence of the operators $(1+\gamma_5)$ in the $\bar{q}qW^{\pm}$ verteces the dependence on the sort of propagating quark disappears again. Thus, at the first order in k the difference between the contribution the diagrams (a) and (b) is absent and $(D_q) = 0$. The situation changes, when additional loops like shown in fig. 3 are taken into account. Then the estimate

$$D_q \sim 2 \cdot 10^{-34} e\ cm \quad [17] \tag{40}$$

follows, if the external quark is considered as the current one. But it seems to be more convenient to consider such quark as the constituent one. Then we obtain $D_q \sim 2 \cdot 10^{-32} e\ cm$.

The EDM of the nucleons can arise also due to the exchange forces between the quarks inside the nucleon [18-20], as it is shown in fig. 4, or D_n can be calculated directly, without applying to quark structure of the nucleon [21]. But in all cases the limit of order of $D_n \sim 10^{-32} e\ cm$ follows from the calculations.

The situation with D_n changes in the models of CP violation beyond the SM. In particular, the Weinberg Model [14] with spontaneous CP violation predicts $D_n \sim (1-3)10^{-25} e\ cm$ or even larger [22] in contradiction with the experimental data. But if such a mechanism takes place simultaneously with the Kobayashi-Maskawa mechanism, then a value of the parameter ε in $K^0 \to \bar{K}^0$ transition would not be connected with a value of D_n, and D_n may have arbitrary value right up to existing experimental number. Of course, the value of D_n close to experimental limit can be obtained in some other models (see review [20]) including the recent model of Hall and Weinberg [23], where a smallness of CP violation is the result of a smallness of CP violating phase $\delta \sim 10^{-3}$.

At last, it should be mentioned that the EDM of the neutron, induced by θ-term (33) is estimated as

$$|D_n| \cong \begin{cases} 2.7 \cdot 10^{-16} \mid \theta \mid e\ cm & [24],\ [25] \\ 3.6 \cdot 10^{-16} \mid \theta \mid e\ cm & [26] \\ 2 \cdot 10^{-15} \mid \theta \mid e\ cm & [27] \end{cases} \tag{41}$$

The estimates of EDM of the neutron in the framework of the Skyrme model give:

$$D_n = \begin{cases} 1.2 \cdot 10^{-16} \mid \theta \mid e\ cm & [28] \\ 2 \cdot 10^{-16} \mid \theta \mid e\ cm & [29] \end{cases} \tag{42}$$

Therefore, the experimental limit on D_n requires

$$\theta \leq 10^{-9} \tag{43}$$

though, in principle, θ could have a value of order of one. Such a smallness of θ excites the desire to find the reasons for $\theta = 0$ and there were a number of the proposals how to get this result (see references in review [20]).

There was some activity also in connection with a contribution to EDM of a nucleon of the operator

$$-\frac{1}{6} g^3 c f^{abc} \epsilon^{\alpha\beta\gamma\delta} G^a_{\alpha\tau} G^{b\tau}_{\beta} G^c_{\gamma\delta} \tag{44}$$

[30], [31] and operators of dimension 8 like

$$\frac{1}{12} g^4 \tilde{G}^a_{\mu\nu} G^{a\mu\nu} G^b_{\alpha\beta} G^{b\alpha\beta} \tag{45}$$

[32] where $G^a_{\mu\nu}$ are the antysymmetric tensors of the gluonic fields. Such operators appear in some special models of CP violation [30] but it is very difficult to calculate the exact value of D_n induced by these operators.

(B.) Electric Dipole Moment of electron (D_e)

In the SM, the EDM of electron is absent at the 3-loop level [33]. A non-zero value of D_e arise due to EDM of the $W^{\pm}$ bosons which appears itself at the 3-loop level. Therefore the EDM of electron appears from 4-loop diagrams and according estimate [34]

$$d_e \approx 8 \cdot 10^{-41} e.cm.$$

This value is far from the existing experimental limit.

2.2 CP violation in $\{K^0\ ,\ \bar{K}^0\}$ system.

In the Standard Model, both mechanisms - indirect and direct CP violation contribute to $K^0 \to 2\pi$ transitions. So that

$$\begin{aligned} \eta_{+-} &= \varepsilon + \varepsilon' \\ \eta_{00} &= \varepsilon - 2\varepsilon' \end{aligned} \tag{46}$$

where ε' is a measure of the direct CP violation in the transition with $\Delta I = 3/2$.

It may seem very strange that ε' is related to the $\Delta I = 3/2$ part of the amplitude, if one takes into account that the direct CP violation in the SM occurs due to so-called "penguin" diagram shown in Fig. 5 and corresponding to $\Delta I = 1/2$ transition. But it is so because of convention [35, 36] to consider the weak amplitude $A_0 = A(K^0 \to 2\pi\ ,\ I = 0)$ as the real one. Then, in the general expressions

$$A(K^0 \to 2\pi) = A_0 e^{i\delta_0 + i\delta(CP=-1)} + A_2 e^{i\delta_2}$$

$$A(\bar{K}^0 \to 2\pi) = A_0 e^{i\delta_0 - i\delta(CP=-1)} + A_2 e^{i\delta_2}$$

the CP-odd phase $\delta(CP = -1)$ originated by the Kobayashi-Maskawa mechanism has to be passed together with δ_0 to the part $A_2 = A(K^0 \to 2\pi\ ,\ I = 2)$.

Before 1989 it was supposed that the diagram in Fig. 5 is the only considerable one producing the direct CP violation. Such as assumption led to estimate

$$\varepsilon'/\varepsilon \approx (1 - 3)10^{-3} \tag{47}$$

But then it was observed [37] that the so-called "electroweak penguin" diagrams (b) and the box diagrams (c) in fig. 6 change the situation. Being suppressed by factor α_{em}/α_s such a diagrams can give a contribution that is enhanced by factor $\frac{A_0}{A_2} \sim 22$ for the imaginary part of amplitude corresponding to $\Delta I = \frac{3}{2}$. The contribution of such diagrams to ε'/ε is of opposite sign to the contribution of usual penguin diagram and at $m_t \approx 150 GeV$ the estimate (47) can be lowered by one order in magnitude.

But what the experiments tell us about a magnitude of ε'/ε? There were two measurements

$$Re(\varepsilon'/\varepsilon) = \begin{cases} (2.3 \pm 0.7)10^{-3} & [38] \\ (0.74 \pm 0.59)10^{-3} & [39] \end{cases} \tag{48}$$

and the last one is consistent with zero value of ε'. The data of PDG [4]

$$\begin{aligned} |\eta_{+-}| &= (2.268 \pm 0.024)10^{-3} \\ |\eta_{00}| &= (2.253 \pm 0.024)10^{-3} \end{aligned} \tag{49}$$

also have no sufficient accuracy to deduce the exact conclusion on a strength of the direct CP violation because of these numbers may be considered as coinsiding ones inside the error bars.

Thus, the existing picture of CP violation is very like to the picture following from the superweak model of CP violation.

In such a situation, a search for CP violating effects in $K^+ \to \pi^+\pi^+\pi^-$ and $K^- \to \pi^-\pi^-\pi^+$ decays looks as very promising and attractive. An observation of such effects would be an evidence of existance of the direct CP-violation.

2.3 CP violating effects in $K^\pm \to \pi^\pm\pi^\pm\pi^\mp$ decays.

There were some reassuring estimates of the difference of widths of $K^+ \to \pi^+\pi^+\pi^-$ and $K^- \to \pi^-\pi^-\pi^+$ decays and a difference in the energy distributions of the "odd" pions in these decays [40, 41]. Contrary to results of calculation of such effects in the lowest p^2-approximation [42-45] giving comparitively small value of the effects the authors of refs. [40,41] claimed that the calculations fulfilled in the p^4-approximation give the one-two order larger values for the width difference and a difference of the slope parameters in decays K^+ and K^-.

Be it true the investigation of CP violation in the decays of charged kaons into three charged pions would be paramount task for the planned Φ factories.

The doubts about results [40,41] were expressed in refs. [43,44,46] basing on the general considerations without the explicit calculation in p^4-approximation. The recent calculations of the slope parameters $g^\pm$ fulfilled in the p^4 approximation [47] gave the result by 30 times smaller than the estimate in ref. [41]. These parameters describe the energy distribution of the "odd" pions in $K^\pm \to 3\pi$ decays:

$$| M(K^\pm \to \pi^\pm\pi^\pm\pi^\mp) |^2 \sim 1 + g^\pm Y + ... \tag{50}$$

where $Y = (s_3 - s_0)/m_\pi^2$, and $s_0 = m_K^2/3 + m_\pi^2$, $s_3 = (p_K - p_{\pi^{odd}})^2$. It was found in ref. [48] that a contribution to the ratio

$$R_g = \frac{g^+ - g^-}{g^+ + g^-} \tag{51}$$

appearing from the terms of order of p^4 in the $| A_{1/2} |^2$ does not exceed 30% of the contribution arising from $| A_{1/2}A^*_{3/2} + A^*_{1/2}A_{3/2} |$ at the p^2-level.

This result contradicts to the statement of the authors of ref. [41] that just the contribution of $| A_{1/2} |^2$ to $(g^+ - g^-)$ arising at the p^4-level leads to considerable enhancement of this quantity.

The resulting estimate for R_g obtained in ref. [47] is

$$| R_g | \leq (5 \pm 2)10^{-5} | \sim \delta_{K-M} | \tag{52}$$

where δ_{K-M} is the phase of Kobayashi-Maskawa.

Such a value of R_g is too small to be observed at the DAPhNE factory. Therefore, an observation of a difference between g^+ and g^- at this machine would be an evidence that CP violation occurs not only due to Kobayashi-Maskawa mechanism.

3 Nearest perspectives to improve our knowledge about CP and CPT violation.

The opportunities of CPLEAR were discussed in the report of A.Schopper. So, it is to the point to consider the possibilities of the DAPhNE factory.

The recent analysis [48] has shown that a measurement of the time distribution of $\pi^+\pi^-$ and $\pi^0\pi^0$ pairs from Φ decay

$$\Phi \to K^0\bar{K}^0 \to \frac{1}{\sqrt{2}}[K_S K_L - K_L K_S] \to \pi^+\pi^-\pi^0\pi^0$$

gives rise to obtain $Re(\frac{\varepsilon'}{\varepsilon})$ and $Im(\frac{\varepsilon'}{\varepsilon})$ with an accuracy of $2 \cdot 10^{-4}$ and $3 \cdot 10^{-3}$ respectively. For this, the distribution $N(d)$ must be measured, where $d = d_c - d_n$ and d_c and d_n are the distances of the vertices of $\pi^+\pi^-$ and $\pi^0\pi^0$ pair production from the initial interaction vertex. The integrated asymmetry

$$A = \frac{N(d>0) - N(d<0)}{N(d>0) + N(d<0)} \cong 3Re(\frac{\varepsilon'}{\varepsilon}) \tag{53}$$

allows a clean determination of $Re\varepsilon'/\varepsilon$. The result for $Im(\varepsilon'/\varepsilon)$ depends on accuracy in determinetion of d and estimated accuracy in measurement of $Im(\frac{\varepsilon'}{\varepsilon})$ turns out to be by one order less than in determination of $Re(\varepsilon'/\varepsilon)$.

As it was mentioned before, the DAPhNE machine will allow to measure the parameter δ_S (see eq.(19) for the first time. Its difference from the parameter δ_L would be an evidence of a breakdown of CPT invariance. The difference $(\delta_L - \delta_S)$ could be determined directly by a measurement of the

asymmetry

$$A_{CPT\neq 1} = \frac{L^{-+} - L^{+-}}{L^{-+} + L^{+-}} \approx \delta_L - \delta_S \tag{54}$$

where $L^{+-}(L^{-+})$ is the number of pairs where the positive lepton is emitted before (after) the negative one. Such an asymmetry can be measured at the DAPhNE with the occuracy $\sim 2 \cdot 10^{-3}$ [48].

The detailed analysis of the limits on the parameters describing CPT violation achievable at the DAPhNE machine was undertaken also in ref. [5]. The results are presented in the Tables 1 and 2. All estimates are obtained for the projected luminocity $L = 5 \cdot 10^{32} s^{-1} cm^{-2}$ and a one year exposition.

4 A few words on CP violation in $\{B^0\ ,\ \bar{B}^0\}$ system.

In SM, an expected magnitude of the parameter ε_B is of the same order as for $\{K^0\ ,\ \bar{K}^0\}$ system.

For the different reasons including obligatory tagging of $B^0(\bar{B}^0)$ the number $N_{B^0\bar{B}^0} \sim 4 \cdot 10^{10}$ will be necessary to observe ε_B at the level 10^{-3} [49]. This number should be compared with $N_{K^0\bar{K}^0} = 5300$ which was sufficient for Christenson et al [2] to establish that $\varepsilon_K \approx 2 \cdot 10^{-3}$.

In the superweak model with

$$g_{SW}(B^0 \to \bar{B}^0) = g_{SW}(K^0 \to \bar{K}^0)$$

it is expected that $\varepsilon_B \sim \frac{1}{10}\varepsilon_K$. But may be $g_{SW}^{BB} \gg g_{SW}^{KK}$?

In general, a phenomenology of CP violation in $\{B^0\ ,\ \bar{B}^0\}$ system is like to one for $\{K^0\ ,\ \bar{K}^0\}$ system except for a small difference between Γ_{B_1} and Γ_{B_2}.

There is one large assymmetry

$$\frac{\Gamma(B^0 \to J/\Psi K_S) - \Gamma(\bar{B}^0 \to J/\Psi K_S)}{\Gamma(B^0 \to J/\Psi K_S) + \Gamma(\bar{B}^0 \to J/\Psi K_S)} \approx -0.47 \sin 2\beta$$

but the branching of this mode of decay is small: $4 \cdot 10^{-4}$.

The details concerning a possibility to observe CP violation in $\{B^0\ ,\ \bar{B}^0\}$ system can be found in ref. [49].

5 Concluding remarks.

1) We need new experiments to clear up the situation with CP violation in CPT invariant world.

(a) Discovery of EDM of the neutron at the level higher than $10^{-31} e\ cm$ or observation of a difference between the slope parameters g^+ and g^- in $K^\pm \to \pi^\pm\pi^\pm\pi^\mp$ decay at the level higher 10^{-4} would be an evidence that the Kobayashi-Maskawa mechanism is not the only source of CP violation.

(b) As the theory now predicts comparatively small value of $\mid \varepsilon'/\varepsilon \mid = few \cdot 10^{-4}$, the more precise measurements are necessary to search for the direct CP violation.

2) We need new experiments to test CPT invariance itself. At present, CPT invariance is tested for $\{K^0\ ,\ \bar{K}^0\}$ system with 2% accuracy only. A measurement of the proper-time distributions of the particles from the decays of $K^0(\bar{K}^0)$ produced in the reactions

$$\bar{p}p \to K^\pm\pi^\mp\bar{K}^0(K^0)$$

or

$$e^+e^- \to K^0\bar{K}^0 \ \ with\ tagging\ \ K^0(\bar{K}^0)$$

will give a possibility to test CPT invariance at the level 10^{-3} in the near future (CPLEAR ,
DAPhNE).

Table 1

Expected accuracy in measurement of the quantities describing CPT violation in K-decays at the DAΦNE.

CPT violating effect	Present limits	References	Expected sensitivity at DAΦNE
$\left\| \frac{m_{K^0}-m_{\bar{K}^0}}{m_{K^0}} \right\|$	$< 3.5 \cdot 10^{-16}$(90%c.l.)	our estimate	$7 \cdot 10^{-18}$
$(\delta_2 - \delta_0) - \arg\ \omega$ $\|\omega\|^2 = \frac{2}{3} \cdot \frac{\Gamma(K^{\pm}\pi^{\pm}\pi^0)}{\Gamma(K_s \to 2\pi)}$	$7.4^0 \pm 6.7^0$	$\delta_2 - \delta_0 =$ $-45.6^0 \pm 5^0$ [50] $\arg\ \omega =$ $-53^0 \pm 4.4^0$ [6]	$\pm 1^0$ $\approx 0.3^0$
$Re\,a$, $a = \frac{A(K_2 \to 2\pi\ ,\ I=0)}{A(K_1 \to 2\pi\ ,\ I=0)}$	$-(0.75 \pm 6)10^{-3}$	our estimate	$\pm 5 \cdot 10^{-4}$
Charge asymmetry in K^0_{l3} : $\delta_S - \delta_L$	no exp. data $\|\delta_S - \delta_L\| \leq 0.07$ (our indirect estimate)	$\delta_S = ?$ $\delta_L =$ $(3.27 \pm 0.12)10^{-3}$	$\approx 7 \cdot 10^{-4}$
$\frac{\tau(K^+)-\tau(K^-)}{\tau(K^+)}$	$(9 \pm 8)10^{-5}$	[4]	$\simeq 10^{-5}$

Table 2

Decay modes of charged kaons, which may be investigated at the DAΦNE for search for CPT violation.

Decay mode, i	To date (PDG-90): 1) $2(\Gamma_i^+ - \Gamma_i^-)/(\Gamma_i^+ + \Gamma_i^-)$ 2) N_{K^+} , N_{K^-}	DAΦNE: 1) expected sensitivity 2) expected $N_{K^+}^{tag}$
$\mu^\pm\nu$	$(-5.4 \pm 4.1) \cdot 10^{-3}$ $2 \cdot 10^7$ [51]	$\pm 0.3 \cdot 10^{-4}$ $\approx 5.6 \cdot 10^9$
$\pi^\pm\pi^0$	$(8 \pm 12) \cdot 10^{-3}$ $2.5 \cdot 10^4$ [52]	$\pm 0.45 \cdot 10^{-4}$ $\approx 1.7 \cdot 10^9$
$\mu^\pm\pi^0\nu$	no data	$\pm 1.3 \cdot 10^{-4}$ $\approx 3 \cdot 10^8$
$e^\pm\pi^0\nu$	no data	$\pm 1.3 \cdot 10^{-4}$ $\approx 4.1 \cdot 10^8$
$e^\pm\nu$	no data	$\pm 5 \cdot 10^{-3}$ $\approx 1.4 \cdot 10^5$
$(\pi^+\pi^+\pi^-)+$ $(\pi^+\pi^0\pi^0)$	no data	$\pm 0.8 \cdot 10^{-4}$ $\approx 6.5 \cdot 10^8$

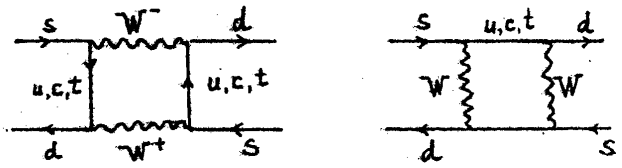

fig.1

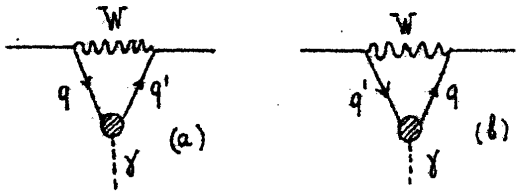

fig.2

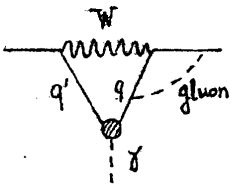

fig.3

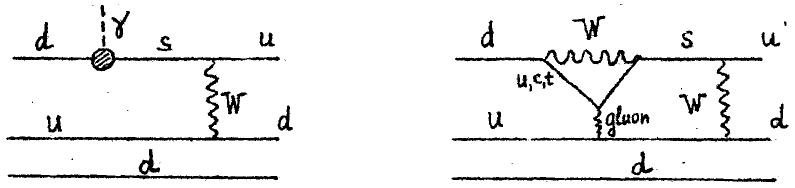

fig.4

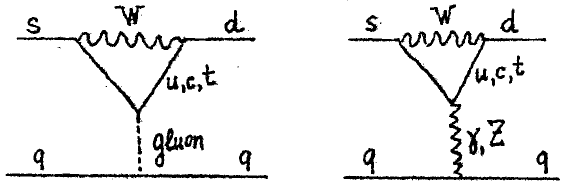

fig.5

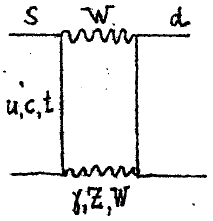

fig.6

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