E2-2014-54

Kh. M. Beshtoev

VIOLATION OF CP INVARIANCE FOR NEUTRAL K^0, D^0, B_d^0, B_s^0 MESONS AND QUARKS IN WEAK INTERACTIONS

Бештоев Х. М. E2-2014-54

Нарушение CP-инвариантности для кварков и нейтральных K^0-, D^0-, B_d^0-, B_s^0-мезонов в слабых взаимодействиях

Работа посвящена рассмотрению возможных схем введения CP-нарушения для нейтральных мезонов и кварков в слабых взаимодействиях. Отмечено, что в общем случае введение CP-фазы только для первого и третьего семейств является некорректным. Такие фазы нужно вводить и для остальных семейств, и при этом не обязательно, чтобы эти фазы были одинаковыми для всех семейств. Кроме того, рассмотрены нарушения CP-инвариантности для K^0-, D^0-, B_d^0-, B_s^0-мезонов, где кроме CP-фаз появляются углы смешивания β_1', β_c, β_d, β_s. Получены выражения для вероятностей переходов при CP-нарушении для этих мезонов. В заключение обсуждается схема CP-нарушения для d-, s-, b-кварков, где появляются углы их смешивания и фазы.

Работа выполнена в Лаборатории физики высоких энергий им. В. И. Векслера и А. М. Балдина ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна, 2014

Beshtoev Kh. M. E2-2014-54

Violation of CP Invariance for Neutral K^0, D^0, B_d^0, B_s^0 Mesons and Quarks in Weak Interactions

CP violation in the Kobayashi–Maskawa matrix was introduced by using phase δ which is the same for the three families of quarks. However, analysis of CP violation of mesons has shown that new small-angle mixings appear besides of CP phases. This work is devoted to the consideration of possible schemes for introducing CP violation. It is noted that in general case it is not correct to use CP phase only for the first and third quark families as it is usually introduced. CP phase has to be presented for all quark families, and moreover these phases cannot be the same for all families. Besides, a common case of CP violation was considered for K^0, D^0, B_d^0, B_s^0 mesons, where mixing angles and phases are present at CP violation. Expressions for transition probabilities for these processes are given. In conclusion, mixing of d, s, b quarks at CP violation was considered with taking into account their angle mixings and phases.

The investigation has been performed at the Veksler and Baldin Laboratory of High Energy Physics, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna, 2014

1. INTRODUCTION

Previously it was supposed that P parity is a well number, however, after theoretical [1] and experimental [2] works it has become clear that in weak interactions P parity is violated. Then in work [3], there has been an advanced supposition that CP parity, but not P parity, is conserved in weak interactions. Work [4] has reported that there is two π-decay modes in K_L decays with a probability of about 0.2%, which is a detection of CP-parity violation.

It has been detected that strangeness S also is violated in weak interactions [5] (see also references in [6]). In order to solve this problem, N. Cabibbo [6] proposes to introduce matrix mixing of d, s quarks. Then we can connect the decay modes of mesons (for example, π and K mesons) or giperons. For this aim, it is necessary to use charged weak interactions current j^{μ}_{F} of d, s quarks (of two quark families) in the following form:

$$j^{\mu}_{F} = \left(\bar{u}\bar{c}\right)_L \gamma^{\mu} V \begin{pmatrix} d \\ s \end{pmatrix}_L, \quad V = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & cos\theta \end{pmatrix}, \tag{1}$$

where V characterizes the mixing of d and s quarks, and θ is the angle mixing of d, s quarks

$$\begin{pmatrix} d' \\ s' \end{pmatrix}_L = V \begin{pmatrix} d \\ s \end{pmatrix}_L . \tag{2}$$

This approach was then extended for the case of three quark families by Kobayashi and Maskawa in [7]. In the case of three quark families, there appears a parameter violating CP parity, while in the case of two quark families this parameter is absent. For introduction of the three quark mixings, we will use again charged vector current J^{μ}, which has the following form:

$$J^{\mu} = (\bar{u}\bar{c}\bar{t})_L \gamma^{\mu} V \begin{pmatrix} d \\ s \\ b \end{pmatrix}_L , \tag{3}$$

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}, \qquad \begin{pmatrix} d' \\ s' \\ b' \end{pmatrix}_L = V \begin{pmatrix} d \\ s \\ b \end{pmatrix}_L , \tag{4}$$

It is more suitable to choose parameterization of V in the following form, which was proposed by Maiani [8]:

$$V = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_\gamma & s_\gamma \\ 0 & -s_\gamma & c_\gamma \end{pmatrix} \begin{pmatrix} c_\beta & 0 & s_\beta \exp(-i\delta) \\ 0 & 1 & 0 \\ -s_\beta \exp(i\delta) & 0 & c_\beta \end{pmatrix} \begin{pmatrix} c_\theta & s_\theta & 0 \\ -s_\theta & c_\theta & 0 \\ 0 & 0 & 1 \end{pmatrix},$$

$$c_\theta = \cos\theta,\ s_\theta = \sin\theta,\ c_\beta = \cos\beta,\ c_\gamma = \cos\gamma,\ \exp(i\delta) = \cos\delta + i\sin\delta, \quad (5)$$

where θ, β, γ are mixing angles of three quarks and δ is the parameter of CP violation. It is important to remark that the parameter of CP violation is the same for all three quark families, i.e., it is a global parameter.

2. CP VIOLATION IN MESON SECTOR

Before considering CP violation, let us consider the case of Kobayashi–Maskawa matrix V' when the parameter of CP violation is zero ($\delta = 0$)

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix},$$

$$V' = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_\gamma & s_\gamma \\ 0 & -s_\gamma & c_\gamma \end{pmatrix} \begin{pmatrix} c_\beta & 0 & s_\beta \\ 0 & 1 & 0 \\ -s_\beta & 0 & c_\beta \end{pmatrix} \begin{pmatrix} c_\theta & s_\theta & 0 \\ -s_\theta & c_\theta & 0 \\ 0 & 0 & 1 \end{pmatrix}. \quad (6)$$

Values of 9 parameters $V_{a,b}, a = 1-3, b = 1-3$ are established [9] by now. The values of θ, β, γ, are established also, but value of δ has not been estibleshed with high precision. Besides, the expression for V in (5) can have another form. For expample, it can be in the form

$$V_2 = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_\gamma & s_\gamma \\ 0 & -s_\gamma & c_\gamma \end{pmatrix} \begin{pmatrix} c_\beta & 0 & s_\beta \\ 0 & 1 & 0 \\ -s_\beta & 0 & c_\beta \end{pmatrix} \begin{pmatrix} c_\theta & s_\theta \exp(-i\delta) & 0 \\ -s_\theta \exp(i\delta) & c_\theta & 0 \\ 0 & 0 & 1 \end{pmatrix}, \quad (7)$$

or in the form

$$V_3 = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_\gamma & s_\gamma \exp(-i\delta) \\ 0 & -s_\gamma \exp(i\delta) & c_\gamma \end{pmatrix} \begin{pmatrix} c_\beta & 0 & s_\beta \\ 0 & 1 & 0 \\ -s_\beta & 0 & c_\beta \end{pmatrix} \begin{pmatrix} c_\theta & s_\theta & 0 \\ -s_\theta & c_\theta & 0 \\ 0 & 0 & 1 \end{pmatrix}. \quad (8)$$

It is not obligatory that the parameter δ in V, V_2, V_3 must be the same. It can be different: δ, δ_2, δ_3.

Let us consider more realistic case, but first consider CP violation for neutral K^0, D^0, B^0 mesons.

2.1. The Case of $K^0, \bar{K}^0$ Mesons. At strangeness violation, K^0, $\bar{K}^0$ mesons are transformed into superposition states of K_1^0, K_2^0 mesons

$$K^0 = \frac{K_1^0 + K_2^0}{\sqrt{2}}, \quad \bar{K}^0 = \frac{K_1^0 - K_2^0}{\sqrt{2}}, \tag{9}$$

and it leads to $K^0, \bar{K}^0$ meson oscillations via K_1^0, K_2^0, which dominate in the time range $t \simeq 0.0 \div 8\tau_{K_1^0}$ ($\tau_{K_1^0}$ is the lifetime of K_1^0 and $\tau_{K_1^0} \cong \tau_{K_S}$ mesons).

CP violation in the system of K^0 mesons was widely investigated experimentally [1,4,9,10] and theoretically [11,12]. At CP violation in the system of K^0 mesons, oscillations are absent and there is realized the interference between K_S, K_L states, which appear at CP violation

$$\begin{aligned} K_1^0(t) &= \cos\beta_1 K_S(t) + \sin\beta_1 \, \mathrm{e}^{i\delta_1} K_L(t), \\ K_2^0(t) &= -\sin\beta_1 \, \mathrm{e}^{-i\delta_1} K_S(t) + \cos\beta_1 K_L(t), \end{aligned} \tag{10}$$

where β_1 is the angle mixing at CP violation, and δ_1 is the CP phase.

There can be the case [11], when

$$\begin{aligned} K_1^0(t) &= \cos\beta_1 K_S(t) + \sin\beta_1 \, \mathrm{e}^{i\delta_1} K_L(t), \\ K_2^0(t) &= -\sin\beta_1 \, \mathrm{e}^{i\delta_1} K_S(t) + \cos\beta_1 K_L(t). \end{aligned} \tag{10$'$}$$

If we separate (factorize) time dependence of $K_S(t), K_L(t)$, then

$$K_S(t) = \mathrm{e}^{-iE_S t - \frac{\Gamma_S t}{2}} K_S(0), \quad K_L(t) = \mathrm{e}^{-iE_L t - \frac{\Gamma_L t}{2}} K_L(0), \tag{10$''$}$$

where $E_k^2 = (p^2 + m_k^2)$, $\quad k = S, L$ and Γ_S, Γ_L are decay widths of K_S, K_L meson states.

Then the probability $P(K^0, K_1^0 \to K_1^0, t)$ of the $K_1^0(t)$ meson state presence in dependence on time t for primary K^0 meson is given by the following expression [12]:

$$\begin{aligned} P(K^0, K_1^0 \to K_1^0, t) = |K_1^0(t)|^2 \simeq \frac{1}{2}\Bigg[&\exp\,(-\Gamma_S t) + \\ + \varepsilon^2 \exp\,(-\Gamma_L t) + 2\varepsilon \exp &\left(\frac{1}{2}(\Gamma_S + \Gamma_l)\, t\right) \cos\left((E_L - E_S) - \delta_1)t\right)\Bigg], \end{aligned} \tag{11}$$

and the probability $P(\bar{K}^0, K_1^0 \to K_1^0, t)$ of the $K_1^0(t)$ meson state presence in dependence on time t for primary $\bar{K}^0$ meson is given by the following expression:

$$\begin{aligned} P(\bar{K}^0, K_1^0 \to K_1^0, t) = |K_1^0(t)|^2 \simeq \frac{1}{2}\Bigg[&\exp\,(-\Gamma_S t) + \\ + \varepsilon^2 \exp\,(-\Gamma_L t) - 2\varepsilon \exp &\left(\frac{1}{2}(\Gamma_S + \Gamma_l)\, t\right) \cos\left((E_L - E_S) - \delta_1)t\right)\Bigg], \end{aligned} \tag{12}$$

where $\varepsilon = \sin\beta_1$ is the parameter of mixing at CP violation [12].

Value for $\sin\beta_1 \simeq 2.23 \cdot 10^{-3}$, $\delta_1 \simeq 43^0$ (see [1, 4, 9, 10]). The K_S, K_L meson interference dominates at $t > 8\tau_{K_S}$. It is important not to mix it up with $K^0, \bar{K}^0$ meson oscillations, which dominate at $t < 8\tau_{K_S}$!

2.2. The Case of $D^0, \bar{D}^0$ Mesons. The case of $D^0, \bar{D}^0$ mesons fundamentally differs from the $K^0, \bar{K}^0$ meson case, since they consist of c, u quarks $D^0 = c\bar{u}$ and $\bar{D}^0 = \bar{c}u$. It is supposed that u, c, t quark states are not mixed in weak interactions, while d, s, b quarks are in mixed states (see Eq. (4)). Therefore the quark block diagram for $D^0, \bar{D}^0$ meson oscillations will strongly differ from the $K^0, \bar{K}^0$ meson oscillations case. We will not come to detailed consideration of $D^0, \bar{D}^0$ meson oscillations, since we are interested in CP violation. However, it is necessary to remark that observation of $D^0, \bar{D}^0$ meson oscillations is a very difficult problem. The task to detect CP violation in this case is also a very hard problem.

At violation of d, s, b number in weak interactions, D^0, $\bar{D}^0$ mesons are transformed into superpositions of D^0_{1c}, D^0_{2c} mesons

$$D^0 = \frac{D^0_{1c} + D^0_{2c}}{\sqrt{2}}, \quad \bar{D}^0 = \frac{D^0_{1c} - D^0_{2c}}{\sqrt{2}}, \tag{13}$$

and it leads to D^0, $\bar{D}^0$ meson oscillations via D^0_{1c}, D^0_{2c}.

At CP violation in the system of D^0, $\bar{D}^0$ mesons, oscillations have to be absent and there is realized the interference between $D_{Sc}(t)$, $D_{Lc}(t)$ states, which appear at CP violation

$$\begin{aligned} D^0_{1c}(t) &= \cos\beta_c D_{Sc}(t) + \sin\beta_c\, \mathrm{e}^{i\delta_c} D_{Lc}(t), \\ D^0_{2c}(t) &= -\sin\beta_c\, \mathrm{e}^{-i\delta_c} D_{Sc}(t) + \cos\beta_c D_{Lc}(t), \end{aligned} \tag{14}$$

where β_c is the angle mixing at CP violation and δ_d is the CP phase.

There can be the case [11] when

$$\begin{aligned} D^0_{1c}(t) &= \cos\beta_c D_{Sc}(t) + \sin\beta_c\, \mathrm{e}^{i\delta_c} D_{Lc}(t), \\ D^0_{2c}(t) &= -\sin\beta_c\, \mathrm{e}^{i\delta_c} D_{Sc}(t) + \cos\beta_c D_{Lc}(t). \end{aligned} \tag{14$'$}$$

If to use the procedure which was done in (11), then the expression for probability $P(D^0, D^0_{1c} \to D^0_{1c}, t)$ of the $D^0_{1c}(t)$ meson state presence in dependence on time t for primary D^0_d meson gets the following form:

$$P(D^0, D^0_{1c} \to D^0_{1c}, t) = |D^0_{1c}(t)|^2 \simeq \frac{1}{2}\Big[\exp\,(-\Gamma_{Sc}t) + \varepsilon_c^2 \exp\,(-\Gamma_{Lc}t) + \\ + 2\varepsilon_c \exp\left(\frac{1}{2}(\Gamma_{Sc} + \Gamma_{Lc})\,t\right)\cos\left((E_{Lc} - E_{Sc}) - \delta_c)t\right], \tag{15}$$

and the probability of the presence of $D^0_{1c}(t)$ meson state in time t dependence for primary $\bar{D}^0_d$ meson is given by the following expression:

$$P(\bar{D}^0, D^0_{1c} \to D^0_{1c}, t) = |D^0_{1c}(t)|^2 \simeq \frac{1}{2}\Bigg[\exp\,(-\Gamma_{Sc}t) + \varepsilon_c^2 \exp\,(-\Gamma_{Lc}t) - \\ - 2\varepsilon_c \exp\left(\frac{1}{2}(\Gamma_{Sc} + \Gamma_{Lc})\,t\right)\cos\left((E_{Lc} - E_{Sc}) - \delta_d)t\right)\Bigg], \quad (16)$$

where $\varepsilon_d = \sin\,\beta_c$, Γ_{Sc}, Γ_{Lc} are the decay widths of D_{Sc}, D_{Lc} meson states [12].

Until now, an indication of a strong presence of CP violation in experiments with D^0, $\bar{D}^0$ mesons [13] has not been found.

2.3. The Case of $B^0, \bar{B}^0$ Mesons. In this case, $B^0, \bar{B}^0$ mesons consist of quarks, which are in mixed states in the framework of weak interactions. In contrast to the K^0 meson case, here there will be two states $B^0_d = b\bar{d}$ and $B^0_s = b\bar{s}$. The quark block diagram for $B^0, \bar{B}^0$ mesons will work in analogy with the $K^0, \bar{K}^0$ meson case (i.e., oscillations will take place there). Now we will consider some CP violation. As in the case of K^0 mesons, at CP violation there has to arise interference between $CP = \pm 1$ states. But observation of this interference term in experiments is a very hard task, since B^0_d, B^0_s have big masses and, hence, very many decay canals. Unfortunately, an indication of the strong presence of CP violation has not been found until now in experiments [14] with $B^0_d, \bar{B}^0_d$ and $B^0_s, \bar{B}^0_s$ mesons. Nevertheless, we can introduce, in analogy with K^0 meson parameters, mixing angles and phase δ_{ds} of CP violation.

At violation of b-number in weak interactions, B^0_d, $\bar{B}^0_d$ mesons are transformed into superpositions of B^0_{1d}, B^0_{2d} bosons

$$B^0_d = \frac{B^0_{1d} + B^0_{2d}}{\sqrt{2}}, \quad \bar{B}^0_d = \frac{B^0_{1d} - B^0_{2d}}{\sqrt{2}}, \quad (17)$$

and it leads to B^0_d, $\bar{B}^0_d$ meson oscillations via B^0_{1d}, B^0_{2d}.

At CP violation in the system of B^0, $\bar{B}^0$ mesons, oscillations have to be absent and there is realized the interference between B_{Sd}, B_{Ld} states, which appear at CP violation

$$\begin{aligned} B^0_{1d}(t) &= \cos\,\beta_d B_{Sd}(t) + \sin\,\beta_d\, \mathrm{e}^{i\delta_d} B_{Ld}(t), \\ B^0_{2d}(t) &= -\sin\,\beta_d\, \mathrm{e}^{-i\delta_d} B_{Sd}(t) + \cos\,\beta_d B_{Ld}(t), \end{aligned} \quad (18)$$

where β_d is the angle mixing at CP violation, and δ_d is the CP phase.

There can be the case [11] when

$$\begin{aligned} B^0_{1d}(t) &= \cos\,\beta_d B_{Sd}(t) + \sin\,\beta_d\, \mathrm{e}^{i\delta_d} B_{Ld}(t), \\ B^0_{2d}(t) &= -\sin\,\beta_d\, \mathrm{e}^{i\delta_d} B_{Sd}(t) + \cos\,\beta_d B_{Ld}(t). \end{aligned} \quad (18')$$

If to use the procedure which was done in (11), then the expression for probability $P(B_d^0, B_{1d}^0 \to B_{1d}^0, t)$ of the $B_{1d}^0(t)$ meson state presence in dependence on time t for primary B_d^0 meson gets the following form:

$$P(B_d^0, B_{1d}^0 \to B_{1d}^0, t) = |B_{1d}^0(t)|^2 \simeq \frac{1}{2}\Bigg[\exp\,(-\Gamma_{Sd}t) + \varepsilon_d^2 \exp\,(-\Gamma_{Ld}t) + \\ + 2\varepsilon_d \exp\left(\frac{1}{2}(\Gamma_{Sd} + \Gamma_{Ld})\,t\right)\cos\left((E_{Ld} - E_{Sd}) - \delta_d)t\right)\Bigg], \quad (19)$$

and the probability $P(\bar{B}_d^0,\, B_{1d}^0 \to B_{1d}^0, t)$ of the presence of $B_{1d}^0(t)$ meson state in time t dependence for primary $\bar{B}_d^0$ meson is given by the following expression:

$$P(\bar{B}_d^0, B_{1d}^0 \to B_{1d}^0, t) = |B_{1d}^0(t)|^2 \simeq \frac{1}{2}\Bigg[\exp\,(-\Gamma_{Sd}t) + \varepsilon_d^2 \exp\,(-\Gamma_{Ld}t) - \\ - 2\varepsilon_d \exp\left(\frac{1}{2}(\Gamma_{Sd} + \Gamma_{Ld})\,t\right)\cos\left((E_{Ld} - E_{Sd}) - \delta_d)t\right)\Bigg], \quad (20)$$

where $\varepsilon_d = \sin\,\beta_d$, Γ_{Sd}, Γ_{Ld} are decay widths of B_{Sd}, B_{Ld} meson states [12].

At violation of b number in weak interactions, B_s^0, $\bar{B}_s^0$ mesons are transformed into superpositions of B_{1s}^0, B_{2s}^0 bosons

$$B_s^0 = \frac{B_{1s}^0 + B_{2s}^0}{\sqrt{2}}, \quad \bar{B}_s^0 = \frac{B_{1s}^0 - B_{2s}^0}{\sqrt{2}}, \quad (21)$$

and it leads to B_s^0-, $\bar{B}_s^0$-meson oscillations via B_{1s}^0, B_{2s}^0.

In the case of B_s^0, $\bar{B}_s^0$ mesons, we have B_{Ss}, B_{Ls} states, which appear at CP violation

$$\begin{aligned} B_{1s}^0(t) &= \cos\,\beta_s B_{Ss}(t) + \sin\,\beta_s\, \mathrm{e}^{i\delta_s} B_{Ls}(t), \\ B_{2s}^0(t) &= -\sin\,\beta_s\, \mathrm{e}^{-i\delta_s} B_{Ss}(t) + \cos\,\beta_s B_{Ls}(t), \end{aligned} \quad (22)$$

where β_s is the angle mixing at CP violation, and δ_s is the CP phase.

There also can be the case [11] when

$$\begin{aligned} B_{1s}^0(t) &= \cos\,\beta_s B_{Ss}(t) + \sin\,\beta_s\, \mathrm{e}^{i\delta_s} B_{Ls}(t), \\ B_{2s}^0(t) &= -\sin\,\beta_s\, \mathrm{e}^{i\delta_s} B_{Ss}(t) + \cos\,\beta_s B_{Ls}(t). \end{aligned} \quad (22')$$

If to use the procedure which was done in (11), then the expression for probability $P(B_d^0, B_{1d}^0 \to B_{1d}^0, t)$ of the presence of $B_{1s}^0(t)$ meson state in dependence on time t for primary B_s^0 meson gets the following form:

$$P(B_d^0, B_{1d}^0 \to B_{1d}^0, t) = |B_{1s}^0(t)|^2 \simeq \frac{1}{2}\Bigg[\exp\,(-\Gamma_{Ss}t) + \varepsilon_s^2 \exp\,(-\Gamma_{Ls}t) + \\ + 2\varepsilon_s \exp\left(\frac{1}{2}\,(\Gamma_{Ss} + \Gamma_{Ls})\,t\right)\cos\left((E_{Ls} - E_{Ss}) - \delta_s)\,t\right)\Bigg], \quad (23)$$

and the probability $P(\bar{B}_d^0, B_{1d}^0 \to B_{1d}^0, t)$ of the presence of $B_{1s}^0(t)$ meson state in time t dependence for primary $\bar{B}_s^0$ meson is given by the following expression:

$$P(\bar{B}_d^0, B_{1d}^0 \to B_{1d}^0, t) = |B_{1s}^0(t)|^2 \simeq \frac{1}{2}\Big[\exp\,(-\Gamma_{Ss}t) + \varepsilon_s^2 \exp\,(-\Gamma_{Ls}t) - \\ - 2\varepsilon_s \exp\left(\frac{1}{2}(\Gamma_{Ss} + \Gamma_{Ls})\,t\right)\cos\left((E_{Ls} - E_{Ss}) - \delta_s)\,t\right\Big], \quad (24)$$

where $\varepsilon = \sin\,\beta_s$, Γ_{Ss}, Γ_{Ls} are decay widths of B_{Ss}, B_{Ls} meson states [12].

3. CP VIOLATION IN THE QUARK SECTOR

Now let us return to CP violation for quarks, but with another approach than it was done in [7]. There CP violation becomes apparent by using CP phase δ. But at consideration of CP violation in the case of K^0, $\bar{K}^0$, mesons we see that there appears a new angle mixing β_1 and the phase δ_1, while the angle mixing β_1 in [7] is absent. For simplification we will consider CP violation in quark sector using pairs of quarks. For the first pair we have

$$\begin{pmatrix} d'' \\ s'' \end{pmatrix}_L = \begin{pmatrix} \cos\,\beta_1' & \sin\,\beta_1'\,\mathrm{e}^{i\delta_1'} \\ -\sin\,\beta_1'\,\mathrm{e}^{i\delta_1'} & \cos\,\beta_1' \end{pmatrix} \begin{pmatrix} d' \\ s' \end{pmatrix}_L. \quad (25)$$

It is obvious that $\beta_1' \neq \beta_1$ and $\delta_1' \neq \delta_1$.

For the second pair of quarks we have

$$\begin{pmatrix} d'' \\ b'' \end{pmatrix}_L = \begin{pmatrix} \cos\,\theta_1' & \sin\,\theta_1'\mathrm{e}^{i\delta_2'} \\ -\sin\,\theta_1'\mathrm{e}^{i\delta_2'} & \cos\,\theta_1' \end{pmatrix} \begin{pmatrix} d' \\ b' \end{pmatrix}_L. \quad (26)$$

For the third pair of quarks we have

$$\begin{pmatrix} s'' \\ b'' \end{pmatrix}_L = \begin{pmatrix} \cos\,\gamma_1' & \sin\,\gamma_1'\mathrm{e}^{i\delta_3'} \\ -\sin\,\gamma_1'\mathrm{e}^{i\delta_3'} & \cos\,\gamma_1' \end{pmatrix} \begin{pmatrix} s' \\ b' \end{pmatrix}_L. \quad (27)$$

Probably origin of all the above parameters β_1', θ_1', γ_1', δ_1', δ_2', δ_3' has a dynamic character and, therefore, for computation of values of these parameters, it is necessary to know the precise dynamic nature of CP violation.

CONCLUSION

CP violation in Kobayashi–Maskawa matrix has been introduced by using phase δ, which is the same for the three families of quarks. However, analysis of CP violation of mesons has shown that new small angle mixings appear besides of CP phases. This work is devoted to the consideration of possible schemes for introducing CP violation. It is noted that in general case it is not correct to use CP phase only for the first and third quark families as it is usually introduced. CP phase has to be presented for all quark families and, moreover, these phases for all families cannot be the same. Besides, the common case of CP violation has been considered for K^0, D^0, B_d^0, B_s^0 mesons, where mixing angles and phases are presented at CP violation. CP violation for K^0 mesons is determined by the angle mixing β_1' and phase δ_1'; for B_d^0 meson, by the angle mixing β_d and phase δ_d; and for B_s^0 meson, by the mixing β_s and phase δ_s. Also are given expressions for transition probabilities for these processes. And in conclusion mixing of d, s, b quarks at CP violation has been considered with taking into account their angle mixings and phases (i.e., there CP angle mixings appear besides of CP phases).

REFERENCES

1. *Lee T. D., Yang C. N.* // Phys. Rev. 1956. V. 104. P. 254.
2. *Wu C. S. et al.* // Phys. Rev. 1957. V. 105. P. 1413; Phys. Rev. 1957. V. 106. P. 1361.
3. *Landau L. D.* // Sov. J. JETP. 1957. V. 32. P. 405.
4. *Christenson J. H. et al.* // Phys. Rev. Lett. 1964. V. 13. P. 138.
5. *Roe B. P. et al.* // Phys. Rev. Lett. 1961. V. 7. P. 346.
6. *Cabibbo N.* // Phys. Rev. Lett. 1963. V. 10. P. 531.
7. *Kobayashi M., Maskawa K.* // Prog. Theor. Phys. 1973. V. 49. P. 652;
   Okun' L. B. Leptons and Quarks. M.: Nauka, 1990.
8. *Maiani L.* // Proc. Int. Symp. on Lepton–Photon Int. Hamburg, DESY, 1977. P. 867.
9. Phys. Lett. B. Review of Part. Phys. 2008. V. 667. P. 145, 733;
   Phys. Rev. D. Review of Part. Phys. 2012. V. 86, 010001. P. 157, 852.
10. *Adler R. et al.* // Phys. Lett. B. 1995. V. 363. P. 243;
    Apostolakis A. et al. // Phys. Lett. B. 1999. V. 458. P. 545;
    Marianna Testa (Kloe Collab.). hep-ex/0505015v.1, 2006.
11. *Wu T. T., Yang C. N.* // Phys. Rev. Lett. 1964. V. 13. P. 380.
12. *Beshtoev Kh. M.* // Nuclear Phys. B (Proc. Supl.). 2011. V. 219-220. P. 276–280;
    hep-ph/1401.5989v.2, Febr 2014.
13. Phys. Lett. B. Review of Part. Phys. 2008. V. 667. P. 783;
    Phys. Rev. D. Review of Part. Phys. 2012. V. 86, 010001. P. 903, 1066.
14. Phys. Lett. B. Review of Part. Phys. 2008. V. 667. P. 914;
    Phys. Rev. D. Review of Part. Phys. 2012. V. 86, 010001. P. 1066.

Received on July 14, 2014.

Редактор *Э. В. Ивашкевич*

Подписано в печать 01.10.2014.
Формат 60 × 90/16. Бумага офсетная. Печать офсетная.
Усл. печ. л. 0,68. Уч.-изд. л. 0,96. Тираж 325 экз. Заказ № 58343.

Издательский отдел Объединенного института ядерных исследований
141980, г. Дубна, Московская обл., ул. Жолио-Кюри, 6.
E-mail: publish@jinr.ru
www.jinr.ru/publish/