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CONTRIBUTION OF THE WEAK INTERACTION TO THE OSCILLATIONS OF K^0 MESONS AND CP VIOLATION

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Вклад слабого взаимодействия в осцилляции K^0-мезонов и CP-нарушение

В данной работе обсуждается осцилляция нейтральных каонов, появляющихся в результате нарушения ароматических чисел механизмом, лежащим вне рамок слабого взаимодействия (W, Z^0-обмена), а именно Кобаяши — Маскавы матрицей. Показано, что вакуумная осцилляция $K^0 \longleftrightarrow \bar{K}^0$ идет без подавления с углом смешивания, равным $\pi/4$, хотя $K_1^0 \longleftrightarrow K_2^0$ идет с сильным подавлением, и в этом случае угол смешивания $\theta = 0{,}0016$ (эта осцилляция является результатом CP-нарушения и перекрытия распределения масс-ширин этих мезонов). Экспериментально измеренный угол CP-нарушения $\delta = 0{,}00327$ ($\delta \cong 2\theta$).

Угол смешивания K_1^0, K_2^0 может не совпасть с параметром CP-нарушения, и поэтому нужно быть осторожным.

Работа выполнена в Лаборатории сверхвысоких энергий ОИЯИ.

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Contribution of the Weak Interaction to the Oscillations of K^0 Mesons and CP Violation

In this work we deal with oscillations of neutral kaons appearing after the violation of flavour numbers by a mechanism outside the weak interaction (W, Z^0 boson exchanges) — by the Kobayashi — Maskawa matrices. It is shown that the vacuum oscillation $K^0 \longleftrightarrow \bar{K}^0$ will proceed without suppression with a mixing angle equal to $\pi/4$, while $K_1^0 \longleftrightarrow K_2^0$ will proceed with strong suppression, and in this case the mixing (i.e., the real $K_1^0 \longleftrightarrow K_2^0$ transition) angle is determined by the angle $\theta = 0.0016$ (these oscillations are the result of CP violation and overlapping of the mass distributions of these mesons). The angle δ of the CP violation measured experimentally is $\delta = 0.00327$ ($\delta \cong 2\theta$).

The mixing parameter of K_1^0, K_2^0 mesons may not coincide with the parameter of CP violation and so one must be carefully.

The investigation has been performed at the Laboratory of Particle Physics, JINR.

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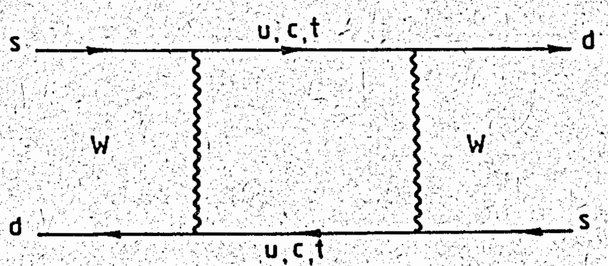
1. Introduction

In this work we deal with oscillations of neutral kaons appearing after the violation of flavour numbers by a mechanism outside the weak interaction (W, Z^0 boson exchanges)-by the Kobayashi-Maskawa matrices. It is shown that the vacuum oscillation $K^\circ \longleftrightarrow \bar{K}^\circ$ will proceed without suppression with a mixing angle equal to $\pi/4$, while $K_1^0 \longleftrightarrow K_2^0$ will proceed with strong suppression, and in this case the mixing (i.e. the real $K_1^0 \longleftrightarrow K_2^0$ transition) angle is determined by the angle $\Theta \simeq 0.0016$ (these oscillations are the result of CP violation and overlapping of the mass distributions of these mesons). The angle δ of the CP violation measured experimentally is $\delta = 0.00327$ ($\delta \simeq 2\,\Theta$).

2. Contribution of weak interaction to the oscillation of K^0 mesons

The interactions of $\bar{K}^\circ \rightarrow \bar{d}\,\gamma_5\,s$ and $K^\circ \rightarrow \bar{s}\,\gamma_5\,d$ mesons are the same owing to the interactions both of s and $\bar{s}$ and of d and $\bar{d}$ being identical. Moreover, if the symmetry with respect to particles and antiparticles of the Kobayashi-Maskawa matrices [1] is taken into account, then the transitions $K^\circ \rightarrow \bar{K}^\circ$ and $\bar{K}^\circ \rightarrow K^\circ$ will be symmetric (CP violation leads to asymmetry of $K^\circ \longleftrightarrow \bar{K}^\circ$ oscillations). Contributions to these transitions will be given by the standard four-vertex diagram [2]



Since K^0 and $\bar{K}^0$ mesons consist of fermions $(s, \bar{s}, d, \bar{d})$, which owing to the left nature of the weak interaction cannot acquire mass through this interaction [3], their masses do not vary. As a result we arrive at the conclusion that the mixing angle for K^0, $\bar{K}^0$ equals $\pi/4$ [3].

The masses of K^0 and $\bar{K}^0$ are the same (the mixing angle equals $\pi/4$), so the mass matrix of K^0 and $\bar{K}^0$ mesons has the form [4]

$$\begin{vmatrix} m_{K^0 K^0} & m_{K^0 \bar{K}^0} \\ m_{\bar{K}^0 K^0} & m_{\bar{K}^0 \bar{K}^0} \end{vmatrix}$$

Having in view further application, we now turn to the matrix of widths for K^0, $\bar{K}^0$ mesons

$$\begin{vmatrix} \Gamma_{K^0 K^0} & \Gamma_{K^0 \bar{K}^0} \\ \Gamma_{\bar{K}^0 K^0} & \Gamma_{\bar{K}^0 \bar{K}^0} \end{vmatrix}, \tag{1}$$

and we shall diagonalize this matrix bearing in mind that the mixing angle for K^0 and $\bar{K}^0$ is $\pi/4$:

$$\begin{vmatrix} \Gamma_{K_1^0 K_1^0} & 0 \\ 0 & \Gamma_{K_2^0 K_2^0} \end{vmatrix} \tag{2}$$

where

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

Then

$$\Gamma_{K^0 K^0} = \Gamma_{\bar{K}^0 \bar{K}^0} = \frac{\Gamma_{K_1^0 K_1^0} + \Gamma_{K_2^0 K_2^0}}{2} \tag{3}$$

$$\Gamma_{\bar{K}^0 K^0} = \Gamma_{K^0 \bar{K}^0} = \frac{\Gamma_{K_1^0 K_1^0} - \Gamma_{K_2^0 K_2^0}}{2}$$

The time (or length) of the $K^0 \longleftrightarrow \bar{K}^0$ oscillation is determined by the formation time of K^0 and $\bar{K}^0$ mesons and, correspondingly, will be equal to

$$t^{-1}_{K^0 \longleftrightarrow \bar{K}^0} = \frac{\Gamma_{K_1^0 K_1^0} + \Gamma_{K_2^0 K_2^0}}{2}$$

Owing to the masses of K^0 and $\bar{K}^0$ being equal and to their widths totally overlapping, such oscillation will be real [5].

Upon diagonalization of the matrix (1) we have come to the mass matrix for K_1^0 and K_2^0:

$$\begin{vmatrix} m_{K_1^0 K_1^0} & 0 \\ 0 & m_{K_2^0 K_2^0} \end{vmatrix} \tag{4}$$

where

$$\begin{aligned} m_{K^0 K^0} &= m_{\bar{K}^0 \bar{K}^0} \\ m_{\bar{K}^0 K^0} &= m_{K^0 \bar{K}^0} \\ m_{K_1^0 K_1^0} &= m_{K^0 K^0} - m_{K^0 \bar{K}^0} \\ m_{K_2^0 K_2^0} &= m_{K^0 K^0} + m_{K^0 \bar{K}^0} \\ m_{K_1^0 K_1^0} + m_{K_2^0 K_2^0} &= m_{K^0 K^0} + m_{\bar{K}^0 \bar{K}^0} \end{aligned} \tag{5}$$

Thus, owing to the contribution of weak interaction (W,Z-boson exchanges), no quark mixing (oscillations) occurs in this case. But, taking into account that weak interactions violate the flavour numbers, by means of the Kobayashi-Maskawa matrices, which lead to the oscillations of K^o-mesons considered above.

3. Possible types of K^o oscillations

If a particle with mass m_o travels in vacuum without undergoing interactions then:

$$P^2 = m_o^2 = inv \qquad (6)$$

If a particle of mass m_o has a width Γ, how the formula (6) be modified ?

We will assume that the formula (6) is not changed in this case. But, the mass m will be distributed according to the Breit - Wigner formula [5]

$$P^2 = m^2$$

$$W(m, m_o, \Gamma, ...) = \frac{c \qquad (\Gamma/2)^2}{(m - m_o)^2 + (\Gamma/2)^2}, \qquad (7)$$

where c - is a normalizing factor.

Now we shell consider possible types of K^o oscillations.

a) If the masses of K^o, $\bar{K}^o$ mesons are equal and the widths of these mesons, Γ_{K^o}, $\Gamma_{\bar{K}^o}$, are also equal, we obtain fully overlapping mass distributions for K^o, $\bar{K}^o$ mesons, and therefore $K^o \longleftrightarrow \bar{K}^o$ transitions proceed without suppression.

b) If the masses and widths of the K^o mesons were not equal and the mass distributions do not fully overlap, then real K^o transitions proceed with suppression (when the mass difference is sufficiently large, the mass distributions do not overlap then real K^o transitions are totally suppressed). Let us consider case b).

4. $K_1^o \longleftrightarrow K_2^o$ transitions(CP violation)

When transition is performed to the K_1^o and K_2^o mesons, there appears a mass difference, and, in this case, it is necessary to take into account the influence of this difference on the oscillation of the K_1^o and K_2^o mesons.The processes of $K_1^o \longleftrightarrow K_2^o$ transition take place when CP parity is violated. We considered this question in ref. [5]. Therein it was shown, that when the particles pass through vacuum, real transition of particles of one sort of a certain mass m_1 into particles of another sort of mass m_2 may take place when permitted by the uncertainty relations, if the widths of these particles permits overlapping their mass difference. This is possible owing to the second particle having time to become a real particle. This means that, in the case of K^o, $\bar{K}^o$ mesons, oscillation will occur without any suppression (the masses of the K^o and $\bar{K}^o$ mesons are identical, and their widths totally overlap). At the same time, in the case of K_1^o and K_2^o mesons the overlapping of their widths due to their mass difference is very small, and, therefore, the oscillation between K_1^o and K_2^o is strongly suppressed .

Now, let us return to the issue of the mixing angle for K_1^o and K_2^o, which is related to the overlapping of the mass distributions that will be manifested as real $K_1^o \longleftrightarrow K_2^o$ transitions (in the case of $K_1^o \longleftrightarrow K_2^o$ virtual transitions decay modes of K^o cannot exist). In the simplest case this mixing angle Θ is

$$\begin{vmatrix} \Gamma_{K_1^o K_1^o} & -\Gamma_{K_2^o K_2^o} \\ -\Gamma_{K_2^o K_2^o} & \Gamma_{K_2^o K_2^o} \end{vmatrix} \qquad \delta \simeq 2\,\Theta , \qquad K_2^{o\prime} = K_2^o - \Theta K_1^o \qquad (8)$$

$$\sin\Theta = \frac{\Gamma_{K_2^o K_2^o}}{\Gamma_{K_1^o K_1^o}} \simeq 0.0016$$

This angle practically coincides with the CP violating term observed experimentally [6], $\delta = 0.00327$.

For the existence of $K_1^o \longleftrightarrow K_2^o$ transitions an interaction violating CP- invariance is requared(for example, superweak interactions [7] or the Kobayashi -Maskawa mechanism [1]). K_1^o ,K_2^o have different masses and widths and $K_1^o \longleftrightarrow K_2^o$ transitions are caused by intersection of the mass distributions of the K_1^o and K_2^o mesons (see eq. (7)).

5. Conclusion

So, we can see that $K^o \to \bar{K}^o$ oscillations are due to four-vertex diagrams (or Cabibbo-Kobayashi-Maskawa matrices), but real $K_1^o \longleftrightarrow K_2^o$ transitions are caused by the mass distributions of these mesons overlapping.

We want to stress that $K_1^o \longleftrightarrow K_2^o$ transitions, in contrast to $K^o \longleftrightarrow \bar{K}^o$ transitions, may be suppressed in the overlapping mechanism of the mass distributions of K_1^o ,K_2^o mesons (if the overlapping is too small). In this case the mixing parameter of K_1^o, K_2^o mesons may not coinside with the perameter of CP violation and, one must be careful.

Contrary to the case $K_1^o \longleftrightarrow K_2^o$ mesons, $B_1^o \longleftrightarrow B_2^o$ transitions are superpermitted transitions, and therefore from B^O meson decay modes we may obtain the correct parameter of CP violation.

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